



Research article

Economic valuation of Harmful Algal Blooms (HAB): Methodological challenges, policy implications, and an empirical application

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ABSTRACT

This paper presents a literature review on the economic valuation of Harmful Algal Bloom (HAB) impacts, identifying methodological challenges, policy implications, and gaps. Unlike previous literature reviews, we are particularly interested in determining whether the economic valuations of HABs have included a policy analysis. Our paper provides a conceptual framework that allows us to evaluate whether applications of economic studies of HABs are consistent with a well-defined economic welfare analysis. It links methodologies and techniques with welfare measures, data types, and econometric methods. Based on this literature review, we present an example of economic valuation that closes the gap between policy analysis and valuation methodology. We use a stated preferences study to estimate a “seafood price premium” to create a fund to support monitoring systems and for damage compensation to producers in the presence of HABs. Results show that most economic studies on HAB valuation do not consider any cost-benefit analysis of a defined policy intervention. The predominant economic valuation methodology uses market information to estimate a proxy for welfare measure of the impact of HABs (loss revenue, sales, exports). Moreover, nonuse and indirect use values are ignored in the literature, while stated preference methodologies are underrepresented. Finally, results from 1293 surveys found that people are willing to pay an increase in the price of mussels to support a policy that informs on HAB. However, the lack of institutional trust affects the probability of paying negatively.

1. Introduction

In most marine and freshwater environments, microscopic, plant-like organisms occur naturally in the surface layer, known as phytoplankton or microalgae, which form the base of the food chain upon which all other marine organisms depend (Anderson, 2009; Lucas et al., 2010). However, global change transforms aquatic ecosystems through progressive warming, acidification, and deoxygenation (Gobler, 2020). Climate change and human activity can alter some environments,

increasing the algae’s nutrients and algal blooms, which can be detrimental to humans because some microalgal species produce potent toxins that accumulate in shellfish, resulting in poisoning syndromes¹ (Hoagland et al., 2002). This phenomenon has been called Harmful Algal Blooms (HABs).

There is a scientific consensus that the impact of HABs on public health, recreation, tourism, fisheries, aquaculture, and the ecosystem has increased over the last decades (Trainer, 2020). According to the US National Office for HABs, several decades ago, HABs affected a few

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¹ Paralytic, diarrhetic, amnesic, or neurotoxic shellfish poisoning, PSP, DSP, ASP, or NSP, respectively. A related phenomenon, known as ciguatera fish poisoning (CFP), occurs when toxic algae living on coral reef seaweeds are consumed by herbivorous fish, which pass the toxins on to larger predators and then deliver the neurotoxins to human consumers.

countries. Today, these events threaten most coastal countries over larger geographic areas and by more than one toxic species, generating an increasing impact. The Harmful Algal Event Database [HAEDAT] indicates that these events have increased in the last decades, from 16 HAB events in 1980 to 605 in 2020. As of 2021 and 2022,² 305 and 169 events were identified (Fig. 1). The causes behind this expansion are in dispute, with explanations ranging from natural reasons to human-related phenomena such as pollution, climatic shifts, transport of algal species via ship ballast water, and improvement in monitoring and detection capabilities. Whatever the reasons, coastal regions worldwide are subject to unprecedented frequency of HAB events (Anderson, 2009).

The severity of the health and socioeconomic consequences of HABs depends on their spatial distributions relative to human populations, the duration, frequencies of occurrence, cell densities, toxicities, and weather conditions (Adams et al., 2018). Among the main harmful effects caused by HABs are fish mortality, shellfish poisonousness, and numerous other problems in marine coastal waters. From an economic perspective, the principal sectors or activities affected by substantial economic losses are human health, commercial fisheries, tourism, and recreation (Sanseverino et al., 2016).

The literature highlights extreme HAB events like the Alexandrium catenella bloom in southeastern Australia (2012–2017), the Pseudo-Nitzschia bloom that spanned from Alaska to Mexico in 2015, and the “Godzilla red tide” of *A. catenella* and *Pseudochattonella Verruculosa* in Chile in 2016. These extreme events have been related to climate change conditions such as warming, stratification intensity, freshwater inputs, and natural patterns of climate variability and can have high economic impacts. The Chilean 2016 HAB resulted in the most significant worldwide fish farm mortality, equivalent to an \$800 million US export loss (0.3% of GDP).³ It also produced substantial social unrest and riots in southern Chile (Trainer et al., 2020). Nevertheless, this amount does not comprise the total economic impact of HABs since it does not consider other direct and indirect costs associated with the main sectors affected.

The US National Office for HABs indicates that estimating the full range of societal impacts of HABs is as tricky as assessing human behavior in response to a traumatic event. They identify effects such as disruption of working patterns, reduction in boat reservations and pier attendance for recreational anglers, the ruin of vacation, and adverse impact on property values. Other impacts of HABs are unwillingness/inability to swim in the contaminated water, concerns about the possible presence of toxins in the drinking water, a decrease in the tap water quality, or even the cessation of water supply to the population (Namsaraev et al., 2020).

Economic losses (damage) are expected to increase due to the intensification of HABs. Therefore, researchers and policymakers have been advised to understand the economic implications of HABs and identify policies that can cope with their effects. However, both research areas still have limitations (economic valuation and policy interventions) (Börger et al., 2014; Hanemann, 2022). While the economic valuation of the impacts of HABs may contribute to this goal, since it can assess the direct and indirect implications of HABs, it is important to recognize that the economic valuation of damages is not enough to deal with HABs. Policymakers must have policy options based on economic principles, equity, fairness, and social objectives.

This paper contributes to understanding HAB’s economic and policy dimensions in several ways. First, we updated the literature reviews on the economic valuation of the impacts of HABs provided by Adams et al. (2018), Kouakou and Poder (2019), Trainer (2020), and Jin et al. (2020), identifying methodological challenges to performing an economic valuation to determine the welfare effects of this phenomenon. Unlike these previous reviews, we are particularly interested in

identifying whether the economic valuations of HABs have included a policy analysis. In other words, we evaluate whether previous applications are consistent with the idea that the economic valuation of damages needs to be grounded in a solid cost-benefit analysis of clearly identified policy interventions if it will be helpful for policy design (Whittington, 2010).

A second contribution of our literature review is that we provide a conceptual framework that allows us to evaluate whether applications of economic studies of HABs are consistent with a well-defined economic welfare analysis. Our research will enable us to link methodologies and the specific techniques used in the selected studies with the welfare measure estimated, the type of data utilized, and the econometric techniques. None of the previous reviews has attempted to characterize these links. In that sense, our findings are novel and add value compared to previous studies. Our main conclusion is that just a few studies close the gap between policy analysis, data availability, and techniques and methods. The few that do it are applications in the area of stated preferences.

Based on these findings, a third contribution is to provide an example of economic valuation that links policy and economic evaluation. We designed a Stated Preferences (SP) study to evaluate one specific policy related to HAB. The policy implies estimating a “price premium” incorporated into seafood products to create a fund to support monitoring systems and to be used for damage compensation in the presence of HABs to reduce producers’ financial stress due to loss of income when fishing is forbidden. In this way, we also aim to contribute to the scarce literature using SP to evaluate HABs.

We ground empirical research around the experience in southern Chile, where a mussel production sector was strongly affected by HABs in 2016. Chile is the largest exporter of mussels worldwide, exporting around USD 200 million annually with a volume of approximately 59,000 tons in 2015 (Fernández et al., 2023). Residents of two big cities were surveyed to determine their willingness to pay (WTP) an additional price for mussels to support a seawater monitoring system to predict the emergence of a red tide and generate a “crisis fund” to support affected producer families. We estimate WTP for the policy and determinants of respondents’ preferences.

The following section describes the material and methods used. Section 3 presents the main results from the review, discussing gaps in the economic valuation, policy instruments, and the WTP estimates. The paper ends with a section of discussion and conclusions.

2. Material and methods

2.1. Literature review and conceptual framework

For the review, keywords searched through Google Scholar and Web of Science using mixed phrases such as “Harmful algal blooms,” “economic valuation,” “policy instruments,” “contingent valuation,” “choice experiment,” “willingness to pay,” and “toxic algae,” among others, identifying 1) the methodologies used in the valuation exercises, 2) the “good” evaluated, 3) information gaps, and 4) policy instruments or interventions discussed in the articles. Only studies containing an identified methodology to derive the economic effects of these phenomena were included.⁴

There are several valuation methods to estimate the economic impact of HABs. Those methods include induced costs and losses, hedonic prices (e.g., changes in the prices of properties close to HABs affected areas), travel cost, contingent valuation, choice experiments, and input-output models, among others. Table 1 presents the main categories used in our conceptual framework. This conceptual framework allows us to evaluate whether the economic studies of HABs are

² Data from 2021 to 2022 was retrieved on March 17, 2023.

³ All values are adjusted to the dollar of December 2022.

⁴ Articles only focusing on social issues related to red tide (e.g., the state of current knowledge of red tides) were excluded.

