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The effect of risk perception on public preferences and willingness-to-pay for reductions in the health risks posed by toxic cyanobacterial blooms

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Abstract

Mass populations of toxin-producing cyanobacteria are an increasingly common occurrence in inland and coastal waters used for recreational purposes. These mass populations pose serious risks to human and animal health and impose potentially significant economic costs on society. In this study, we used contingent valuation to elicit public willingness-to-pay (WTP) for reductions in the health risks posed by blooms of toxin-producing cyanobacteria in Loch Leven, Scotland. We found that 55% of respondents (68% excluding protest voters) were willing-to-pay for a reduction in the number of days per year (from 90, to either 45 or 0 days) that cyanobacteria pose a risk to human health at Loch Leven. The mean WTP for a risk reduction was UK£7.91-9.55/household/year, estimated using a logistic spike model. In addition, we found that participation in the market for risk reductions, as well as the amount respondents were willing-to-pay, was strongly dependent on socioeconomic status, usage of the waterbody and attitudes to the environment, as well as individual-specific perceptions and attitudes to risk. This study demonstrates that anticipated health risk reductions are an important nonmarket benefit of improving water quality in recreational waters and should be accounted for in future cost-benefit analyses such as those being undertaken under the auspices of the European Union's Water Framework Directive, but also that such values depend on risk perceptions and attitudes.

Introduction

1.1. Cyanobacteria and human health

Cyanobacteria (blue-green algae) are a diverse group of naturally occurring, photosynthetic microorganisms found almost ubiquitously in fresh, transitional and marine waters. They form an integral component of the microbial biodiversity of aquatic ecosystems and also fulfil key functional roles in biogeochemical cycling (Whitton B and Potts M, 2000). However, in warm and nutrient-enriched waters, cyanobacteria readily form mass populations as planktonic blooms, surface scums and benthic mats. These mass populations can pose serious risks to human and animal health because cyanobacteria are capable of producing a range of bioactive toxins (cyanotoxins) that have been shown to have neurotoxic, hepatotoxic and tumour-promoting, cytotoxic, genotoxic and endotoxic properties. The toxicity, speed and mode of action of these toxins vary greatly but they include some of the most potent of all bioproducts found in inland waterbodies (Codd et al., 2005).

Mass populations of toxin-producing cyanobacteria are a globally increasingly phenomenon in inland and coastal waters because of nutrient inputs from human activities and sources (e.g. agriculture, industry, sewage) (Smith, 2003) and recent climate warming (Paerl and Huisman, 2008). Affected waters include those used for drinking water supplies, livestock watering, fishing, crop irrigation and recreation (Codd et al., 2005). Human exposure to cyanobacterial blooms and their toxins is potentially widespread and can occur through several routes including accidental and/or incidental dermal contact, ingestion and inhalation during recreational and occupational activities (Pilotto et al., 2004;Stewart et al., 2006;Caller et al., 2009) and through the consumption of ineffectively-treated drinking water (Falconer et al., 1983), shellfish and finfish (Falconer et al., 1992) and spray-irrigated crops (Codd et al., 1999;Crush et al., 2008).

There is an increasing body of evidence ascribing a range of adverse human health outcomes to acute and chronic exposure to cyanotoxins. These include dermatological (Pilotto et al., 2004;Stewart et al., 2006), respiratory (Turner et al., 1990) and gastro-intestinal effects (Teixeira et al., 1993) as well as acute liver failure (Carmichael et al., 2001). While the most frequently reported ill health effects comprise relatively minor hay fever-like symptoms, pruritic skin rashes and gastroenteritis, several case reports also document incidences of acute (Turner et al., 1990) and lethal toxicoses (Carmichael et al., 2001;Stewart et al., 2006)}. Research has also linked cyanotoxins to clusters of primary liver cancer (Svircev et al., 2009) and as possible potentiators of neurodegenerative disease (Amyotrophic Lateral Sclerosis: Motor Neurone Disease) (Ince and Codd, 2005;Metcalf and Codd, 2009)}.

The long-term control of cyanobacterial populations and their associated health risks can only be achieved effectively through the reduction of internal and external nutrient loads (primarily P and N) to waterbodies (Codd et al., 2005). Such reductions are costly, whether in terms of investments in improved sewage treatment, in costs of changes in catchment management, or investments in waterbody remediation. In Europe, the Water Framework Directive (WFD) (2000/60/EC) is the flagship policy intended to deliver improvements in the status of inland surface waters. The central aim of the WFD is achieve “good ecological status” in all surface (and ground) waters by 2015. The WFD stands apart as the first European Directive to explicitly recognise the role of economics in achieving environmental quality objectives through its requirement that Member States assess the social costs and benefits of measures of achieving good ecological status during the formulation of River Basin Management Plans (RBMPs).

