REPORT

Valuation of ecotoxicological impacts from tributyltin based on a quantitative environmental assessment framework

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Abstract In the scientific literature, few valuations of biodiversity and ecosystem services following the impacts of toxicity are available, hampered by the lack of ecotoxicological documentation. Here, tributyltin is used to conduct a contingent valuation study as well as cost-benefit analysis (CBA) of measures for improving the environmental status in Swedish coastal waters of the Baltic Sea. Benefits considering different dimensions when assessing environmental status are highlighted and a quantitative environmental assessment framework based on available technology, ecological conditions, and economic valuation methodology is developed. Two scenarios are used in the valuation study: (a) achieving good environmental status by 2020 in accordance with EU legislation (USD 119 household⁻¹ year⁻¹) and (b) achieving visible improvements by 2100 due to natural degradation (USD 108 household⁻¹ year⁻¹) during 8 years. The later scenario was used to illustrate an application of the assessment framework. The CBA results indicate that both scenarios might generate a welfare improvement.

Keywords Contingent valuation · Stated preferences · Marine water framework · TBT · Toxic compounds · Marine environment

INTRODUCTION

Many valuations of biodiversity and ecosystem services such as air and water cleaning and recreation (CICES 2013) have been made, but very few have valued the

impacts of toxicity (Martin-Ortega et al. 2011). This research field is hampered by the limited knowledge of ecological impacts following exposure to hazardous chemical pollutants. However, the detrimental biological effects of tributyltin (TBT) on marine biota are well recognized (e.g., Bryan et al. 1987; Fisher et al. 1990) and negative impacts of TBT pollution on the marine environment in the Baltic Sea have been documented (Eklund et al. 2008). TBT has previously been used in a risk-based analysis by Moore and Postle (1994), but the authors were unable to include non-market values in the impacts caused by the compound.

Tributyltin, TBT

The use of TBT has been regulated through several bans and regulations (EC 2003, 2006), and although the TBT concentration remains high in some regions, the ban of TBT has resulted in decreasing temporal trends of TBT in sediments, as well as in benthic biota and fish (Helcom 2010). The impact of organic contaminants is associated with the degradation rate (i.e., the time it takes for TBT to decompose), a factor that is usually temperature dependent, and estimates of TBT half-life vary between regions (e.g., Saradin et al. 1995; Viglino et al. 2004). For Oslo harbor, Cornelissen et al. (2008) reports a half-life of more than 10 up to 20 years. Due to the similar temperatures, the value in Swedish waters can be regarded as being of similar magnitude.

Locations throughout the Baltic Sea and along the Swedish west coast are exposed to similar environmental problems and require similar actions for improvement when it comes to reducing the TBT concentrations. For example, the TBT effluents from paint used on leisure

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boats and ships can be reduced by building more efficient boat washers where old boat paint is collected, or by collecting paint flakes from boat dry docking areas, where many boat owners remove old paint. Dredging is an alternative for decreasing the TBT concentrations in the sea as TBT compounds are deposited rather close to the source of exposure (Eklund et al. 2008). (More information on biological effects and formal restrictions of TBT is provided in Appendix S1.)

Environmental status regarding TBT

The Marine Strategy Framework Directive (MSFD) (EC 2008) aims at achieving or maintaining good environmental status (GES) in marine waters of all member states of the European Union by 2020. According to the MSFD, GES regarding hazardous substances is reached when “concentrations of contaminants are at levels not giving rise to pollution impacts” (EC 2008). GES is determined from quality assessments based on target levels representing a threshold that should not be exceeded. In the Baltic Sea, TBT and their degradation products are found in significant levels, and GES regarding TBT is not achieved at any assessed site within Sweden’s territorial waters (Helcom 2010). Even actions for an immediate cessation of TBT discharge would not result in GES for centuries, due to the slow degradation rate of the chemical, as discussed in Eklund et al. (2008).