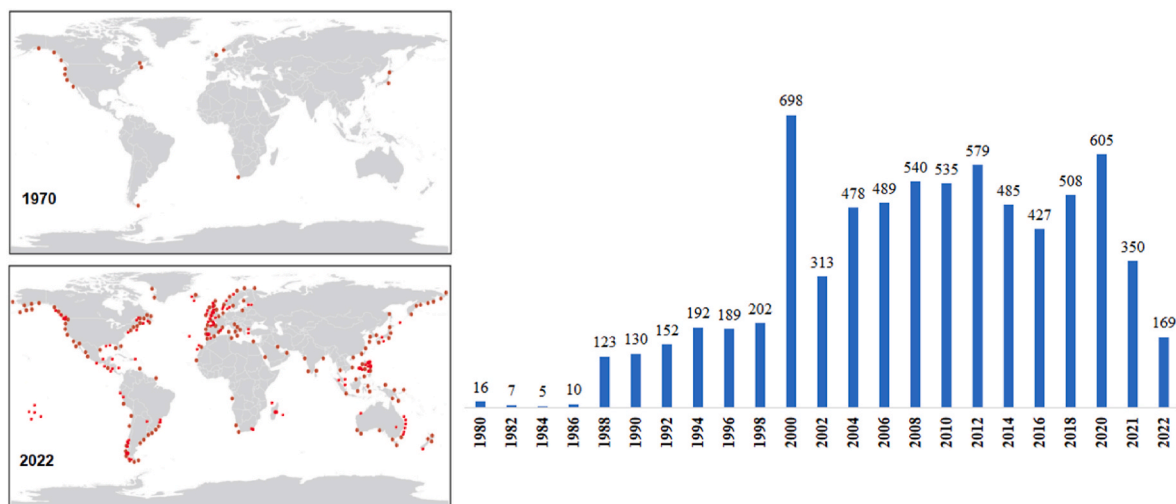


Fig. 1. Distribution of PSP toxins in 1970 and 2022 and yearly HAB events. Source: US National Office for HABs (USNOHAB) and Anderson (2009) updated using IOC-UNESCO Harmful Algal Information System and Harmful Algal Event Database [HAEDAT].

Table 1
Classification of methodologies, data, welfare measures, and econometrics.

Methodology	Subclassification	Techniques	Welfare Measure	Type of data	Econometric tools/others
Revealed Preferences (RP)	Market Price (MPr)	Demand and supply function estimation	Consumer and producer surplus	<ul style="list-style-type: none"> ✓ Time series ✓ cross-section ✓ Panel Data 	Time series and Panel Data
	Market Price proxy (MPr proxy)	<ul style="list-style-type: none"> ✓ Avoided costs ✓ Induced costs ✓ Averting behavior 	Proxies for welfare measures: <ul style="list-style-type: none"> ✓ change in sales, ✓ change in revenues, ✓ induced costs, ✓ Cost of illness, ✓ average expenditures Consumer surplus	Production and consumption, expenditures, sales.	<ul style="list-style-type: none"> ✓ Time series analysis ✓ Price*quantity proxy ✓ “Dif in dif” approaches
	Travel Cost (TC)	<ul style="list-style-type: none"> ✓ Single site ✓ Multiple Site 	WTP for changes in attributes	Aggregate or individual data on trips and expenditures	Random Utility Models, count data (Poisson type models)
	Hedonic Prices (HP)	-		Real state transactions, wages	OLS, spatial analysis, instrumental variables.
Stated Preferences (SP)	Contingent Valuation (CV)	<ul style="list-style-type: none"> ✓ Referendum models, ✓ bidding card, ✓ open-ended ✓ close-ended 	Estimate WTP, WTA (compensating or equivalent variation)	Cross-section or panel data of individuals’ responses to surveys.	<ul style="list-style-type: none"> ✓ Random Utility Models ✓ Discrete Choice Models (probit, logit) ✓ Limited dependent models (Tobit type).
	Contingent behavior (CB)	<ul style="list-style-type: none"> ✓ Choice, Rating, ✓ Ranking, 			<ul style="list-style-type: none"> ✓ Random Utility Models ✓ Discrete Choice Models ✓ Multinomial Models ✓ Random parameter models ✓ Latent class models
	Choice Experiments (CE)				
Benefit Transfer (BT)	Unit Value Transfer		WTP, WTA, change in consumer or producer surplus or proxies.	Values from previous studies	NONE
	Function Value Transfer			Values from previous studies	Regression analysis, Panel data estimation

consistent with well-defined economic welfare analysis. It links a classification of methodologies (columns 1 and 2) and techniques (column 3) with the welfare measure that can be estimated (column 4), the type of data used for the estimation (column 5), and the econometric tools (column 6).

Table 1 includes Revealed Preferences (RP), SP and Benefit Transfer (BT) (Haab and McConnell, 2002; Bockstael and McConnell, 2007; Freeman III et al., 2014; Champ et al., 2017). RP relies upon data obtained through markets (including subrogate markets), such as changes in consumer expenditures and production, prices and quantities, changes in sales, induced costs, and averting behavior. The most common RP methods using subrogate market information (indirect markets) are travel cost and hedonic prices.

In contrast, through survey methods, SP approaches ask individuals to state their WTP or willingness to accept (WTA) for specific changes in

the provision of goods or services (Bateman et al., 2001). SP approaches include contingent valuation (CV) and choice experiment (CE) (Kanninen, 2007). These methods often use surveys to ask people about their economic value by asking how they would vote on a referendum to establish a program to prevent HAB-related losses (Adams et al., 2018). In CV, people face only one alternative (besides the status quo). In contrast, in CE, respondents are asked to indicate their preference among two or more multi-attribute options (Johnston et al., 2017). Including price as an attribute permits a multidimensional, preference-based valuation to be used in benefit-cost analysis or any other applicable policy analysis (Holmes et al., 2017).

BT uses information from previous studies (study sites) to “transfer” or forecast the economic value of a new site or situation (policy site). Researchers can transfer a single value (unit value transfer) or a transfer function, which depends on variables from several previous studies, like

a meta-analysis approach (Johnston et al., 2015). A full description of these methodologies is beyond the scope of this paper. Please see Champ et al. (2017), Freeman III et al. (2014), or Johnston et al. (2015) for details on these approaches.

The use of RP or SP is related to the type of benefit one is interested in measuring (welfare measure, column 4 of Table 1). Our analysis is also based on the conceptual framework for economic valuation applied to HABs, summarized by Van den Bergh et al. (2002). It subdivides the *total economic value* (TEV) into *use* and *nonuse value* and identifies the appropriate methodology for each case (RP or SP). *Use value* refers to the damages arising from the impact of the alga blooms connected to the direct or indirect *use* of the goods or ecosystem services affected (own benefit or someone else). The use value is composed of the *direct use value* (DUV, damages caused by HABs to tourism, recreation, fishery, and human health), *indirect use value* (IUV, injuries to the functioning of the marine ecosystem), and *option value* (OV, possibility of own or someone else future use) (Hanemann, 2022). Nonuse value is not linked to any current or future use. It includes *bequest value* (BV, benefit accruing to any individual from the knowledge that future generations might benefit from a marine ecosystem being free from HABs) and an *existence value* (EV refers to the benefit derived simply from the knowledge that marine species are protected without even being used) (Van den Bergh et al., 2002).

An economic valuation should start by identifying the type of economic value (use or nonuse) affected by the HABs and the relevant population impacted or depositary of these values (market extension) (Freeman III, 2014). Economic valuation aims to estimate society's welfare change by estimating the *consumer and producer surplus* (the area between the demand or supply functions and the market price) (Johansson, 1991).⁵ When market price information is available, social welfare changes (consumer and producer surplus) can be calculated using price and quantities to estimate a demand and supply function and, from them, estimate surpluses (Adams et al., 2018; Khan and Rockel, 1988). This theoretically consistent approach is rarely used due to data limitations that do not allow proper econometric estimation of demand and supply functions. Instead, researchers and policymakers often use price and quantity information to estimate revenue (price times quantity as a proxy for welfare measure) (Habas and Gilbert, 1974; Dyson and Huppert, 2010; Sanseverino et al., 2016; Adams et al., 2018). Some researchers argue that this is a standard and direct market method for estimating economic losses (Dyson and Huppert, 2010) that provides a relatively accurate means for estimating economic changes (Dyson and Huppert, 2010; Adams et al., 2018). While this simple approach is advantageous from a communicational perspective with policymakers and other stakeholders, it has two theoretical drawbacks. First, it ignores the consumer surplus, representing a significant part of the economic value and the methodological developments in literature. Second, it includes both the producer's surplus and the cost of production which cannot be considered a measure of social welfare (it is indeed a cost, not a benefit).

Instead, SP directly estimates welfare measures expressed as WTP or WTA for changes in economic conditions (column 4 of Table 1). In some cases, it is possible to have reliable market data for a complementary good (subrogate market) to the environmental good under analysis. For instance, this could be the case for recreational and touristic activities and impacts on property values. We could use the travel cost or hedonic price method if the information is dependable. Impacts on morbidity or mortality can be estimated using either RP or SP by the estimation of the Value of a Statistical Life (VSL) or injury (VSI) (Viscusi and Aldy, 2003; Vásquez-Lavin et al., 2022).

⁵ Economists are interested in two other welfare measures, compensating variation, or equivalent variation, which can be expressed as WTP or WTA (Hanemann, 1991). These two welfare measures can be approximated using the consumer surplus. We will not address this subtlety here. See Willig (1976) and Hausmann (1981) for a discussion.

2.2. Stated preferences study example

Currently, the Chilean government relies on banning seafood consumption from the areas affected by red tide. Unfortunately, people stop consuming other seafood immune to the red tide or products from unaffected places for fear of being contaminated, given the insecurity about where their seafood comes from. Based on the literature review, we identified a program that could address the health impacts and the lack of information about the origin of seafood and provide a crisis fund to support producers in the event of a HAB (Whitehead et al., 2003; Jin et al., 2008). The program combines a monitoring alert system with a crisis fund. It aims to create a fund to support three components.