It is widely recognised that the declining status of surface waters globally imposes substantial economic costs on society (Pretty et al., 2003;Dodds et al., 2009) and thus the anticipated improvements in ecological status of Europe's surface waters under the WFD can be expected to generate significant social and economic benefits. It has been widely shown that nonmarket values are likely to represent a significant component of these economic benefits (Hanley et al., 2006b;Del Saz-Salazar et al., 2009;Martin-Ortega and Berbel, 2010). The mitigation of water-related human health risks is one such nonmarket benefit that might arise through efforts to improve the ecological status of Europe's surface waters. However, estimates of the welfare benefits of water-related health risk mitigations are currently incomplete. In particular, few studies have attempted to estimate the benefits of reducing health risks posed by toxigenic cyanobacteria in waterbodies used for drinking and/or recreation. Such benefit estimates are, however, necessary, if cost-benefit comparisons of water quality improvements are to be undertaken. This paper presents such benefit estimates for a high-resource waterbody in Scotland impacted by blooms of toxin-producing cyanobacteria. Additionally, we investigate the effect of changes in risk perception on the local population's willingness to pay (WTP) for measures to reduce the occurrence of cyanobacteria blooms of human health significance.

1.2. Estimating the benefits of reductions in cyanobacteria

The economic value of changes in ecosystem services can be estimated through the use of a range of methods (Hanley N and Barbier EB, 2009). These include: stated preference methods such as contingent valuation and choice experiments; revealed preference methods such as hedonic pricing and travel cost models: and production function approaches. Choosing an appropriate method for a given empirical setting requires a consideration of the nature of environmental benefits or costs to be measured (UK NEA, 2011). Where variations in environmental quality solely impact on users of a particular environmental resource, then revealed preference methods are often a preferred approach. However, when benefits are likely to accrue to both users and non-users of the resource, or where changes in environmental quality beyond the range of current variation are in prospect, a stated preference method is more appropriate (Hanley and Barbier, 2009). Previous studies of the economic benefits of water quality improvements have shown both use and non-use values to be important (Hanley et al., 2003a;Holmes et al., 2004;Birol et al., 2006). Given our expectation that both those who directly use our case study waterbody (e.g. for fishing) and those who do not directly use the waterbody might have positive values for improvements in water quality, a stated preference method – contingent valuation – was chosen for the present study.

The maxim of contingent valuation is that an individual, when presented with a contingent (i.e. hypothetical) market for a specific change in an environmental good or service, will reveal their underlying preference for that change through their survey response (Bateman et al., 2002). The value that an individual places on a nonmarket environmental good can be estimated from the largest amount of money they would be prepared to pay for the delivery of the environmental good, their maximum WTP (or alternatively the lowest amount they would be prepared to accept to forgo that same good). Aggregating WTP amounts across the beneficiaries of a change in environmental quality yields an estimate of the social economic benefit of that change.

Formally, if an individual, 's, utility is derived from the consumption of a vector of privately supplied goods available at market prices , a vector of public (environmental) goods , and available income , we can write the (indirect) utility function as:

$$v(P,Q,m) \tag{1}$$

If the quantity of an environmental good such as safe water increases from Q_0 to Q_1 , then the associated welfare gain (consumer surplus or WTP) can be quantified as:

$$v(P_0,Q_0,m_0) = v(P_0,Q_1,m_0 - WTP) \tag{2}$$

WTP represents the reduction in income available to spend on market goods necessary to offset the increase of water quality from Q_0 to Q_1.

In a random utility model, individual i 's indirect utility function can be specified as combining an observable, deterministic component with a random component (e), which is un-observable (McFadden D, 1974):

$$v_i(P_i, Q_i, m_i) = V_i(Z_i, Q_i, m_i, e_i) \tag{3}$$

We can now omit the price vector (as market prices remain constant in the hypothetical choices respondents make) and include a vector of individual-specific attributes, Z , which includes socio-demographic characteristics of the respondent. The new random component of the utility function, ε , reflects the researcher's inability to observe all characteristics influencing the individual's utility function, and hence fully deterministically predict choices, which remain to some extent random[1].

[1] Otherwise the model could not deal with different choices made by two seemingly identical (in terms of observed characteristics) individuals.

As noted above, stated preference methods such as contingent valuation have been widely used to determine public preferences and WTP for improvements in the quality of surface waters. This includes studies on the nonmarket benefits of improving the status of rivers and lakes (Cooper et al., 2004;Hanley et al., 2006b) and coastal bathing waters (Georgiou et al., 1998;Hanley et al., 2003a). Del Saz-Salazar (2009), for example, used both discrete choice and open-ended contingent valuation surveys to show that on average people living in the River Serpis basin in Spain were willing to pay between US$141–146/household/year towards improvements in water quality under the WFD. This clearly demonstrates that the potential nonmarket benefits of improvements in the ecological status of surface waters are not insignificant, but that such analyses say little about the specific benefits of water-related health risk-reductions because broad improvements in 'ecological status' provide multiple benefits to society.