Valuation of ecosystem services

In order to manage ecosystem services better, awareness of their value needs to be improved. Estimating the economic value of ecosystem services would allow their incorporation into green accounting. According to the UN convention on biological diversity (UN 1992), the value of ecosystem services must also be a part of economic assessments and policy decisions by 2020 at the latest (Prop 2009/10:155; SOU 2011:34). This convention has been signed by Sweden and other countries. If values of ecosystem services are available, cost benefit analyses (CBA) can then be enlarged to provide a better basis for decision making. Also, the Water Framework Directive (WFD) (EC 2000 Article 5), as well as the MSFD (EC 2008), require economic analyses connected to their action programs, i.e., both costs and benefits of a program should be presented in order to enable investigation of general welfare effects and distributional impacts. Besides CBA, other environmental systems analysis (ESA) tools, such as Life Cycle Assessment (LCA), Life Cycle Costing, and Strategic Environmental Assessment, can also use economic values for weighting different environmental impacts (Ahlroth et al. 2011). The lack of values for ecotoxicological impacts has so far limited the use of

economic valuation methods in ESA tools (Ahlroth and Finnveden 2011).

Environmental status assessment

As there is no priority between the hazardous compounds listed by the MSFD, there is a risk that very strict target levels (due to severe toxicity) are regarded as unachievable. Such reasoning would potentially undermine the credibility of the target levels per se and there is a risk that actions are focused where they are more likely to yield results (i.e., fulfill GES). The framework for assessing environmental status regarding hazardous substances under the MSFD is limited to two levels; either GES is fulfilled or it is not. In order to evaluate and quantify changes of environmental status, a detailed quantitative environmental assessment framework including several levels is useful. Status assessments in the Baltic Sea, performed by Helcom (2010) for example, have extended the framework by including levels indicating the impact on sensitive organisms, such as sterility in gastropods or EU quality standards for human consumption of seafood. Such a framework is constructed entirely from a toxicological perspective. However, including consideration of valuation methodology would benefit estimations of monetary aspects for a certain environmental improvement. An assessment framework including knowledge about practical feasibility, i.e., available methods for improving the environmental status, would also provide information regarding the aspects of specific management options for improving the environmental status.

Several valuation studies (e.g., Kosenius 2010; Östberg et al. 2012) on environmental status improvements in water, use a framework that relates to the status classification of the WFD (EC 2000). However, those studies have focused on environmental impacts of nitrogen and phosphorus emissions, rather than on ecotoxicological impacts. Furthermore, these studies are based on existing frameworks for nitrogen and phosphorus.

Aim of study

This paper aims to (1) conduct a contingent valuation (CV) study and present estimates for values of ecotoxicological impacts that can be used in CBA and ESA tools, (2) by applying CBA methodology, evaluate the goal of reaching GES by 2020 in accordance with the MSFD from a welfare perspective, and (3) illustrate how ecological knowledge and practical feasibility can be incorporated into valuation and CBA methodology. A quantitative environmental assessment framework including several levels of environmental status is developed and applied in valuation and CBA analysis in order to reach the third aim.

MATERIALS AND METHODS

The quantitative environmental assessment framework

See Appendix S1 for details.

The quantitative environmental assessment framework indicating environmental status is based on a combination of documented biological effects due to TBT exposure, non-market valuation methodology, and practical feasibility (available technology). The development and reasoning behind the assessment framework is provided as ESM. Four levels of environmental status are defined; *good*, *moderate*, *poor*, and *bad*. *Good* status corresponds to current GES definitions (EU 2005) and is represented by a qualitative standard set for sediments at $0.02 \mu\text{g kg}^{-1}$ dry weight. An area with a TBT concentration between 0.02 and $1.5 \mu\text{g kg}^{-1}$ dry weight is defined as having *moderate* status, an area with a TBT concentration between 1.5 and $100 \mu\text{g kg}^{-1}$ dry weight is defined as having *poor* status, and an area with a TBT concentration greater than $100 \mu\text{g kg}^{-1}$ dry weight is defined as having *bad* status. The corresponding ecological impacts on different animal and plant groups, presented in Table 1 are based on data concerning ecological impacts for the aquatic environment compiled in the EQS Substance Data Sheet for TBT (EU 2005). The environmental status quo (today's levels) differs between *moderate*, *poor*, and *bad* in different parts of the study area (the study area is further described in Appendix S1). It should be noted that the framework only includes impacts on ecosystems and not humans as there is a lack of studies on the effects on humans.