1. To create an early-warning monitoring system for the emergence of an HAB to avoid acute health threat events associated with consuming contaminated seafood. This component aims to reduce uncertainty and increase preparedness for the event.
2. To inform people about the HAB event timely and certify the origin of seafood not affected by the event. This component seeks to reduce ignorance about the origin of seafood and to increase confidence regarding seafood that is secure to eat.
3. To generate a "crisis fund" to aid affected producers that need to stop commercialization in the presence of HAB. This last component looks at mitigating the economic impacts of HAB on producers' financial sustainability. The fund accumulates during non-crisis periods and is financed jointly by companies, the government, and an increase in the mussels' price.

The contingent valuation (CV) method was the most appropriate methodology for this objective. CV uses questionnaires to elicit people's WTP by creating a hypothetical market where respondents can choose between the situation with and without the program (status quo) (Bateman et al., 2001; Carson et al., 2003; Carson et al., 2003; Mitchell and Carson, 1989).⁶ The study evaluated the responses of mussel consumers to an increase in the price of the product (prime) to finance the program. The survey explains to respondents the past red tide event, its impacts, and the proposed program. The survey was applied in the two large cities (Santiago and Concepción) from October to December 2016, targeting individuals aged 18 years and above who were regular consumers of mussels (weekly or monthly). We conducted four focus groups and two pilot surveys (125 observations) to evaluate the survey. The survey followed a probabilistic multi-stage sampling design, randomly choosing neighborhoods and blocks and then selecting households.

Since there are many product presentations (fresh with shell, fresh only meat, frozen with shell, frozen only meat, canned in oil or water), we identified the need to standardize the product to a quarter kilo of mussel using focus groups and pilot surveys.⁷ The survey offers 250 g of meat regardless of the presence of shells in the product (equivalent to approximately forty-five units). The cost of the product was, on average, CL\$1250. Then, the WTP question was: "Would you be willing to pay an additional \$A_t pesos for 250 g (one quarter) of mussel meat for these measures to be implemented?" The amount \$A_t varies in different surveys to

⁶ The validity of CV applications has been the object of a long discussion. In particular after the Exxon Valdez oil spill in Alaska in the 1990s (R. Carson et al., 2003). Some issues evaluated are reliability (Arrow et al., 1993; Diamond et al., 1993) and embedding effects (Desvousges et al., 1993; Diamond et al., 1993; Kahneman, 1992; Payne et al. (2000)). A symposium in the *Journal of Economic Perspectives*'s CV (Carson, 2012; Hausman, 2012) and *Applied Economics Perspective and Policy* (Desvousges et al., 2016; Haab et al., 2016) summarized part of this discussion. A CV study involves much more than a mere question of WTP (Arrow et al., 1993; Johnston et al., 2017).

⁷ Various products have different weights. We use visual aids to represent the 250 grs in each format. Sometimes we need additions or subtractions to reach 250 g.

get enough variation to estimate a WTP response function. The bids were 250, 500, 650, 950, 1100, 1250, and 1500 Chilean pesos.

Additionally, we evaluate people's trust in the institutions in charge of conducting the policy instruments that seek to prevent or mitigate the effects related to HABs and assess how this trust influences their WTP. In SP applications related to food, Yeh et al. (2020) show that attitudes and trust significantly explain consumers' preferences for different attributes. Similarly, latent class models showed that respondents who trust the food system are less averse to certain products, which indicates that generalized trust affects consumers' consumption choices (Ding et al., 2012).

While there are many dimensions of trust as part of social capital parameters, such as social trust, institutional trust, social networks, and social reciprocity (Jones et al., 2015; Habibov et al., 2019), we are interested in institutional trust since this is relevant to explaining the WTP for the implementation of the policy (Wiser, 2007; Jones et al., 2011; Habibov et al., 2019; Byaro and Kinyondo, 2020). Individuals with higher trust in institutions are expected to have a higher probability of paying to implement the policy. Generalized trust refers to confidence in unknown people by the respondent or in situations where the person being trusted is not specified. In contrast, institutional trust refers to confidence in all types of institutions (OECD, 2017). This research focused on respondents' trust in the government that provides information about risks related to red tide.

The relevance of institutional trust for WTP estimations has been identified in several papers either theoretically (Oh and Hong, 2012) or empirically (Krystallis and Chrysohoidis, 2005; Meyerhoff and Liebe, 2006; Birol and Das, 2012; Jones et al., 2015). Institutional distrust may lead individuals to refuse to participate in surveys, provide a protest response, or indicate low values of their WTP (Birol and Das, 2012; Chen and Hua, 2015; Kassahun et al., 2021). In particular, Jones et al. (2015) evaluate how social capital affects WTP for coastal defenses to cope with climate change events. In the context of HABs, only one article includes trust as an explanatory variable in the policy evaluation (L'Ecuyer-Sauvageau et al., 2019). Unlike our application, they use a CE focusing on recreational activities. Recreational activities are irrelevant in the Chilean case since most of the burden is on seafood production. To avoid an exhausting long survey, we decided to use a single question regarding trust instead of the multiple-question study suggested by the OECD Guidelines that are used to measure several trust constructions. A similar approach was followed by L'Ecuyer-Sauvageau et al. (2019). Future research might evaluate whether a simple versus multiple-question approach explains people's WTP better.

2.2.1. Survey design

The survey instrument starts with a series of filter questions to identify the target population. In that sense, the questions include the following: "Are you over 18 years of age?", "Are mussels normally consumed in your home?" (Weekly or monthly) and "Do they not consume because nobody likes them?" If the person is under 18 years of age or answers that "no one in their household likes mussels," thank the respondent for their time and survey another household. Otherwise, proceed with taking the survey. We asked people about their knowledge of the origin of the mussels they consume. The survey also included a section collecting sociodemographic information.

The survey also explains the red tide concept: "It is a natural phenomenon caused by the increase of some tiny algae (microalgae) in water. These algae are the food of mussels and other marine organisms. Red tide can cause damage to people's health who consume them. Additionally, it produces economic losses for aquaculture and extractive activity." (Free translation from Spanish) Followed by:

"Scientists believe this phenomenon will repeat itself more often in the future and that it is inevitable, given the changes in the ocean. For this reason, they have been seeking mechanisms to predict more accurately when a red tide event will occur to take protective measures."

"According to the Chilean Ministry of Health, from 1970 to date, HABs

have increased the frequency and extension of diarrheal, amnesic, and paralyzing toxin events. Its development and duration depend on biological, hydrological, and meteorological factors. The toxins of importance in Chile are Diarrheal Poison of Shellfish, Amnesic Poison of Shellfish, and Paralyzing Poison of Shellfish."

"In addition, since 1995, Chile has had a National Program for Surveillance and Control of Harmful Algal Phenomena in all affected regions. This program aims to minimize health risks, understand the phenomenon's magnitude and evolution, and timely detect levels of toxins to adopt measures to protect the population. Among the activities performed are control at disembarkation, cultivation, and natural bank areas and prohibiting extraction and commercialization, health promotion actions, risk communication, and surveillance of clinical cases.

The Ministry of Health annually promotes a preventive campaign that clearly describes what HAB is, what the symptoms are, ways to prevent poisoning, and a series of recommendations to avoid intoxication.

Nevertheless, these actions are insufficient given the recurrence of the phenomenon, the size of the areas affected, and its severity. That is why we are implementing a tripartite fundraising program (government, industry, and consumers) to create a seawater monitoring system to predict the emergence of red tides, inform people opportunistically, and help small and medium-sized producers when these events occur. The idea is to reduce producers' financial instability associated with social problems and increase fairness in allocating the adverse effects of the red tide." This section is followed by the valuation question described above.

A recurring critique of the CV method is that individuals do not respond to the interview as a consumer. In other words, they are not using their structure of preferences for goods; instead, the individual assumes a different role, commonly that of a citizen (Blamey et al., 1995). According to Sagoff (1994), a gap exists between preference and choice elements, between preferences and satisfaction, and finally between these elements and well-being. When acting as citizens, individuals are more influenced by ethical, religious, or political considerations. In this context, there will be situations where individuals are unwilling to accept compensation for the loss of a good or service. In other words, there is no possibility of exchange between money and environmental goods in these cases, which prevents the researcher from conducting a cost-benefit analysis. Vant (2000) argues that ethical considerations cannot be reduced to a single metric like money, especially in environmental valuation, given the complexity of environmental decisions.

On the other hand, Soderqvist (1998) provides evidence that some respondents considered their ethical beliefs when answering the question of WTP. However, he suggests that empirical evidence rejects the hypothesis of the absence of trade-offs between environmental goods and income. In our application, most of the components in the setting appeal to direct benefit to the consumers; only the last element in the setting captures altruism and fairness, which are valid motivations for contributing to the crisis fund, and since we do not ask individuals to accept any compensation, the distinction between consumer and citizen should not be a significant problem for the interpretation of our results.

2.2.2. Statistical approach

Estimating the WTP from discrete choice CV studies requires certain specific techniques that allow us to use parametric and nonparametric approaches (Hanemann and Kanninen, 1999; Haab and McConnell, 2002; Champ et al., 2003). This paper follows the most straightforward parametric model that permits the inclusion of covariates in the regression. A linear utility function is $v_j = \alpha + \beta y + \epsilon_j$, where v_j is the indirect utility in the situation j (0 for status quo and 1 for new situation), y is income, ϵ_j is an error term (normally distributed in the Probit model) and (α, β) are parameters to be estimated. This is the most common function used in CV because of its simplicity in assessing and interpreting the parameters and calculating the WTP (Louviere et al., 2000). The dependent variable is defined as $y_i = 1$ for a positive answer

and a $y_i = 0$ otherwise. A respondent will be willing to pay the amount only if the utility or benefits of doing so is higher than the utility of the status quo (Hanemann, 1984; Haab and McConnell, 2002). Other covariates enter the model through α , and the income effect is captured by coefficient β . Given the linear utility function, the WTP's mean (and median) is $E(WTP) = \alpha/\beta$.