There have been a few attempts to elicit WTP estimates for reductions in nutrient loads to waterbodies, which contain explicit links to changes in waterborne health-risks. One of the first such attempts was a coordinated series of surveys in Poland, Lithuania, and Sweden aimed at estimating benefits of limiting the level of eutrophication in the Baltic Sea (Georgiou S et al., 1995). Georgiou et al. (2000), found that the economic benefits of reducing the health risks posed by microbial pathogens at two UK bathing waters were UK£20.17-£35.41/household/year and, further, and more importantly, that the aggregated benefits were comparable to the costs of mitigation. Johnson et al. (2008) developed benefit estimates for reductions in the health risks posed by intestinal enterococci in the River Irvine catchment in Scotland using a benefits transfer model based on dose-response relationships. They found the aggregated nonmarket benefits to be a not insignificant £276,000 per annum, but in this instance this sum was lower than the anticipated costs of mitigation. By contrast, Machato and Murato (2002) found that a reduction in the human health risks posed by faecal coliforms on the Estoril coast in Portugal only constituted a small component of the total welfare benefits of improved water quality status, which were instead dominated by amenity-related use values. Hanley et al. (2003a) used a contingent behaviour approach to estimate benefits of reductions in coastal water pollution in South-West Scotland linked to pathogen measures under the Bathing Waters Directive, but did not link individual WTP to changes in perceived or actual health risks.

These studies highlight current uncertainties surrounding public preferences and WTP for water-related health risk reductions. Moreover, very few studies have attempted to estimate the nonmarket benefits of reductions in the health risks posed by toxic cyanobacterial blooms in inland waterbodies. Pearson et al. (2001) used a contingent valuation survey to estimate the costs associated with loss of recreational access caused by cyanobacterial blooms in Rutland Water in the UK. They estimated that the welfare benefits of keeping the reservoir free from cyanobacterial blooms to be in the region of £365,000 to £521,000 per annum. However, because the contingent market used in this study was based on recreational usage rather than health-risk reductions, it is difficult to disentangle the health benefits from those related to general amenity benefits. More recently, Kosenius et al. (2010) used choice experiments to explore consumer preferences for improvements in water quality attributes in the Baltic Sea. It was shown that reductions in cyanobacterial blooms ranked second only to improvements in water clarity in determining public preferences, but again this was not necessarily because of the implied benefits to human health. Clearly, a better understanding of the nonmarket value of reductions in health risks posed by toxic cyanobacterial blooms is needed to support the decision-making process under the WFD and other water-related policies.

1.3. The effect of risk perception on WTP

It is widely established that an individual's WTP for an environmental good is likely to be determined by a number of socioeconomic factors including income, education, and knowledge and use of the resource in question. Work has shown that an individual's WTP for health-risk reductions is also dependent on their perception of- and attitude towards those risks. More specifically, individuals who perceive there to be a greater health risk are generally more likely to be willing-to-pay (and willing-to-pay more) for a given reduction in that risk. Sukharomana and Supalla (1998), for example, found that that an individuals' WTP for groundwater improvements in Nebraska in the USA increased if the perceived risk was greater. Similarly, Georgiou et al. (1998) showed that an individual's WTP for improvements in bathing water quality was not only dependent on their socioeconomic status, but was also strongly correlated with their perception of the health risks from exposure to polluted coastal bathing waters.

There are often marked discrepancies between peoples' perceptions of risk and that measured scientifically or "objectively" (Kraus et al., 1992;May and Burger, 1996;Campbell et al., 2002). The work of cognitive psychologists has shown that lay perceptions are often strongly influenced by a variety of personal, social and cultural factors. Langford et al. (2000), for example, found that public perceptions of risks from polluted bathing waters could be explained by cultural theory. They argue that social solidarities shape individual worldviews and influence cognitive judgements about the magnitude and acceptability of risk. This raises the possibility that, in the absence of adequate consumer information, personal, social or cultural misperceptions of environmental health risks might bias public preferences and WTP for health risk reductions. This is shown by Sukharomana and Supalla (1998) who found that discrepancies between actual and perceived risks relating to nitrate pollution in groundwaters led to a reduction in WTP values.

Given these gaps in the existing evidence base, the aims of the present study were thus threefold: (1) to explore the public's knowledge and perceptions about the specific health risks associated with toxic cyanobacterial blooms; (2) to elicit public preferences and WTP estimates for reductions in these health risks; and (3) to establish what effect, if any, risk perception has on individual's WTP for health-risk reductions. We used a contingent valuation survey administered to residents living near to Loch Leven in Scotland to achieve these.