Valuation scenarios

The valuation analysis regarding the economic benefits of reaching different levels in the assessment framework in Swedish marine waters is based on data obtained in a non-market valuation study using the CV method. In addition to

the collection of paint flakes in boat washers and boat parking area, dredging of sediment from the bottom of the sea and treating it to remove the TBT is another relevant targeting policy action for improving environmental status with respect to TBT in the marine environment. These actions provide results over different time scales. Remediation of polluted sediment yields results relatively quickly, but does not prevent paint flakes from falling off boats in the future. Collection of paint flakes, on the other hand, pays off in a longer run since it takes time for the existing levels of TBT in sediment to decompose. A combination of both actions yields the quickest and most effective action.

In the survey conducted as part of this study, the respondents were asked to answer questions on two scenarios for actions to reduce the levels of TBT along the Swedish coast of the Baltic Sea. The first scenario was based on only the prevention of the release of paint flakes and then allowing natural degradation to slowly decrease the levels of TBT with one level in the environmental assessment framework (*One-level* scenario). The purpose of this scenario is to make an application of the environmental assessment framework that includes several levels of environmental status. The second scenario, with the aim to reach GES by 2020, was based on a combination of remediation of sediment and preventing the release of further paint flakes (*GES* scenario). These scenarios were selected because: (a) the GES goal can be evaluated from a practical and welfare perspective and b) the results from the *GES* scenario can be compared to a situation where no additional measures are implemented except for hindering TBT from entering the water. Also, the two scenarios give us the possibility of comparing values of different achievements in different time perspectives.

Survey

The valuation survey was carried out during spring 2012. A voluntary internet panel managed by EasyResearch was

Table 1 Environmental impacts of TBT on different groups of organisms

TBT concentrations ($\mu\text{g kg}^{-1}$)	Environmental status	Growth disorders	Physical defects	Decreased reproduction	Increased mortality	Acute poisoning
<0.02	Good					
0.02–1.5	Moderate	Snails and clams	Snails and clams	Snails, clams, and crustaceans	Snails, clams, and crustaceans	
1.5–100	Poor	Snails, clams, fish, worms, insects, and plants	Snails, clams, and fish	Snails, clams, crustaceans, and fish	Snails, clams, and crustaceans	Snails, clams, crustaceans, fish, and worms
>100	Bad	Snails, clams, fish, worms, insects, and plants	Snails, clams, and fish	Snails, clams, crustaceans, fish, and plants	Snails, clams, and crustaceans	Snails, clams, crustaceans, fish, worms, plants, and amphibians

used, representing a random sample of the Swedish population aged between 18 and 80 years (where the proportions of sex, age, income, education, and so forth reflected those of the population). The company sent reminders to the panel until the quotas of representative sex, age, income, education groups, and so forth were filled (507 respondents finalized the questionnaire). A pilot study, lasting for about a week, indicated that no major changes to the questionnaire were needed; the questionnaire in the main study was therefore distributed after only minor changes.

The survey included four parts. The first part investigated the respondents' opinions on the valued good, e.g., whether the respondent visits the seaside, follows environmental debates, has a boat, etc. The second part consisted of the two scenarios and the willingness-to-pay (WTP) questions, as well as questions asking why the respondent was or was not willing to pay. The scenarios were randomly distributed with half of the sample initiating with the *GES* scenario and the other half with the *One-level* scenario. The third part asked for information on socioeconomic factors. The fourth part asked for information that would be of help in evaluating the validity of the study.

The respondents were informed that the assessment scale can be used to visualize the environmental status in different parts of Swedish waters, i.e., how large impact the levels of TBT have on the marine environment and that the total impact caused by TBT on the ecosystem increases with increasing levels of TBT (also visualized in the framework, see Table 1). The latter probably diminishes the services we humans can elicit from the ecosystem. Also, the respondents were informed that the impacts on human gains from ecosystem services are difficult to estimate, but there is much information about how single groups of species (i.e., the biodiversity) are affected by increased levels of TBT. The current environmental status in different parts of Swedish waters, as well as the status after actions in accordance with the two scenarios, are presented on maps. It is assumed that if no measures are taken the environmental status will remain the same as today.