We include in the explanatory variables age of individuals, years of education, a dummy variable that takes a value of 1 if the individual only eats fish when there is a red tide, a dummy variable that takes a value of 1 if the respondent consumes fish and shellfish from unaffected areas in the event of a red tide, a dummy variable that takes value one if the individual trusts the government when it provides information and certifies that the products, they consume are free of red tide and a variable that takes value one when the respondent declares to be male.

3. Results

We organized the presentation of the results as follows. First, we summarize the studies that estimated the economic impacts of HAB events and identify information gaps and policy instruments for HAB management. Second, we estimate the WTP for the policy and evaluate the importance of trust in the WTP.

3.1. Literature review

The conceptual framework for the analysis was presented in Table 1, with a classification of the different methodological approaches and their links to economic welfare measures. We found applications of all three broad categories: revealed preferences (RP) (37/54 studies, 68.5%), stated preferences (SP) (10/54 studies, 18.5%), and benefits transfer (BT) (4/54 studies, 7.4%)⁸; in comparison, the remaining 3/54 studies contain two of the previous classifications and represent 5.6% of the included papers. Each has subcategories, specific techniques, goals regarding welfare measure estimation, data types, and econometric approaches. For instance, in RP, we distinguished the subcategories of market price valuation (MPV), market price proxies (MPV proxy), Travel Cost (TC), and Hedonic Prices (HP). On the other hand, we have Contingent Valuation (CV) and Choice Experiments (CE) in SP. BT includes unit value transfer or a value transfer function, which depends on the number of previous studies available.

Theoretically consistent welfare measures include consumer and producer surplus and Hicksian welfare measure (compensating or equivalent variation) measures such as WTP or WTA compensation. SP and some RP techniques, such as TC and HP models, are meant to estimate these theoretically consistent welfare measures. While market price valuation can potentially estimate consumer and producer surpluses, in most of the identified studies using direct market information, a proxy is used for estimating welfare measures (MPV proxy). There are many proxies for doing this estimation. For instance, some researchers use reductions in sales, production, revenues, or exports as proxies. Some researchers acknowledge these differences by distinguishing between economic welfare measures (social cost of HABs measure using changes in surpluses) and changes in the overall economy, called *economic impacts* (Anderson et al., 2000; Habas and Gilbert, 1974).

Finally, several data types are found in the literature, including time series, cross-sectional, panel data, aggregated data, and individual-level data derived from secondary sources or surveys. There are also different tools for the analysis, going from simple multiplication of prices and quantities (price*quantity) to linear regression models (OLS) or even more sophisticated time series methods and discrete choice models such as the multinomial logit model (MNL) and the random parameter models (RPM).

Table 2 summarizes the selected papers that explicitly include the

economic valuation of HAB events. We consider several categories: year of publication, country, spatial scope, country, method category, and subcategory, type of value (use or nonuse), sample type, data, econometric tools, overall value estimate, policy proposal, estimated welfare measure, products, polluter, and policy analysis. We also included the paper by Van den Bergh et al. (2002), which presents a theoretical approach to valuation, and Adams et al. (2018), which has a literature review.

The articles vary significantly regarding the scope of the analyses, the methodologies, and the type of policy evaluated. Therefore, making any meaningful comparison of the economic values is difficult. For example, some studies include comprehensive analyses of vast coastal areas (Anderson et al., 2000; Hoagland et al., 2002; Lucas et al., 2010; Yang et al., 2018). Other studies analyze several events (several types of alga blooms), different periods, diverse economic losses (health, productivity, recreation), and various products (clams, oysters, recreational fishing, scallops). Others are more localized regional analyses (one site, one product, and one event) (Habas and Gilbert, 1974; Cummins, 2012). Considering this complexity, we calculated the economic impact as a GDP fraction at a national level as a comparative benchmark.⁹ A better comparison can be made by including the mentioned nuances, but getting data at the necessary detail level is markedly challenging for the available studies. Notoriously, most studies are from developed countries (46/54, 85.2%), in the USA (32/54, 59.3%), and just a few in developing countries (Cook Islands, China, Ghana, and Chile) (Mardones et al., 2020; Trick et al., 2020).

RP dominates the literature, with thirty-seven out of 54 articles (72.2%). We found only two hedonic price models (Wolf, 2018; Osseni et al., 2019) and four travel cost applications (Nunes and Van den Bergh, 2004; Huhtala and Lankia, 2012; Wolf et al., 2019; Lim et al., 2020). The most conspicuous result is that the RP literature focuses primarily on "economic impact analyses" (impact on the economy) and uses market information other than prices and quantities (the MPr proxy approach), with thirty-two out of 54 studies using that approach (59% of the total number of studies but 87% of the RP literature). The proxies include sales reductions, loss revenue, the average expenditure of tourists, and reduction in landings and medical costs (Habas and Gilbert, 1974; Diaby, 1996; Anderson et al., 2000; Evans and Jones, 2001; Hoagland et al., 2002; Larkin and Adams, 2007; Dyson and Huppert, 2010; Nierenberg et al., 2010; Cummins, 2012; Rongo and Van Woesik, 2012; Hoagland et al., 2014; Oliveira et al., 2015; Martino et al., 2020; among several others). Only two studies estimate demand and/or supply functions (Khan and Rockel, 1988; Wessells et al., 1995), but only Khan and Rockel (1988) estimate consumer and producer surpluses.

Overall, time series data and time series analysis dominate the market price (proxy) valuation approach (Larkin and Adams, 2007; Hoagland et al., 2009; Morgan et al., 2009; Hoagland et al., 2014; Anderson and Villarreal, 2020; Martino et al., 2020). These studies aim to quantify direct and indirect costs (Cummins, 2012; Sanseverino et al., 2016; Kouakou and Poder, 2019) and losses (Wessells et al., 1995; Hoagland et al., 2002; Nierenberg et al., 2010; Adams et al., 2018) associated to HABs. For instance, Nierenberg et al. (2010) estimate the economic losses due to the reduced lifeguard attendance during blooms. They count the cost by multiplying absenteeism by the average daily salary to extrapolate the annual county-level total cost. This procedure is the classical price time quantity approach (Lipton, 1999; Morgan et al., 2008; Park et al., 2013). In this context, the importance of defining multipliers to capture the full ramifications of economic impacts was pointed out by several authors. Therefore, they use input-output analysis to estimate the total effects of HABs on the economy (Evans and Jones, 2001; Oh and Ditton, 2008; Dyson and Huppert, 2010; Ramos et al., 2021). Another method compares scenarios with and without HABs (Jin et al., 2008) and multiplies these differences by prices. Finally, modern

⁸ We repeat the acronyms here to avoid going back to the introduction.

⁹ We thanks to an anonymous reviewer for this suggestion.

Table 2

Papers estimating the economic impact of HABs.

	Authors	Year	Country	Spatial Scope	Temporal Scope	Category	Subcategory	Sample	Data	Econometrics or other tools	Type of Value	Results (2022 US\$)	Policy Proposal
1	Habas and Gilbert	1974	USA	West coast of Florida (7 counties)	1971	RP	MPr proxy: Sale reductions, average expenditures of tourists in restaurants, hotels, value of landed fish, beach cleanup.	Secondary data and interviews.	Time series	Price * quantity	DUV: Revenue losses to the tourism, industry, and commercial fisheries. Hotels, restaurants, tourism expenditures, and beach clean up.	\$115.2 million (0.005% of GDP)	NO
2	Khan and Rockel	1988	USA	New York State	NA	RP	MPr: Demand and supply function estimations	22 years of landings	Time series	OLS	DUV: Consumer surplus	Not reported	NO
3	Wessells et al.	1995	Canada	Montreal	1987–1991	RP	MPr: Demand estimation	198	Time series	OLS + Price* quantity	DUV: Sale losses	8% less annual sales	NO
4	Diaby	1996	USA	North Carolina, Neuse River	1995	RP	MPr proxy: reduction in landings	landings	Time series	Price * quantity	DUV: commercial fishing	A reduction of 47%	NO
5	Lipton	1999	USA	Maryland	Jan–Dec 1997	RP	MPr proxy: Calculation of lost sales and recreational trips	71	Survey of seafood industry members; NMFS/MRFSS	Price * quantity	DUV: Lost in revenue due to decline in trips	Lost revenue of \$4.0 million (0.0002% of GDP)	NO
6	Anderson et al.	2000	USA	USA, National Scope	1987–1992	BT	MPr proxy: lost revenue, expenditures for environmental monitoring and management, and other costs. Lost wages, work days, expenditures in tourism.	170 experts	Expert opinion	Benefit Transfer	DUV: public health, commercial fishery, recreation and tourism, monitoring, management.	\$50.1 - \$138.7 million annually (0.002–0.005 % of GDP)	NO
7	Evans and Jones	2001	USA	Texas, Galveston county.	2000	RP	MPr proxy: sales losses	32 surveys to businesses	Cross section	Input-output analysis	DUV: Area Businesses Closures and Losses, Beach Clean Up, oyster production.	\$52.1 million annually (0.002 % of GDP)	NO
8	Hoagland et al.	2002	USA	USA, National Scope	1987–1992	BT	MPr proxy: lost revenue, lost sales, medical costs, expenditures for environmental monitoring and management. Lost wages, work days, expenditures in tourism.	170 experts	Expert opinion	Benefit Transfer	DUV: Lost sales or factor markets, medical costs (productivity), monitoring and management, other costs.	\$39.5- \$136.5 million annually (0.002–0.005 % of GDP)	NO
9	Whitehead et al.	2003	USA	Mid-Atlantic Region (Maryland, North Carolina)	2001	SP	Contingent valuation (CV), contingent behavior (CB), demand estimation	1807	Cross section	Random effect probit model, random effect tobit, Bivariate probit.	DUV: consumer surplus per seafood meal and WTP for seafood inspection.	Aggregated consumer surplus loss: \$59.6–116.1 million. (0.002–0.005 % of GDP WTP \$11.3 per meal for mandatory seafood inspection.	Yes. Mandatory seafood inspection program
10	Nunes and Van den Bergh	2004	Netherlands	North-Holland	2001	RP, SP	Contingent-valuation (CV) travel cost (TC)	242	Cross-section travel data and WTP responses	Generalized travel costs. Dichotomous-choice elicitation question	DUV: Recreation value	Total welfare loss of \$379.66 million (0.04 % of GDP)	Yes. Protection Program