2. Case study

Loch Leven is the largest lake in lowland Scotland (56°12′N, 3°22′W) and one of the most important in terms of natural, cultural and scientific heritage. The lake has a surface area of 13.3 km^2 and mean and maximum depths of 3.9 and 25.5 m respectively. The catchment covers some 145 km^2, nearly 75% of which consists of agricultural land and less than 3% is urbanised. The lake supports internationally important numbers of migratory, overwintering and breeding waterfowl and is an internationally renowned brown trout fishery. Its importance as a site for conservation is evidenced by its designation as a National Nature Reserve (NNR), a Site of Special Scientific Interest (SSSI), a Special Protected Area (SPA) and a Ramsar site. The lake also supplies water to several downstream industries including paper and textile mills and is a popular tourist destination.

The lake has suffered from intense summer blooms of cyanobacteria for several decades because of historically high nutrient loadings from sewage treatment works, septic tanks, industry and agricultural runoff. The introduction of tertiary treatment technologies at two local sewage works during the 1990s significantly reduced point-source phosphorus loads (Bailey-Watts and Kirika, 1999), and recently the lake has started to show signs of ecological recovery (Ferguson et al., 2008; Carvalho et al., 2011), but nutrient inputs from diffuse sources remain an issue. The occurrence of toxigenic cyanobacterial blooms on the lake poses significant risks to human health. The concentration of microcystins[2] in the lake during blooms has, for example, been shown on occasion to significantly exceed current World Health Organisation (WHO) guideline levels for recreational waters (Tyler et al., 2009;Hunter et al., 2010)}.

Blooms of toxin-producing cyanobacteria in Loch Leven are a significant socioeconomic concern and an issue that has received considerable attention in the local media. For example, one particularly intense bloom of microcystin-containing *Anabaena-flos-aquae* in the summer of 1992 was associated with a major fish-kill (Rodger HD et al., 1994;Codd GA et al., 1995) and led to the cancellation of the World Angling Championships. This event, infamously referred to locally as "Scum Saturday", was estimated to have cost the local economy up to £1 million (LLAMAG, 1999) in lost revenue in that year alone and caused considerable longer-term damage to the international reputation of the fishery.

3. Survey design

3.1. Survey instrument

The data for this study were compiled from responses to a postal questionnaire administered in July 2008 to local residents in the towns of Kinross and Milnathort

[2] Microcystins are one of the most common and potent groups of cyanotoxins currently recognised

near to Loch Leven. Following on from a series of focus groups with local residents, the questionnaire was piloted through face-to-face interviews conducted with an independent set of respondents representing approximately 10% of the final sample size and was revised accordingly in light of the feedback received. Subsequently, 1400 questionnaires were mailed to addresses selected at random from the electoral roll. A follow-up letter was sent 4 weeks later to improve the response rate. In total, 391 responses were received (28%) of which 370 were useable. This response rate compares favourably with other recent stated preference studies of environmental benefits carried out by mail in Scotland (Bergmann et al., 2006;Hanley et al., 2006a;Hanley et al., 2010)

The questionnaire was structured into five sections. The first section explained the purpose of the survey and provided a non-technical explanation of (i) what cyanobacteria are; (ii) ecological and health problems they cause; and (iii) the practical options available for health-risk mitigation at Loch Leven. It also emphasised that it would cost money to reduce the health risks posed by cyanobacterial blooms on the lake. The second section included a series of questions about attitudes to the environment and questions about how often respondents visit the lake and the activities they undertake there. The third section explored the respondents' attitude and behaviour towards environmental health risks, including those posed by cyanobacteria, both generally and specifically at Loch Leven. The questions were based on the psychometric paradigm of Slovic (1987) and those used previously in a similar context by Georgiou et al (1998). The fourth part included the contingent valuation scenario and an additional follow-up question to identify protest votes (zero willingness to pay responses which are not indicative of zero value). The final part of the questionnaire was devoted to a series of standard demographic questions (e.g. age, sex, education, employment, income).

3.2. Valuation scenarios

It is important that the hypothetical market scenarios used in contingent valuation studies of environmental goods have a strong scientific underpinning and be credible and acceptable to respondents. The valuation scenario used in this study was based upon the current guideline levels for microcystin-LR in recreational waterbodies established by the WHO (WHO, 2003) /d}. Because microcystins are not measured routinely in waterbodies, the WHO guideline levels also provide toxin-equivalent chlorophyll-*a* concentrations to facilitate risk assessment. The guideline levels suggest that, where toxin-producing cyanobacteria are dominant, cell numbers equivalent to a chlorophyll-*a* concentration of 10 $\mu g\ l^{-1}$ and above may pose a risk to human health. We used routine monitoring data held by the UK's Centre for Ecology & Hydrology for the two years prior to the survey (2006–2007) to determine the number of days per year that the concentration of chlorophyll *a* is equal to or above the 10 $\mu g\ l^{-1}$ guideline level established by the WHO for periods when cyanobacteria are dominant in the water column. This analysis provided a baseline estimate of 90 Risk Days (RDs) (broadly July to October) per year under current conditions.