Valuation question

See Appendix S2 for details.

The main benefit of the CV method and other stated preference methods is that they capture non-use values such as existence values, which revealed preference methods do not (Hanemann 1994). Previous stated preference studies on ecosystem services in the Baltic Sea show that respondents experience large existence values (e.g., Östberg et al. 2012; Ahtiainen et al. 2013). Further, previous CV studies on ecosystem services in marine areas show that the respondents value most ecosystem services in the marine waters, rather than only a few (e.g., Östberg

et al. 2012; Ahtiainen et al. 2013). That is, the CV method has been shown to be suitable for valuing changes in ecosystem services in marine waters.

The Classic and Interval Open-Ended (CIOE) question by Håkansson (2008) was used in the survey since it captures valuation uncertainty—many previous valuation studies have shown that a large proportion of the respondents are uncertain regarding their valuation of environmental goods and services (e.g., Ibid). The format gives the respondents the opportunity to choose whether to give the answer as a self-selected point value or as a self-selected range. The intervals are interpreted as the respondents' uncertainty around a point value, i.e., that individuals state an interval because they only know that their valuation is within the self-selected range, see Appendix S2 for details. The funding of the proposed improvement projects was assumed to be an annual tax paid per household between 2013 and 2020 in both scenarios.

When a respondent stated that he/she did not want to pay for a scenario, his/her true WTP is interpreted as zero and used as the true WTP when estimating the mean WTP. Protest answers, such as “the polluter should pay”, “the measures are not reliable”, or “the costs should be covered by existing taxes”, are excluded from the analysis as they are outliers above 1000 euros. Three responses over 1000 euros have been removed from the *GES* scenario and seven from the *One-level* scenario.

A stated exact value is interpreted as the respondent having no valuation uncertainty, i.e., it is used as the true WTP when estimating the mean WTP (e.g., Håkansson 2008). For a stated interval, the mid-point is used as the true WTP (e.g., Hanley et al. 2009) when estimating the mean WTP.

Using the mid-point in the stated range as the true WTP value when estimating the mean WTP, information about the valuation uncertainty that the respondents revealed through the range question is not incorporated. Hence, it could be argued that the mean WTP value should be complemented by upper and lower estimates. The mean WTP of the left and right ends of the ranges stated in the responses to the range question can be interpreted as lower and upper boundaries of the mean WTP (mean WTP_L and mean WTP_U, respectively) (e.g., Håkansson 2008). Thus, these estimates are also presented.

Costs and benefits

In order to investigate the welfare effects of reaching the ecological standard in line with the *One-level* and *GES* scenarios, results from the valuation study were used in a CBA. Here, the advantages and disadvantages of the different scenarios were numerically weighted and compared

in monetary terms. If the benefits are greater than or equal to the costs, an action is worth considering since it leads to a welfare improvement for society. The option with the highest net benefit (benefits minus costs) is usually recommended. In all calculations, the figures are transformed into USD using an exchange rate of 1 SEK = 0.14 USD.

The cost estimates of an environmental improvement are based on a literature review of the financial costs of using different methods to improve the environmental status. In the analysis, the WTP estimates are used to obtain a national value of the benefits from reducing TBT levels according to the scenarios. The lower and upper boundaries of WTP are presented to illustrate the uncertainty in the estimates. The different estimates of the WTP per household are multiplied by the number of households in Sweden. The population of Sweden in September 2012 was 9 540 065, with an average of 2 people per household (SCB 2013). To further illustrate the uncertainty, the benefit estimates for each year are discounted over 8 years, as the benefits are assumed to be distributed between 2013 and 2020, using zero and 6 %. The lowest and highest costs, i.e., the lower and higher costs for the *One-level* and the *GES* scenarios, are discounted over 8 years using the same percentages.

RESULTS

Descriptive statistics from the valuation study

See Appendix S3 for details.