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Table 2 (continued)

	Authors	Year	Country	Spatial Scope	Temporal Scope	Category	Subcategory	Sample	Data	Econometrics or other tools	Type of Value	Results (2022 US\$)	Policy Proposal
11	Cesar and van Beukering	2004	USA	Hawaii	2001	RP	MPr Proxy: Calculated reductions in business using available dynamic econ-ecol simulation model and available economic values	Interviews to: 50 divers, 260 snorkelers and 150 nonusers	Previous studies, including survey-based non-market valuation	Simplified dynamic simulation model	DUV: Loss in value of marketable goods and services	WTP of \$15.6 and \$19.50 if used for conservation	NO
12	Morgan and Larkin	2006	USA	Southwest Florida	1996–2005	RP	MPr proxy: losses to restaurants	339 obs	Time series	Time series analysis of daily observations	DUV: Daily Restaurant Sales Losses	Daily sales reduced by \$906.39 (5%–14% of daily sales)	NO
13	Parsons et al.	2006	USA	Mid-Atlantic region	2001	SP	Contingent behavior	160 seafood consumers. 15 interviews	Cross section	Contingent behavior analysis	DUV: Loss in consumption	Aggregate Cost of \$60 million per month	NO
14	Larkin and Adams	2007	USA	Northwest, Florida	1995–1999	RP	MPr proxy: revenue losses	47	Time series	Time series analysis.	DUV: Business sector: Restaurants and Lodging, Decision Making	\$78.2 million annually (0.003 % of GDP)	NO
15	Jin et al.	2008	USA	New England (Maine and Massachusetts)	1990–2005	RP	MPr proxy: Reduction in landings, imports, prices.	Value of monthly landings (2000–2005)	Time series	Scenario comparisons	DUV: Direct economic impacts and Net economic benefit of commercial shellfish fisheries	\$3.4 - \$25.5 million annually (0.0001–0.001 % of GDP)	NO
16	Dodds et al.	2009	USA	US freshwater	NA	RP, BT	MPr proxy: Losses per trip-related expenses, percent of gain or Loss of property values, Cost of recovering species. Drinking water treatment costs.	secondary information and surveys to agencies	Cross section	Price * quantities, Benefit transfer, Value function.	DUV: Recreation, real estate values, spending on recovery of threatened and endangered species, and drinking water.	\$3.1 billion annually (0.1 % of GDP)	NO
17	Jin and Hoagland	2008	USA	New England (Maine and Massachusetts)	NA	RP	MPr proxy: a predicted model for public and private responses.	NA	Time series	scenario comparisons	DUV: The value of long term annual predictors.	\$1.01 - \$4.24 million annually (0.00004–0.0002 % of GDP)	Yes. Monitoring technologies and predictive models for forecasting bloom events
18	Morgan et al.	2008	USA	Florida Gulf Coast (18 cities, 9 counties)	2004–2007	RP	MPr proxy: induced Cost and losses to cities and counties	27 counties (managers)	interviews	Price* quantity	DUV: beach cleanup, dead fish removal	\$924,827 for the period (0.00004 % of GDP)	NO
19	Oh and Ditton	2008	USA	Poosum Kingdom Lake, Texas	1986–2005	RP	MPr proxy: Output losses	Not specified	Secondary data on sales and taxes.	Input-output analysis. Time series intervention analysis	DUV: Effects on recreational fishing	Total economic output loss of \$3.96 million (0.0002 % of GDP) and considerable declines of visitors	NO
20	Morgan et al.	2009	USA	Southwest Florida	1998–2005	RP	MPr proxy: losses to restaurants	2032	Time series	Time series analysis.	DUV: Daily Restaurant Sales Losses	\$1194.1 - \$30,819.7 per red tide event	NO
21	Hoagland et al., 2009	2009	USA	Florida, Sarasota County	2001–2006	RP	MPr proxy: Cost of illness (number of cases multiplied by Cost of illness)	261	Time series	Doses-response function + Time series analysis + price*quantity	DUV: Respiratory illness costs	\$0.7 - \$5.75 million annually (0.00003–0.0002 % of GDP)	NO

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Table 2 (continued)

	Authors	Year	Country	Spatial Scope	Temporal Scope	Category	Subcategory	Sample	Data	Econometrics or other tools	Type of Value	Results (2022 US\$)	Policy Proposal
22	Morgan et al.	2010	USA	Sarasota and Manatee Counties, Florida	2008	RP	Choice model for the probability of behavioral change.	755	Cross section	Dichotomous choice model. Multinomial Choice model.	DUV: Saltwater fishing from a boat, saltwater fishing from a pier or beach, beach-going, and patronage of restaurants located near the beach	37% of restaurants and 70% of beachgoers affected	NO
23	Nierenberg et al.	2010	USA	Sarasota, Florida	2004–2005	RP	MPr proxy: Costs and Losses.	39	Panel lifeguard attendance	Price*quantity	DUV: Reduced Lifeguard attendance and salary loss	\$135,613.6 annually (0.00001 % of GDP)	NO
24	Lucas et al.	2010	USA	Florida	2010	SP	Contingent valuation (CV)	14,400	Cross section	Dichotomous choice, WTP for different strategies.	DUV: Human Health; Fishery; Tourism and Recreation; Monitoring and Management	Not reported	Yes. Prevention, Mitigation, and Control Strategies
25	Dyson and Huppert	2010	USA	Washington State.	2008	RP	MPr proxy: Recreationists' spendings	240	Cross section	Input-output analysis, recreational spending survey	DUV: Recreational razor clam fishery	\$33.12 million annually (0.001 % of GDP)	NO
26	Taylor and Longo	2010	Bulgaria	Varna Bay	2010	SP	Choice experiment (CE)	850	Panel data survey	Multinomial logit models	DUV: One-time tax (a program that provides beaches free HAB)	WTP: \$17.7	Yes. Beach free from algal blooms
27	Morgan et al.	2011	USA	Florida gulf coast	2002–2004	RP	MPr proxy: revenue losses	93	Time series of visitors	Time series analysis of daily observations	DUV: attendance at the park	\$ 22,310.13	NO
28	Ralston et al.	2011	USA	USA	Annual	BT	Benefit transfer	Not specified	Other papers (secondary)	Cost and sensitivity analysis	DUV: Costs associated with health effects of HAB	Annual costs of \$1184.26 million (0.05 % of GDP)	NO
29	Cummins	2012	USA	Texas, Calhoun County	2011–2012	RP	MPr proxy: Costs and Losses	NA	Cross section	Input-output	DUV: Losses due to closures of local harvesting areas. Sacks of oysters and their value (landed on the local docks).	\$11,011.54 per vessel and captain and \$7341.02 per deckhand	NO
30	Huhtala and Lankia	2012	Finland	Finland	2008	RP	Travel Cost (TC)	343	Cross section	Travel cost analysis	DUV: Recreation value	Decreases value per trip by 40% and aggregate consumer surplus by 6%, or approx. \$29.38 million annually. (0.01 % of GDP)	NO
31	Rongo and Van Woesik	2012	Cook Islands	Rarotonga	2011	RP	MPr Proxy: Food consumption and subsistence fishing comparisons	179 households	Cross section	Cost-savings-and-avoidance valuation	DUV: Loss in value of marketable goods and services	Up to \$1.6 million annually (0.6 % of GDP)	NO

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Table 2 (continued)