This baseline scenario was subsequently used to construct a hypothetical market at two levels of scope. In the contingent valuation section of the survey, the sample was split and respondents were asked if they would be willing-to-pay towards measures to reduce the number of RDs from the current average of 90 RDs per year to either 45 or zero RDs per year. This is similar to the hypothetical market used by Kosenius et al. (2010) for water quality improvements in the Baltic Sea. Respondents were told that this reduction in risk could be achieved through reductions in nutrient loads, particularly from agriculture and septic tanks. The respondents were also reminded of alternative expenditure possibilities and the availability of other lakes in the local area where cyanobacteria do not pose risks to human health.

Those respondents who agreed to participate in the hypothetical market (that is, those people who indicated that they would be willing to pay in principle for the risk reduction) were then asked to specify how much they would be willing to pay to fund measures to reduce the number of RDs to either 45 or zero. The proposed payment vehicle was an increase in the cost of domestic water supply set by the local council. This was seen as the most credible method and it also reduced incentives for free-riding associated with voluntary contribution mechanisms. The respondents were asked to specify their maximum WTP from a series of values presented on a payment card (Bateman et al., 2002), with the vector of prices anchored by responses elicited through the initial pilot survey.

3.3. Econometric approach

Two types of model were estimated from the data collected: a "market participation" model, which predicts the probability of a respondent being willing to pay in principle for the risk reduction; and a willingness to pay model, which explained variation in respondents' maximum WTP. Market participation was modelled using a binary logit model with individual-specific demographic and attitudinal and behavioural variables (to the environment and environmental health risks) included as linear arguments in the model specification. This enabled coefficients and standard errors for factors influencing the likelihood of an individual being willing to pay for health risk reductions to be estimated. The binary regression model was fitted in Limdep v. 9.0.

In order to estimate the WTP bid function, several modelling approaches were applied. These included non-parametric methods, interval regression and modelling in WTP-space, in which the normal, logistic, lognormal and Weibull distributions were fitted to the observed data (Haab T and McConnell K, 2003). In addition, since our data included a considerable number of responses identified as non-protest zero WTPs, a spike model with various bid functions was applied (Kristrom, 1997). The results of these models were evaluated using the Vuong test (Vuong QH, 1989) for comparing the performance of non-nested models. The test results indicated that the spike model with a logistic distribution provided the best fit for the data.

The observation of respondent choices – reactions to the proposed change in the quantity or quality of public goods for prices specified in the hypothetical scenario – allows one to draw conclusions about the probability of agreeing to pay ($Y_i = 1$) a specified amount t_k:

$$\Pr\left(Y_i^{t_{ki}}\right) = \Pr\left(WTP\left(Z_i, m_i, e_i\right) > t_{ki}\right) = \Pr\left(V_i\left(Z_i, Q_i^1, m_i - t_{ki}, e_i^1\right) > V_i\left(Z_i, Q_i^0, y_i, e_i^0\right)\right) \quad (4)$$

If the deterministic and additive components of the utility function are additively separable and the error terms are identically and independently distributed, Eq. **Error! Reference source not found.** can be rewritten as:

$$\Pr\left(Y_i^{t_{ki}}\right) = \Pr\left(e_i^1 - e_i^0 < V_i\left(Z_i, Q_i^1, m_i - t_{ki}, e_i^1\right) - V_i\left(Z_i, Q_i^0, y_i, e_i^0\right)\right) \quad (5)$$

If, in turn, the utility function is linear in its variables, this probability can be conveniently expressed in a form that allows the estimation of respondent preferences in WTP-space, i.e. fitting one of the parametric distributions of WTP to the observed choice data ($WTP_i = f\left(Z_i, Q_i, m_i, \varepsilon_i\right)$).

Many common distributional assumptions (e.g. log-logistic, log-normal or Weibull) imply that all respondents have strictly positive WTP. That is, they unrealistically assume all respondents must have a WTP>0.[3] However, it is common to have a significant number of zero WTP responses in contingent valuation studies. Zero consumption of a good (i.e. the offered price is higher than respondent's WTP) may occur because of corner solutions of the utility-maximization problem; however, it may also be the case that consumers are not 'in-the-market' for the good. This refers to situations when the good does not contribute to the respondent's utility at all (even at zero price). In recognition of this, the spike model provides a way to account for a non-zero probability of WTP=0 and combines this with a continuous distribution for WTP>0.