As the pilot survey and the main survey did not differ to any significant extent, the data from the two surveys have been merged. A total of 700 respondents were contacted and 536 completed the survey, giving a response rate of almost 77%. 217 responses are regarded as protest bids and have thus been removed from the analysis. 53.7% (288) of the respondents are female. Mean age in the survey is 50 years ranging between 18 and 80 years. The average income per household after tax is USD 4635.

Regarding the respondents' use of Swedish coastal and marine areas, the majority of the respondents have visited the seaside during the previous year (81.5%). Only 2.4% have never visited the seaside. The respondents were also asked about their degree of prior knowledge about hazardous compounds in the sea causing damage to animals

and plants. The results imply a high level of prior knowledge of the problems.

When asked about the importance of different ecosystem services to themselves, such as recreation, esthetic values, pollution control, and space and waterways, existence values are regarded as the most important of all services.

WTP estimates

The proportions of respondents that stated that they are willing to pay for the implementation of the proposed *One-level* and *GES* scenarios do not differ significantly from the proportion of respondents who reported that they are not willing to pay (Table 2). The differences in the scenarios presented to the respondents do not seem to influence the proportion of non-zero/zero responses or the proportions of protest bids (*t* test $p < 0.05$). There is no significant difference between the proportions for the different scenarios stating an exact monetary sum or a range (Table 2), indicating that the respondents do not perceive greater uncertainty with the *One-level* scenario, despite the one-level time perspective. The proportion that gave an exact sum is smaller than the proportion that gave a range in both scenarios. This implies that many respondents are uncertain about their WTP.

Table 3 presents the mean WTP for each of the scenarios, together with their respective mean WTP_L and WTP_U estimates. Irrespective of the mean WTP estimate used, there is a tendency towards a higher WTP for the *GES* scenario than for the *One-level* scenario, but a Mann–Whitney test show that the difference is not significant. The higher WTP for the *GES* scenario was expected, as the change is greater and the time frame is shorter before the environmental status would reach good. The respondents would then have an actual chance of experiencing the change themselves. The fact of there being no difference in mean WTP values between scenarios in CV studies is not uncommon (e.g., Håkansson 2008; Ahtaiainen et al. 2013). It might be argued that this result is due to some kind of scope effect, the respondents see a rather small difference between the two scenarios. However, the respondents state that they have a good understanding of the questionnaire and the scenarios. That is, the results cannot be explained by the respondents without understanding what they are valuing (see Appendix S3 for details).

The mean WTP estimates cannot be considered to be high if compared to results from recent valuation studies

Table 2 Proportions (%) of respondents who stated positive WTP, zero WTP, and protest bids. Proportions of those stating a positive WTP (WTP yes) who opted to give an exact sum or a range. Actual numbers in brackets

	WTP yes	Zero WTP	Protest bids	Total	Exact	Range	Total
<i>One-level</i> scenario	68.3 (366)	10.4 (56)	21.3 (114)	100 (536)	17.5 (64)	82.5 (302)	100 (366)
<i>GES</i> scenario	71.6 (384)	9.1 (49)	19.2 (103)	100 (536)	17.7 (68)	82.3 (316)	100 (384)

Table 3 Mean and median WTP estimates for the scenarios. Per year and household (in USD). Confidence interval for $p < 0.05$ within brackets

	Mean WTP	Mean WTP _L	Mean WTP _U
<i>One-level</i> scenario	107.79 (89.12–126.45)	73.65 (58.11–89.19)	129.26 (108.98–149.56)
<i>GES</i> scenario	119.31 (100.58–138.04)	82.84 (66.39–99.29)	156.74 (132.51–180.99)

that present WTP estimates for water quality improvements due to less eutrophication in regional areas of the Baltic Sea. For example, Kosenius (2010) estimates the mean marginal WTP per year and Finnish household during 20 years for improving the water quality status in the Gulf of Finland to be between 271 and 488 euros. Östberg et al. (2012) estimate the mean WTP for improving the water quality status in the Baltic Sea south of Stockholm to be between 51 and 61 euros per month and Swedish household during 20 years.