	Authors	Year	Country	Spatial Scope	Temporal Scope	Category	Subcategory	Sample	Data	Econometrics or other tools	Type of Value	Results (2022 US\$)	Policy Proposal
32	Agúndez et al.	2013	France	France	1997–2007	RP	Economic performance of specific technological adoption. Does not value the impact of HAB	579 financial reports of 81 farms	Secondary data of financial reports	Benefit Transfer	Cost-benefit analysis of two technological solutions	Not reported	Yes. Safeguarding storage and accelerated detoxification
33	Park et al.	2013	Korea	Korea	1981–2012	RP	MPr proxy: revenue losses	Not specified	Fish/shellfish kills	Price * quantity	DUV: Lost in revenue due to fish kills	Losses between \$5.40 - \$60 million (0.0003–0.004 % of GDP)	Yes. Precautionary management through monitoring network and prevention strategy
34	Hoagland et al.	2014	USA	Florida, Southwest	1988–2010	RP	MPr proxy: Cost of illness	NA	Time series	Time series analysis	DUV: human health	\$2.5 - \$30.4 million annually (0.0001–0.001 % of GDP)	NO
35	Salojärvi.	2014	Finland	Finland	2012	SP	Choice experiment (CE)	158	Panel survey data	Multinomial logit models, Random parameter models	DUV and NUV: Ecological status of the Gulf of Finland	WTP of \$275.6 - \$504.8 for moderate and \$511.8 - \$827.4 for substantial management	Yes. Intervention scenarios
36	Kirkpatrick et al.	2014	USA	Sarasota, Florida	2012	BT	Does not include valuation, only perceptions. But, a complementary material has estimates using previous studies—or secondary data.	117	Cross section	Benefit Transfer	Perceptions and knowledge of red tide	Not reported	NO
37	Oliveira et al.	2015	Portugal	Coast of mainland Portugal	2006–2012	RP	MPr proxy: revenue losses	Not specified	Daily activity data of the fleet	Stochastic frontier analysis models	DUV: Lost sales or factor markets, medical costs (productivity), monitoring and management, other costs.	Not reported	NO
38	Sanseverino et al.	2016	Global	Global	NA	RP	MPr proxy: Costs and Losses	Not specified	Literature review	benefit transfer	DUV: Human Health; Fishery; Tourism and Recreation; Monitoring and Management	\$12.7 billion annually (0.01 % of GDP)	NO
39	Zhang and Sohngen	2018	USA	Ohio, Lake Erie	2013–2014	SP	Choice experiment (CE)	767	Panel survey data	Discrete choice models, multinomial logit, Generalized multinomial logit	DUV: Welfare losses from HABs, not catch rate.	WTP: \$9.5 - \$11.8 per trip for one less mile and \$51.7 - \$60.3 for one less hour needed. \$76.9 - \$113.6 for improving water clarity and \$47.3 - \$71 for policy	Yes. Reduction in size and intensity. Reduction of phosphorous and nitrogen.
40	Wolf	2018	USA	Ohio, Lake Erie	2009–2014	RP	Hedonic price (HP), MPr proxy: fishing expenditures, Total revenue loss, Travel cost (TC)	6862 months by zip code obs. 749 web-based survey	Time series of Annual fishing registration data. Monthly license counts.	Count data model. Random utility models, Multinomial logit, Latent class	DUV: Housing market, tourism and recreation revenues and demand.	Loss of \$2.66 - \$70.03 million (0.0001–0.003 % of GDP) annually, depending on the sector.	Yes. Remediation policies will likely have strong

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Table 2 (continued)

Authors	Year	Country	Spatial Scope	Temporal Scope	Category	Subcategory	Sample	Data	Econometrics or other tools	Type of Value	Results (2022 US\$)	Policy Proposal
								Spatial measures.	model. Spatial econometrics		Welfare losses by more than \$473.15 million (0.02 % of GDP).	distributional effects.
41 Yang et al.	2018	China	Chinese Yellow Sea	2008, 2009, 2012, 2014	SP	Contingent valuation (CV)	299	Cross-section of Several surveys	WTP for different mitigation programs	DUV: Costs associated to mitigation strategies	Total yearly costs of \$3.3 million (0.0002 % of GDP). WTP of \$10.6 among residents and \$14.1 among tourists.	Yes. Prevention and Mitigation program
42 Wolf et al.	2019	USA	Ohio, Lake Erie	2017	SP	SP: Discrete Choice travel cost	549	Panel survey data	Mixed logit, conditional logit, latent class	DUV: Beachgoers and recreational anglers	Aggregate Loss of \$8.9 and \$79.9 million (0.0003–0.003 % of GDP) for beachgoers and recreational anglers, respectively	Yes. Prevention scenarios, reduction in phosphorous and E. Coli.
43 Kouakou and Poder	2019	Several	Several	2019	RP	Descriptive analysis, systematic review (QALYS)	16 studies	Cross-section of studies	Benefit Transfer	DUV: Health Costs	Up to \$14,572.84 for digestive illness and \$16,879.29 for respiratory illness	NO
44 L'Ecuyer-Sauvageau et al.	2019	Canada	Quebec	2017	SP	Choice experiment (CE)	252	Panel survey data	Discrete choice models, multinomial logit, RPL	DUV: Visual aspect, recreational activities, Odour. IUUV: Ecological health, Cost.	WTP: \$313.79 yearly per household	Yes. Improve water quality
45 Osseni et al.	2019	France	Britanny	2010–2012	RP	Hedonic price (HP)	8003	Cross section	Linear regression OLS, spatial models, and maximum likelihood	DUV: Rural housing market	WTP: \$269.93	Yes. Reducing nitrogen and phosphorous
46 Bechard	2020	USA	Florida	2005, 2006, 2018	RP	MPr proxy: sales	202	Panel data	Difference-in-differences model	DUV: Lodging Sector, Restaurant Sector	\$3.65 million monthly (0.0001 % of GDP)	NO
47 Martino et al.	2020	Scotland	Scotland	2009–2018	RP	MPr proxy: production levels	100	Panel data	Time series analysis. Autoregressive models production function estimation	DUV: change in production	Yearly production loss of 15% and economic Loss of \$2.13 million per year (0.0001% of GDP)	NO
48 Ramos et al.	2021	Chile	Chile	2013–2016	RP	MPr proxy: reduction in family income	NA	Secondary data for IO analysis	Input-output analysis	DUV: Effects on family income due to unemployment.	Decline of total output by 5,64% and total income by 1.81%	NO
49 Anderson and Villarreal	2020	Chile	Los Lagos Region	2010–2019	RP	MPr proxy: exports	NA	Time series	Time series analysis.	DUV: Ocean-derived products export of the Los Lagos region.	28% loss of ocean-based exports	NO
50 Ofori and Rouleau	2020	Ghana	Elmina	2020	SP	Contingent valuation (CV)	502	Cross section	Interval regression	DUV	WTP: \$14.17, \$6.25, and \$7.94 as mean monthly WTP for high-income, low-	Yes. Seaweed cleanup

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Table 2 (continued)

Authors	Year	Country	Spatial Scope	Temporal Scope	Category	Subcategory	Sample	Data	Econometrics or other tools	Type of Value	Results (2022 US\$)	Policy Proposal
51 Jin et al.	2020	Global	Global	NA	SP, RP	NA	Not specified	Review of selected articles		DUV	income, and all households, respectively They provided examples based on other papers included in this table.	NO
52 Lim et al.	2020	Korea	Korea	2010–2018	RP	TCM MprProxy: Revenue loss, Management costs	Not specified	Primary data and secondary data	Poisson, negative binomial for TCM	DUV: Consumer surplus, Expenditures, revenue loss	Consumer surplus: \$122 per trip Total Loss: \$16.1 Million per year (0.001 % of GDP) Damage: \$7.7 million year (0.0005 % of GDP) Total \$147 Million (0.009 % of GDP) Management and research: \$5.5 Million year (0.0003 % of GDP)	Yes, Yellow Clay
53 Trick et al.	2020	South Pacific Island	South Pacific Island	Not specified	RP	MprProxy: Revenue loss, Management costs, health costs	Not specified	Secondary data	NA	DUV: Health costs, lost economic output, lost economic profits of fishers, reduced profits, losses in economic welfare.	NA: only Description	No
54 Mardones et al.	2020	Chile	Chile	2019 2014–2018	RP	MprProxy: Shellfish Harvested, health costs	Not specified	Secondary data	Price * quantity	DUV: Shellfish harvesting, hospitalization costs	Harvesting: \$6.9 million (0.002 % of GDP) Health: \$93K	Monitoring system

econometric approaches considering causality are scarce in the literature, with only [Bechard \(2020\)](#) using a difference-in-differences model, and others suggest using general equilibrium models ([Jin et al., 2020](#)).

The SP literature, covering ten studies, was initially dominated by CV applications ([Whitehead et al., 2003](#); [Nunes and Van den Bergh, 2004](#); [Lucas et al., 2010](#); [Morgan et al., 2010](#)), but we can see more applications of CE lately ([Taylor and Longo, 2010](#); [Salojärvi, 2014](#); [Zhang and Sohngen, 2018](#); [L'Ecuyer-Sauvageau et al., 2019](#)). A few studies also use contingent behavior to understand people's responses to HABs ([Morgan et al., 2008](#); [Parsons et al., 2006](#)). SP applications use discrete choice models for binary (probit, logit) or multinomial responses (conditional logit, random parameters models, latent classes models).

Only a few studies use a "benefit transfer approach" by adding estimates from previous studies or reports ([Anderson et al., 2000](#); [Hoagland et al., 2002](#); [Dodds et al., 2009](#); [Kirkpatrick et al., 2014](#)). For instance, [Sanseverino et al. \(2016\)](#) use a simple unit value transfer function to approximate the economic cost of the HAB event. Several problems arise with his approach. First, whether one should add values covering different periods and economic losses (production, health, sales, revenues, WTP for products) is unclear. Second, given that economic value is contingent on the population affected by the loss, benefits transfer assumes that the preference structure of the population in both studies (the previous studies and the new study) is the same. This is not easy to sustain in many of these cases.

Regarding the type of value considered in the studies, most studies focus on the direct impact of HABs, including commercial fisheries, tourism, recreation, health impacts, and the cost of monitoring and management. Nonuse and indirect use values (effect on marine ecosystems) are entirely ignored in the literature on the economic value of HABs. While some SP applications could include a nonuse value component or indirect use value, these papers do not explicitly acknowledge this. Most are looking at some dimensions of tourism and recreation.