Spike models use two contingent valuation responses, incorporating a binary variable reflecting market participation ($S=1$, $S=0$ otherwise) and a second variable expressing whether the respondent agreed to pay the specified bid (since our study used a payment card, we use a set of dummy variables Y^{t_k} taking the value 1 for the highest bid the respondent was willing to pay, and 0 otherwise). The payment card allowed us to infer the lower and upper bound of each respondent's WTP, providing the respondent was 'in-the-market'. As a result, if we denote these respondents' cumulative distribution function of WTP as G, the probability of selecting bid t_k on a payment card (providing a respondent is 'in-the-market') can be expressed as:

$$\Pr\left(t_i^k\right)=G\left(t_i^{k+1}\right)-G\left(t_i^k\right) \tag{6}$$

[3] Similarly, assuming continuous distributions such as normal or lognormal implies that (1) some of the respondents have negative WTP, and (2) the probability of WTP=0 is very close to the probability of WTP=0+ε; in most cases these implications are unrealistic.

and the overall cumulative distribution function of WTP of all respondents (denoted F), becomes:

$$F(t)=\begin{cases}0 & \text{for} \quad t<0 \\ p & \text{for} \quad t=0 \\ G(t) & \text{for} \quad t>0\end{cases} \tag{7}$$

and hence there is a jump-discontinuity (spike) in the probability density function at WTP=0.

Combining these together, the log-likelihood function of observing the particular set of choices of N individuals in the sample is given by:

$$\log L=\sum_{i=1}^{N} S_i \sum_{t_k=0}^{t_k=K} Y_i^{t_k} \ln\left(F\left(t_{k+1}\right)-F\left(t_k\right)\right)+\sum_{i=1}^{N}\left(1-S_i\right)\ln\left(F\left(0\right)\right) \tag{8}$$

This likelihood function can be programmed for maximization in all econometric packages, resulting in estimation of parameters of WTP distribution. We used Nlogit v.4.0 in Limdep v.9.0 (Econometric Software, Inc.).

4. Results

4.1. Descriptive statistics

The demographics of the sample are shown in Table 1. The sex distribution of the sample was very similar to that of the wider population of the Perth and Kinross area. The average age of respondents was 52.8 years which, although relatively high, reflects the fact that there is a higher proportion of older age groups resident in the counties of Perth and Kinross (38% of the population are >50 years) and those under 18 years of age were excluded from the survey. The employment statistics show a slightly greater proportion of professional and retired persons in the sample than the general population, indicating a possible sample selection effect.

On average, respondents visited Loch Leven once every two weeks, with walking and relaxing the most commonly cited activities undertaken; the vast majority of respondents typically did not have contact with the water during these visits and less than 5% of the sample used the lake for angling or other watersports. In total, 77.8% of the sample felt that access to clean and unpolluted waterbodies was important for their quality of life and a further 74.3% were of the opinion that the actions of humans had caused a decline in water quality in the local area. However, only 31.7% of respondents believed that efforts to improve the water quality status of waterbodies in the local area should be funded by public money.

The quality of the water in Loch Leven was most frequently rated as "fair"; but less than 20% of the sample believed that water quality in the lake was "good" or getting better, and almost 36% of the sample believed water quality in the lake was not improving or getting worse. The majority of respondents believed the risks posed to them personally by toxic cyanobacterial blooms at Loch Leven at the time of the survey was low; only 6.2% of the sample perceived the risks to be high. However, almost 42% of the sample believed that the risks had increased over the last 10 years; 56.5% agreed that exposure to toxic cyanobacterial bloom could result in ill health and 32.2% felt the outcomes were likely to be serious. Intriguingly, only 26.8% of the sample were aware, before the survey, of any of the potential health outcomes that may result from exposure. Slightly less than 18% were comfortable with the current level of risk whereas 17% felt the risks affected them personally. More than 58% of the sample believed that it was up to the individual whether they put themselves at risk of exposure; 64.5% were of the opinion that the risks were not fully understood and only 16.3% were of the opinion that the authorities adequately manage the risks.

4.2. Respondents' risk perception

Our survey contained a number of attitude questions related to perception of the environmental and health risks. It was not possible to use all of them as explanatory variables of respondents' WTP since the answers to many of the questions were correlated (perhaps because they were measuring the same constructs), resulting in multi-colinearity of variables in the model. Because of this redundancy, we performed explanatory factor analysis on the attitude variables in order to identify main factors that account for the most variance in the observed attitudes. A similar approach was used by Cooper et al. (2004) and Aldrich et al. (Aldrich GA et al., 2007) in order to verify the influence of pro-environmental attitudes on WTP. However, to our knowledge, this is the first attempt to use factor analysis to investigate the effects of risk perception on WTP for measures related to environmental goods.