Costs

See Appendix S1 for details.

Costs for the One-level scenario

A boat washer for small boats including installation and maintenance costs between USD 1.19×10^5 and 1.61×10^5 and one for larger boats between USD 1.54×10^5 and 1.89×10^5 . Washing facilities with filters, tanks, and separators cost between USD 22 400 and 49 000. Maintenance costs are not included in these figures (Havs- och Vattenmyndigheten 2012).

In the study, cost estimates for 1000 harbors are presented along with estimates for 40 sites for comparison. A conservative estimate of the costs of implementing improved collection facilities for TBT is then calculated by multiplying the number of harbors by the cost of one boat wash (*small* for a lower estimate and *large* for a higher estimate) and one washing facility (assuming only one of these facilities in each harbor, which is probably an underestimation). A low estimate using a cheaper boat washer for smaller boats and cheaper washing facilities for 1000 harbors would be USD 1.41×10^8 . With the more expensive boat washer for larger boats and the more expensive washing facilities installed in 1000 harbors, the estimated cost would be about USD 2.38×10^8 . Maintenance costs, except for the washers, are not included.

Costs for the GES scenario

In order to reach the goal for the *GES* scenario, the levels of TBT must decrease towards zero by 2020. This would in practice involve dredging of numerous sites along the Swedish coastline. As the highest concentrations of TBT

are detected in harbors, marinas, and fairways, the calculations are focused on these areas. This is also where the MSFD applies, not in marine open waters.

The total cost for 1000 sites (based on Magnusson et al. 2006; Holm et al. 2007) would be USD 1.56×10^9 using the lower cost estimate, and USD 1.18×10^{10} using the higher cost estimate. In addition to dredging costs, costs for preventing release of paint flakes containing TBT described for the *One-level* scenario are also included in the *GES* scenario.

Costs and benefits results

The benefits and costs related to TBT for 40 and 1000 sites, as well as the net benefit, are presented in Table 4. As can be seen, the net benefits related to TBT vary between USD 2.12×10^9 and 4.92×10^9 for the *One-level* scenario and between USD -8.89×10^9 and 5.90×10^9 for the *GES* scenario.

According to the sensitivity analysis, the measures described in the *One-level* scenario are always beneficial even when the lower WTP and the higher costs are used, independent of the discount rate used. When 40 sites are considered, the net benefits are even higher. The *GES* scenario, on the other hand, is always beneficial except when high costs and low WTP estimates are considered for 1000 sites.

Since the approach in the *GES* scenario was designed to lead to the political goal of *good* status being achieved in Swedish waters by 2020, it is more reasonable to assume that 1000 sites, rather than 40, are needed to be restored. This means that installing washing facilities, in this example one boat wash and one cleaning facility with collection in each site, combined with dredging and treatment of polluted sediment, thus reaching *GES* in 2020, might be beneficial for Swedish society depending on remediation prices and WTP estimates.

DISCUSSION

Valuation study

Our results show that the inhabitants of Sweden find the topic in the valuation study important and are prepared to pay for reducing the pollution levels in Swedish coastal waters in order to improve their environmental status. The high response rate (77%), together with a high level of prior knowledge of environmental problems and the fact

Table 4 Sensitivity analysis for total benefits, costs, and net benefits. The upper and lower WTP estimates are combined with the higher and lower cost estimates. The costs are discounted for 0 and 6%, assuming an even distribution of costs per year. Numbers for 40 sites in brackets. In USD