Considering the previous distinctions, in Chile, [Ramos et al. \(2021\)](#) found that the total output and income declined by 5.64% and 1.81%, respectively. [Anderson and Villarreal \(2020\)](#) estimated a 28% loss of ocean-based exports in the Los Lagos region in Chile. In the rest of the world, values for the whole economy have been estimated at up to \$ 136.5 million for the United States (0.005% of GDP) ([Hoagland et al., 2002](#)). For specific States, the annual impacts have been estimated to be \$115.2 million (0.005% of GDP) for Florida ([Lucas et al., 2010](#)), \$52.1 million (0.002% of GDP) in Texas ([Evans and Jones, 2001](#)), \$33.12 million (0.001% of GDP) for Washington ([Dyson and Huppert, 2010](#)) and up to \$4.24 million (0.0002% of GDP) for New England ([Jin et al., 2008](#)). Specifically for health impacts, [Kouakou and Poder \(2019\)](#) estimated health costs for digestive illness to be up to \$ 14,572.84 for severe cases and up to \$ 16,879.29 for severe respiratory illness. Parallely, reductions in annual sales are estimated at around 8% by [Wessells et al. \(1995\)](#) in Canada. In Scotland, [Martino et al. \(2020\)](#) estimated a yearly production loss of 15% and an economic loss of \$ 2.13 million (0.0001% of GDP) per year in Scottish shellfish farms.

Unfortunately, these values are not at all comparable. They differ in the magnitude of the area affected, the number of products, the time horizon, etc. It was not possible to find a metric that makes them comparable. A better approach would be to express these values as a portion of the corresponding GDP, sales, export value, etc., considering geographical adjustments. In this way, we could see how relevant the impact is to the economy. More importantly, these values should be associated with a policy intervention in which the avoided cost can be clearly estimated.

3.1.1. Policy instruments for HAB management and valuation

Policies instruments (see [Table 3](#)) for HABs are classified into prevention, restoration, amelioration, and no action ([Anderson et al., 2001](#); [Anderson, 2009](#)). Prevention is more cost-effective and environmentally desirable than measures taken following the introduction of an invasive

Table 3
Policy categories for HAB management.

Policy	Description	Examples
Prevention	The minimization of the probability of HAB formation and reducing/eliminating the introduction of polluting matter into the sea from land-based sources and activities.	The Law of the Sea (LOS) Convention requires States to take all measures necessary to prevent, reduce and control the intentional/accidental introduction of species to a particular part of the marine environment.
Restoration (Control)	Implemented once HABs have occurred to keep them from spreading. They may involve direct chemical, physical or biological control measures to target existing blooms.	Shipping companies are forced to internalize the costs (polluter pay principle). Early warning systems and national contingency plans. Reduce or eliminate inputs of nutrients from various land-based sources and activities.
Amelioration	Characterized by punctual, individual programs that comprise the various mitigation measures that can be adopted to reduce impacts on marine living resources, human health, or recreation.	Cleaning activities such as removing of algae from the beach.
No Action*	Accept all the damages. Limited by international law	

* From an economic perspective, this strategy makes sense when either all the mentioned policies are ineffective, or the cost of no action is low. Source: Own elaboration using [Van den Bergh et al.'s \(2002\)](#), [Anderson \(2009\)](#), and [Anderson et al., \(2001\)](#).

alien ([Anderson et al., 2000](#); [Van den Bergh et al., 2002](#); [Anderson, 2009](#)). [Table 4](#) shows different examples of monitoring and management strategies adopted by countries ([Castro et al., 2016](#)). From our data, 17 out of 54 articles explicitly included any of these strategies, with prevention the most common (52.9%), followed by mitigation (29.4%). In comparison, we identified only one (5.9%) article addressing control strategies and two articles including a mix of strategies (11.8%) (see last column of [Table 2](#)).

In Latin America and the Caribbean region, a network for early warning of HAB and biotoxins in seafood has been integrated since 2009. However, most countries in the area are challenged by the lack of resources to maintain or expand monitoring programs ([Alonso, 2018](#)). Early warning of HAB is of excellent value in reducing HAB consequences ([Davidson et al., 2016, 2020](#)). Another policy instrument is to charge a premium price for products to raise funds that can be used to mitigate these events ([Palm-Forster et al., 2017](#)).

The HAB economic valuation literature identified beach and water cleaning, early warning systems, food inspection, price premiums, and information campaigns as the central evaluated policy ([Whitehead et al.,](#)

Table 4
Management strategy examples.

Category	Management Strategy
Mitigation	Routine monitoring programs for toxins in shellfish. Towing of fishnet pens away from the sites of intense HAB. Charge premium prices over seafood products.
Prevention	Control of sewage or waste discharges. Sewage reduction strategies.
Control:	
Mechanical	Removal of HAB cells from the water by dispersing clay over the water surface.
Biological	Biocontrol: releasing one organism to control another.
Chemical	Toxic chemical release.
Genetic	Genetic manipulation.
Environmental	Large-scale manipulation of nutrient levels in coastal waters through pollution control policies.

Source: Own elaboration using [Anderson's \(2009\)](#) paper.

2003; Nunes and Van den Bergh, 2004; Jin et al., 2008; Taylor and Longo, 2010; Osseni et al., 2019). Nevertheless, two critical distinctions differentiate RP and SP applications in this regard. Most of the RP applications attempt to estimate the total impact of the HABs on the economy, either locally, nationally, or globally. Those studies implicitly assumed that the HAB events provoke substantial economic losses (cost) for the whole economy, which warrants any policy intervention. Therefore, they omit any discussion of policy options. However, even considering that many of the estimations underestimate the total monetary value because they cannot estimate all the losses, they do not represent a considerable proportion of the GDP of a region. Of course, they are relevant for specific sectors or groups and deserve attention to avoid environmental and social costs. More importantly, these studies implicitly assumed in the analysis that these losses are avoidable. However, they do not address or identify any policy instrument to reach that goal. This issue is a weak point in these applications because it is unclear how much of the costs are avoidable and, therefore, can be considered a benefit of policy intervention. If nothing were avoidable, then having a valuation of the event does not provide helpful information for decision-making.

On the contrary, most SP studies and TC applications estimate the WTP for specific activities or policies (Whitehead et al., 2003; Ofori and Rouleau, 2020) but do not attempt to evaluate the impact on the whole economy. They look at estimating individuals' preference structure for different policy interventions and to understand behavioral responses that can be linked to cost-benefit analysis. They explicitly estimate the welfare changes associated with measurements that reduce the events' presence, intensity, or impacts. For instance, several papers addressing HAB in inland water bodies (lakes and rivers) (Diaby, 1996; Dodds et al., 2009; Zhang and Sohngen, 2018; Wolf et al., 2019) focus on avoiding eutrophication by reducing agricultural fertilizers whose benefits are linked directly to recreational water activities (fishing, swimming). This non-point source pollution seems more important for freshwater bodies than ocean cases (L'Ecuyer-Sauvageau et al., 2019; Osseni et al., 2019; Wolf, 2018). Non-point source pollution is mentioned explicitly in only four articles (L'Ecuyer-Sauvageau et al., 2019; Osseni et al., 2019; Van den Bergh et al., 2002; Wolf, 2018) and indirectly in two other papers (Dodds et al., 2009 and Palm-Foster et al., 2017). Van den Bergh et al. (2002) mention non-point pollution as a potential enhancement of the implementation of existing legal and economic instruments to target both point and non-point sources of pollution. In all cases, non-point pollution is discussed only briefly, with the authors noting that policies should address the issue but not provide a comprehensive analysis.

WTP estimates for different policy interventions can be easily compared with the project's costs or among different interventions. For instance, Whitehead et al. (2003) estimated that consumers would pay 70% more for seafood meals to ensure product inspection. Having the cost of this inspection allows us to compare costs and benefits and evaluate if the policy is socially desirable. In Bulgaria, Taylor and Longo (2010) estimated the willingness to pay \$ 17.7 for a one-time tax to implement a program that provides beaches free of HABs. Osseni et al. (2019) estimated a WTP of \$ 269.93 to reduce HAB pollution levels in France. In Finland, Salojärvi (2014) estimated the WTP per respondent at \$275.6 to \$827.4, depending on the intensity of the management intervention. Finally, in Ghana, Ofori and Rouleau (2020) calculated a WTP for a seaweed cleanup between \$ 6.25 and \$ 14.17, depending on the household income.

Nevertheless, in many cases, the policy is vaguely defined, or its feasibility is not discussed in the articles. For instance, Taylor and Longo (2010) assume that HAB can be avoided altogether. This might not be realistic in many marine and coastal areas, particularly in the climate change context (Wolf et al., 2019). A completely ignored policy in these economic and policy analyses is nature-based solutions. Like agrobiodiversity, which can be used as a natural insurance for risk-averse farmers (Baumgärtner and Quaas, 2008), there are new interventions for mitigating HAB by controlling nutrient enrichment (Mardones et al.,

2020). One of these approaches is Integrated Multi-Trophic Aquaculture, which uses shellfish and macroalgal culturing to remove nutrients. This approach could also reduce microalgae (Chopin et al., 2012; Holdt and Edwards, 2014; Wartenberg et al., 2017). Innovative interventions such as these deserve more research in the future.

3.2. Empirical CV application: willingness to Pay estimations

Out of the 1298 interviews, five persons did not offer an answer, 691 (53.4%) accepted to pay the premium, and 602 (46.6%) rejected. Moreover, when facing a red tide alert, Fig. 2 shows that most consumers prefer not to consume any seafood (50.5%), while others prefer to consume only seafood coming from unaffected areas (33.8%), and the lower fraction prefer to consume only fish (14.8%). Additionally, 426 respondents (32.8%) indicated they would not consume seafood even if a "trustworthy" institution certified the product's safety (the products were not contaminated). This group shows a higher proportion of negative responses regarding the WTP (222 negative responses versus 204 positives). We observed the opposite behavior from those who trust the responsible institution, presenting a higher proportion of positive responses regarding their WTP (487 positive responses versus 380 negative).