Responses to attitudinal questions were subjected to explanatory factor analysis using squared multiple correlations as prior communality estimates. The principal factor method was used to extract the factors, followed by a varimax (orthogonal) rotation. Interrogation of the scree plot suggested three meaningful factors with eigenvalues > 1 and we assumed items loaded on a given factor if the loading was greater than 0.4. Using these criteria, attitude questions were associated with the factors they loaded on and were labelled (1) 'Level of concern towards environmental health risks'; (2) 'Attitude to risks posed by toxic cyanobacteria; and (3) 'Knowledge and perception of health outcomes associated with exposure to cyanobacterial toxins', respectively. The questionnaire items used in the factor analysis and the corresponding factor loadings are presented in Table 2. The analysis was conducted in SAS v.9.2 econometric package.

4.3. Model of market participation

In total, 205 out of the 370 respondents (55.4%; 69.0% excluding protest votes) were willing to pay for reductions in the risks posed by toxic cyanobacteria at Loch Leven; 73 of the remaining 165 responses (19.7% of total sample) were protest bids, which were removed from the sample.[4] The most commonly cited reason for protest voting was that the "polluter should pay", with the polluter often perceived to be local farmers and the fishery.

The model estimates for market participation are shown in Table 3. The model was estimated using the individual loadings of the three factors as independent explanatory variables of WTP. In addition, the variables representing individuals' socio-demographic status were included in the model specification. These included the respondent's household income, usage of Loch Leven, and membership of environmental organisations. In total, six variables were found to be statistically significant determinants of market participation at $\alpha = 0.05$. This included explanatory variables relating to respondents' socio-demographic status, including income, employment status, household size and membership of environmental organizations. Generally speaking, respondents in full-time employment, with higher incomes and from smaller households were more likely to enter the market for health risk reductions. This agrees strongly with *a priori* expectations regarding the effect of socioeconomic status on market participation. In addition, we found that being a frequent user of the lake made the respondents less likely to be willing to pay for its improvement. This can be explained by the fact that those respondents who use the lake most frequently for recreation do so because they have little concern for the

[4] Respondents who stated that they would not be willing to pay anything for cyanobacteria health risk reductions in Loch Leven, and at the same time provided reasons indicating their disbelief in the hypothetical scenario rather than economic or preference reasons, were classified as protest zero responses.

potential health risks posed by toxic cyanobacteria and thus have no incentive to pay for reductions in the risks.

The respondent's attitude to the health risks associated with cyanobacterial blooms (Factor 2) was also a significant explanatory variable; respondents who perceived the risks from cyanobacteria to be not significant, low or acceptable, were less likely to be willing to pay for their reductions. In contrast, neither general concern relating to environmental health risks (Factor 1), nor awareness of potential health outcomes from exposure to cyanobacterial toxins (Factor 3), proved to be statistically significant in explaining market participation. We also found that the scope of the risk reduction (from 90 to 45 or from 90 to 0 RDs per year) did not affect the likelihood of respondents participating in the market.

4.4. Respondents' WTP and the influence of risk perception

The spike model of the observed respondents' WTP was also estimated using the individual loadings of the three factors related to perceived health risks as independent explanatory variables as well as the variables representing individuals' socio-demographic status as per the model of market participation (Table 4). In total, 5 variables were found to be statistically significant determinants of individuals' WTP. In addition to being sensitive to the scope of the risk reduction offered, respondents who expressed a high level of concern regarding environmental health risks (Factor 1) were on average willing to pay more for reductions in the risk posed by cyanobacterial blooms. In contrast, those respondents who were indifferent to the risks posed by cyanobacterial blooms (Factor 2) were willing to pay significantly less; whereas those respondents whose answers loaded highly on Factor 3, a measure of their knowledge and perceptions of the likely health outcomes, were not willing to pay statistically more or less than others. In addition, we found that the more affluent respondents were willing to pay more. The frequency of use of the lake was also again negatively related to the amount individuals' WTP. We found that the respondents who were members of environmental organizations were statistically willing to pay more as well.

Finally, our sample was divided into two sub-samples depending on whether they had bid for a reduction from 90 RDs to 0 or 45 RDs. The mean WTP of these subsamples was £9.55 and £7.91 respectively. These amounts were not statistically different, mainly due to the relatively small size of each sub-sample and the associated large standard errors.[5] Nonetheless, they show the relationship generally expected by scope sensitivity. The WTP for each scenario of risk reduction, the associated standard errors, and the 95% confidence intervals for the estimates are provided in Table 5.

5. Discussion

5.1. Nonmarket benefits of health risk reductions

The survey revealed that more than 68% of respondents (excluding those who protest voted) were willing to pay to reduce the risks posed by toxic cyanobacterial blooms at Loch Leven. The mean WTP estimated by the logistic spike model of £7.91-9.55/household/year equates to approximately 0.02% of the mean annual household income of the sample. If we aggregate these estimates over the local population (i.e. the towns of Kinross and Milnathort; population approximately 15 000), the total economic benefit of the proposed risk reductions would total £118,650-143,250 per annum. This is, however, likely to be a very conservative estimate of the true aggregated benefits because many regular users of the lake come from other parts of

[5] Several previous studies have reported a lack of scope sensitivity for health risk reductions (Hammitt and Graham, 1999;Smith, 2005).