	One-level scenario				GES scenario			
	WTP _L		WTP _U		WTP _L		WTP _U	
Benefits								
0%	2.81 × 10 ⁹		4.93 × 10 ⁹		3.16 × 10 ⁹		5.98 × 10 ⁹	
6%	2.31 × 10 ⁹		4.06 × 10 ⁹		2.60 × 10 ⁹		4.92 × 10 ⁹	
	One-level scenario				GES scenario			
	WTP _L		WTP _U		WTP _L		WTP _U	
	Low	High	Low	High	Low	High	Low	High
Costs								
0%	1.41 × 10 ⁸ (7.92 × 10 ⁶)	2.39 × 10 ⁸ (1.17 × 10 ⁷)	1.41 × 10 ⁸ (7.92 × 10 ⁶)	2.39 × 10 ⁸ (1.17 × 10 ⁷)	1.72 × 10 ⁹ (8.41 × 10 ⁷)	1.21 × 10 ¹⁰ (5.91 × 10 ⁸)	1.72 × 10 ⁹ (8.41 × 10 ⁷)	1.21 × 10 ¹⁰ (5.91 × 10 ⁸)
6%	1.16 × 10 ⁸ (6.52 × 10 ⁶)	1.96 × 10 ⁸ (9.72 × 10 ⁶)	1.16 × 10 ⁸ (6.52 × 10 ⁶)	1.96 × 10 ⁸ (9.72 × 10 ⁶)	1.41 × 10 ⁹ (7.01 × 10 ⁷)	9.92 × 10 ⁹ (4.92 × 10 ⁸)	1.41 × 10 ⁹ (7.01 × 10 ⁷)	9.92 × 10 ⁹ (4.92 × 10 ⁸)
Net benefits								
0%	2.67 × 10 ⁹ (2.80 × 10 ⁹)	2.57 × 10 ⁹ (2.80 × 10 ⁹)	4.79 × 10 ⁹ (4.92 × 10 ⁹)	4.69 × 10 ⁹ (4.92 × 10 ⁹)	1.44 × 10 ⁹ (3.08 × 10 ⁹)	−8.89 × 10 ⁹ (2.57 × 10 ⁹)	4.27 × 10 ⁹ (5.90 × 10 ⁹)	−6.07 × 10 ⁹ (5.39 × 10 ⁹)
6%	2.20 × 10 ⁹ (2.31 × 10 ⁹)	2.12 × 10 ⁹ (2.30 × 10 ⁹)	3.94 × 10 ⁹ (4.05 × 10 ⁹)	3.86 × 10 ⁹ (4.05 × 10 ⁹)	1.19 × 10 ⁹ (2.53 × 10 ⁹)	−7.31 × 10 ⁹ (2.11 × 10 ⁹)	3.51 × 10 ⁹ (4.85 × 10 ⁹)	−4.99 × 10 ⁹ (4.43 × 10 ⁹)

that the respondents find the ecosystem services in Swedish waters to be of big importance, support this conclusion.

The proportion of respondents stating that they have never visited the seaside (2.4%) corresponds to results presented by Ahtiainen et al. (2013) where the Baltic Sea is considered. Clearly, regular visits to the seaside and sea-related activities are part of Swedish culture. Furthermore, the survey was regarded as comprehensible, indicating that people have knowledge about the issues and/or that the questionnaire was well formulated.

The respondents placed a particularly high value on existence values. This implies that people consider it important to have clean sea water, even though they do not use the sea themselves, or to have the sea well maintained for future generations. This result is in line with earlier studies by Johnston et al. (2011), which demonstrate that non-use values are rated highly in aquatic ecosystems. Studies focusing on the Baltic Sea have also found high values for existence values (e.g., Kosenius 2010; Östberg et al. 2012).

The average household income in the survey was lower than the average income in Sweden in 2011 (see Appendix S3). The fact that the average household income in our sample was below average for the whole population could be an indication of the presented mean WTP values in this paper being an underestimation of the true mean WTP values. This is since a higher income might be correlated with a higher WTP.

The risk of selection bias in this survey is considered low. Most of the inhabitants in Sweden have internet access, but a bias towards respondents who like/have time to respond to a lot of surveys is a fact. This is also the case for other types of survey methods though, and WTP values usually does not differ, as shown by e.g., Lindhjem and Navrud (2008).