To explore the premium size, we estimated a model using only the BID as the explanatory variable and a second model with other socio-demographic and behavioral explanatory variables (Age, years of education, whether they consume only fish when there is a red tide alert, whether they consume fish or shellfish from unaffected areas in the event of a red tide alert, trust in institutions, family size, and gender). Table 5 shows that people were willing to pay an increase between \$1.79 to \$1.82 for the price of 250 g of mussels' (Confidence intervals are provided in brackets). Trust in institutions and gender (male) are statistically significant. Institutional trust had a positive sign; the higher the institutional trust, the higher the WTP. Regarding gender, males have a lower WTP than females, which is unsurprising as wide evidence shows females are more prone to sustainable consumption than males (Testa et al., 2021). The rest of the explanatory variables were not statistically significant.

Therefore, we found a positive and relevant premium for a well-defined policy for HAB events in Chile. Moreover, there is a positive relationship between trust and WTP. This is the most relevant result from a policy perspective; even if the policy is well designed, institutional distrust can jeopardize the reach of socially desirable goals.

4. Discussion and conclusions

Given the scope of previous empirical studies in Chile and worldwide that focused on reductions in output and income (Ramos et al., 2021) or export loss (Anderson and Villarreal, 2020), this study adds to the scarce literature using SP. It provides the perspective of consumers instead of producers, linked to people's awareness regarding the HAB problem and whether people are willing to finance policies to deal with the adverse effects of these events. This is particularly meaningful considering the lack of studies providing a precisely defined policy that we identified in the comprehensive literature overview offered in this article.

Our empirical application shows that people are willing to support the policy intervention (positive WTP), including an early-warning monitoring system and a crisis fund to support fishers during the outbreak. Nevertheless, the most critical finding is that institutional trust is crucial to ensuring any policy intervention's success. This result is consistent with previous studies showing that government trust influences citizens' WTP for a public project. Citizens' trust in the government highly leveraged their WTP for the project. Therefore, the economic value of a public project can be underestimated even when the government and the citizens desire the project (Oh and Hong, 2012). Studies in developing countries show that citizens are becoming more aware of environmental issues and are willing to pay for their

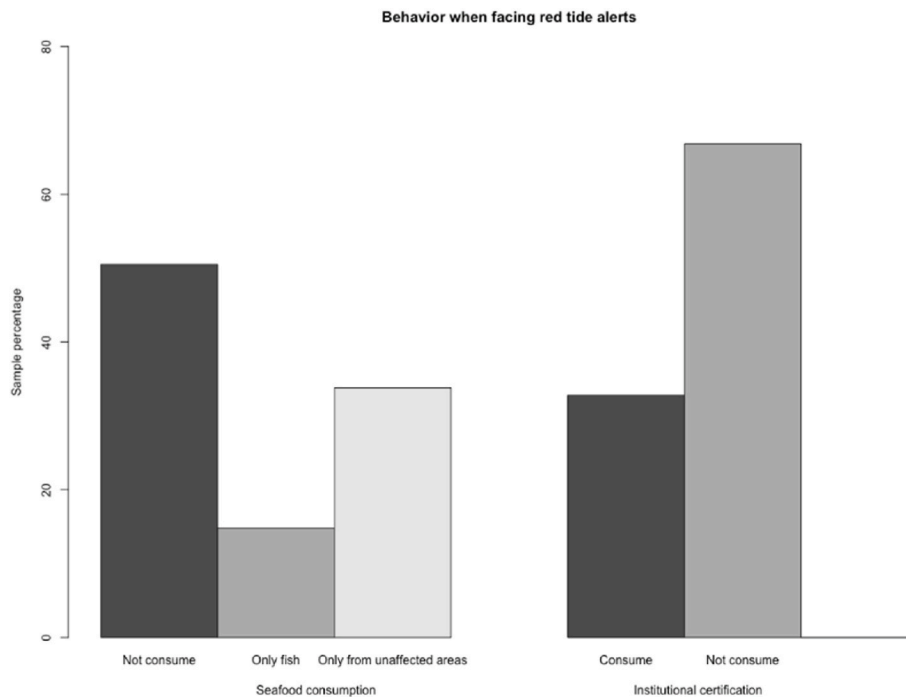


Fig. 2. Stated consumption behavior when facing red tide alerts.

Table 5
Estimations of logit models.

Dependent variable Y = 1 for a positive response, 0 otherwise.		
BID	-0.00173*** (0.000209)	-0.00170*** (0.000212)
Constant	1.669*** (0.194)	1.753*** (0.396)
Age		-0.00414 (0.00323)
Years of education		-0.0101 (0.0159)
Only Fish		0.118 (0.173)
Unaffected areas		-0.0144 (0.133)
Trust in institution		0.335** (0.127)
Family size		0.0126 (0.0337)
Male		-0.204+ (0.118)
WTP in US\$ (CI)	1.82 (1.69, 1.94)	1.79 (0.96, 2.62)
N	1293	1275

Standard errors in parenthesis, +p < 0.1, *p < 0.05, **p < 0.01, ***p < 0.001.

conservation and management. However, citizens are not willing to pay for improvements in publicly provided goods due to their lack of trust in the efficacy of the local governments in their provision (Birol and Das, 2012). Also, environmental quality in developing countries has been increasingly recognized as one of the key determinants of quality of life; however, distrust of authorities responsible for the provision of environmental goods results in protest responses (Chen and Hua, 2015).

On a broader perspective, the literature review identified that the global economic losses from HAB events seem significant in four main sectors: 1) human health, 2) commercial fishery, 3) tourism and recreation, and 4) monitoring and management. HABs are natural hazards that can lead to serious public health and socioeconomic consequences, consistently increasing in duration and intensity due to human environmental interaction and rising temperatures due to climate change. Losses associated with these events are significant and are expected to

increase. This is why countries need to study the economic repercussions of these phenomena and determine the best way to monitor and mitigate their effects.

Furthermore, the literature review shows that countries are becoming more interested in determining these impacts. However, the applications are still highly concentrated in the USA, with scarce applications in developing countries. There are also many aspects in which future research could improve our knowledge and policy efficacy. First, we need to identify comparable values of economic impacts among different applications of RP and SP. Second, future studies should include nonuse and indirect use value estimations that have been ignored in the literature. Third, the economic analysis should be part of an interdisciplinary approach, including weather conditions, HAB intensity, duration, and nonlinearities of the impacts.

Fourth, a significant gap is identifying policies to cope with HAB risks (Larkin and Adams, 2013; Adams et al., 2018). The weakest aspect of the economic evaluations is the lack of a precise policy evaluation that can be linked to avoidable costs. In our opinion, this issue is pervasive in applying nonmarket valuation to extreme climate events. It is based on the expectation that finding a substantial economic impact warrants the implementation of some interventions to reduce the impacts of the extreme event. Nevertheless, it is likely that the impacts cannot be avoided altogether or that the economic impact can be reduced only partially. Assuming that the estimated impact is avoidable for some undefined policy intervention is a misleading economic approach. Accordingly, the economic valuation of damages needs to be grounded in a solid cost-benefit analysis of clearly identified policy interventions (Whittington, 2010). In fact, Jin et al. (2020) argue that the effects of an HAB should be examined in terms of economic welfare (consumer and producer surplus) in a counterfactual analysis. Unfortunately, most papers estimate the economic impacts but lack any counterfactual policy analysis. Most economic evaluations assessed do not even include a discussion of an explicit (or vague) policy intervention.

Besides, even though SP applications have some precise policy evaluation, this policy is vaguely defined, and its feasibility is unclear. In our case, we found that people are willing to pay an increase in the price of mussels to support a combination of a monitoring and alert system with a crisis fund policy. This is a precise and clear police intervention.

However, the lack of institutional trust affects the probability of paying negatively.

More importantly, economic valuation is not a solution but a mechanism to increase public awareness of HABs. Our main finding is that most of the current approaches do not link their estimates to any policy that can solve any specific issue related to HABs. In the short run, the HABs are unavoidable, so the local (national policies) are limited to reducing exposure, avoiding sickness and death from eating contaminated products, and helping the producers cope with the cyclical event. We attempted this in our empirical application and found overall support for those policies. On top of that, we show that understudied elements of the literature can play critical roles. Trust and a move towards the customer-centered design of policies that are linked at a global scale phenomena can begin to be tackled at local levels through place-based SP approaches that include novel dimensions.

Nevertheless, we need to keep in perspective the relevance of planetary politics and make the distinction between the scope and temporality of different policy interventions. Those articles that include some policies aim to reduce the impact of the events and not solve the problem. Researchers, governments, and policymakers should also consider more normative and holistic ways to deal with HABs. The economic valuation literature does not cover this issue, which may be explained because it lies beyond the scope of the analysis. Nevertheless, it is important to increase the multidisciplinary approach to attempt to solve the HABs problem in the future (Wells et al., 2020).

Credit author Statement

Felipe Vásquez-Lavín: Study Design, Supervision, Methodology, Conceptualization, Writing – Original draft, Review & Editing, **Jose Carias:** Data curation, Writing- Original draft preparation, **Stefan Gelcich:** Conceptualization, Writing - Review & Editing, **Roberto D. Ponce-Oliva:** Writing - Review & Editing, **Manuel Barrientos:** Study Design, data analysis, Writing – Review & Editing.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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