Consequences of actions to reach GES by 2020

Actions carried out to reach the goal of GES regarding environmental status of TBT by 2020, involve substantial dredging along the Swedish coasts. Dredging might in itself lead to unwanted side effects, such as stirring up hazardous compounds embedded in the sediment. However, various actions can be undertaken to reduce such effects (Sweco 2007). Dredging would remove other toxic compounds in addition to TBT from the sea and greater environmental improvements of the marine environment would follow, including improvements in human health impacts in terms of quality of seafood. Therefore, the presented value for the GES scenario might be an underestimation of the actual benefits of dredging. The effects of other hazardous substances may result in similar effects on the same ecosystem services, for example reduced biodiversity. Thus, the total value of improving the environmental status that will occur due to dredging according to different valuation studies focusing on

different toxic compounds cannot be added up. This is because such a procedure could generate some degree of double counting. It would obviously be of policy interest to conduct valuation studies that consider environmental impacts linked to several ecotoxic compounds. It would also be of interest to investigate the toxicological impacts on human health. Nonetheless, with current ecological knowledge it is still difficult to conduct such studies in a proper manner.

The costs of measures are most probably underestimated, as only harbors have been taken into consideration. The polluted areas can be found also in fairways and various sites along the coast. Furthermore, the sample sites are isolated while TBT is evenly spread on the sea bottom. This will probably increase the area necessary to be dredged in order to accomplishing the scenario of reaching GES.

Consequences of reaching a one-level improvement by 2100

Due to the variety of uncertainties regarding the cost estimates, a number of assumptions had to be made in the *One-level* scenario. Despite the great uncertainties, the measures described in the *One-level* scenario always generate a welfare improvement. However, as in the GES scenario, there are issues involved that are not handled in this study, such as the risk of double counting if results from different valuation studies focusing on different toxic compounds are added up.

Environmental assessment framework

Since the environmental assessment framework is based on current knowledge (ecological, economical, and technological), it needs to be updated over time as new knowledge is added and methods for measuring toxicity levels, ecological consequences, and monetary valuation improves. The framework also needs to be adjusted to different areas and situations.

Input to ESA tools

In the weighting sets for different impact categories that are used in ESA tools, weighting factors for marine toxicity are rarely found due to few available valuation studies that focus on toxicity in marine areas. The purpose of weighting is to simplify the comparison between different impacts and categories, as well as to save time and money. Weighting factors are very useful for policy makers and other stakeholders who need to evaluate impacts of different projects. The WTP results obtained from this study

have been used to derive a weighting factor for the impact category marine toxicity (Noring 2014).

CONCLUSIONS

The lack of values for ecotoxicological impacts has so far limited the use of economic valuation methods in ESA tools. This is the first valuation study on improved environmental status due to decreased TBT concentrations in water bodies. In order for policy makers to monitor environmental improvements more closely, a more detailed scale for different substances than the current two-level framework (not GES vs. GES) for assessing environmental status regarding hazardous substances in the MSFD (GES/not GES) would be useful. In this study, we present a case study on how such a framework could be developed.

In this study we present two scenarios for use in a valuation study. The first scenario is to reach GES by 2020 in accordance with the EU legislation. The valuation results from this scenario were used as input when evaluating the GES goal from a welfare perspective. That is, in order to evaluate this scenario it would have been enough with the current two-level framework. The second scenario is to reach visible improvements by 2100 due to natural degradation, i.e., a one-level improvement of the environmental status in the four-level scale that is developed in our framework. This scenario was developed for presenting an application of the framework in a valuation and CBA setting.

Including several dimensions when developing an assessment framework makes quantification of stepwise environmental improvements more straightforward and useful for evaluation processes for the success of management actions and means to reach specific goals set by policy makers. It also aids economic evaluation of the benefits of improvements and cost estimates if the improvements can be achieved by existing technologies. Estimates of the net benefits of environmental improvements, as well as the total welfare change of these improvements are valuable information for policy makers. It is, for example, useful when new environmental goals are being discussed and evaluated. Further studies on valuation of ecosystems targeting the effects of hazardous substances are warranted. This requires increased knowledge about biological effects following exposure to hazardous substances.

The results from our study show that the WTP per household and year was 119 USD for reaching GES by 2020, and 108 USD per household and year for achieving visible improvements by 2100. The results from the CBA suggest that reaching GES by 2020 might be beneficial for society under certain circumstances. The results also show, given the suggested measures, that achieving visible

improvements by 2100 due to natural degradation is beneficial for society.

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