Perth and Kinross. If we aggregate the estimates over the total population of Perth and Kinross (134 949), the welfare benefits would approximate some £1.1-1.3 million per annum. This is, conversely, likely to be a slight overestimate of the aggregated benefits because of the likelihood of distance-decay effects (Hanley et al., 2003b), and realistically the true figure is likely to lie somewhere between the estimates for the local population and that for the wider region.

Clearly, the economic benefits of reducing the occurrence of toxic cyanobacterial blooms are not insignificant, particularly given such actions would also accrue other benefits (e.g. greater biodiversity, improved amenity) not considered in our contingent market. As such, these nonmarket benefits could make a substantial contribution towards offsetting the potential costs of mitigation. It is difficult to make direct comparisons between the welfare estimates obtained here and those reported in elsewhere because there is a lack of directly comparable studies. That said, the derived benefit estimates were of a similar magnitude to those estimated by Pearson et al. (2001) (£16.74/household/year; £22.24/household/year after adjustments for inflation[6]) for improvements in recreational access at Rutland Water, UK through reductions in the occurrence of cyanobacterial blooms. The fact that the welfare estimates calculated in this study were slightly smaller than those found by Pearson et al. (2001) is probably explained by the fact that the latter study was conducted only three years after the occurrence of major health and recreational usage problems at Rutland Water (and in other waterbodies in the wider area). Whereas, at Loch Leven, the last major (and well publicised) incident was the 'Scum Saturday' event in 1992, some 16 years prior to our study. Public awareness of the health issues associated with toxigenic cyanobacteria at Loch Leven has therefore probably decreased

[6]Inflation estimates based on the Consumer Price Index

markedly over the intervening years, partly also due to increased immigration into the area, and this will have undoubtedly influenced the welfare estimates elicited in this study. However, our estimates are much lower than the €149-611/household/year reported by Kosenius (2010) for improvements, including reductions in the occurrence of cyanobacterial blooms, in the Baltic Sea ecosystem. But in this earlier study individuals were bidding for a far wider range of benefits and therefore one might expect the derived welfare estimates to be greater than for health risk reductions alone.

It is intriguing that more than two thirds of respondents were willing to pay for risk reductions in spite of the fact that the vast majority were of the opinion that the risks did not affect them personally. This lack of personal concern was probably partly due to the fact that very few of those surveyed had regular contact with the water in Loch Leven, allied to the general lack of knowledge amongst those interviewed about cyanobacteria and their toxins, as well as possible exposure routes and health outcomes. The willingness of respondents to pay for reductions in health risks that they did not perceive to affect them personally suggests that altruism might have been a key motivation behind individuals' WTP for the proposed risk reductions. Previous studies have shown that altruistic behaviour can significantly influence an individual's WTP for water quality improvements (Cooper et al., 2004;Loomis JB et al., 2009) and it would seem that such effects were important in this study.

However, an alternative or additional interpretation might be that the respondents were valuing a wider set of goods beyond the health risk reductions offered through the hypothetical market. Clearly, efforts to reduce the occurrence of toxic cyanobacterial blooms in Loch Leven would provide multiple nonmarket benefits and it might be that some respondents were bidding for other benefits and not necessarily for the health risk reductions on offer in the contingent market.

5.2. The importance of risk perception

The models developed in this study show that the determinants of public preferences and WTP for water-related health risk reductions are complex. Clearly, individual demographic and socioeconomic factors are important determinants of public preferences and WTP for reductions in the risks posed by cyanobacterial blooms. However, our study also emphasises that attitudes to the environment and risk perception also play significant roles in the formation of consumer preferences for environmental health risk reductions, both in terms of influencing the likelihood of an individual entering the market and the amount they are willing to pay. It is perhaps not surprising that such factors were generally of secondary importance to other socioeconomic factors in influencing market participation and WTP, particularly given this study was undertaken against a background of economic recession. However, the results of this study clearly show that cognitive judgements about the magnitude and acceptability of risks need to be taken into account in contingent valuation studies of health risk reductions.

It was very apparent that individual-specific attitudes and perceptions towards the health risks posed by cyanobacterial blooms at Loch Leven varied greatly across the sample reflecting underlying differences in consumer knowledge. It has been suggested that the perceived risk is effectively a measure of consumer gain from risk mitigation measures (Sukharomana and Supalla, 1998) and, as such, the effect observed on the WTP estimates elicited in this study is consistent with utility theory in the sense that those individuals who perceived a greater risk were generally more willing to pay for mitigation measures. Here, the potential for disparity between the perceived risk and the actual, scientifically determined, risk becomes important. Our survey highlighted that public knowledge of the risks posed by toxic cyanobacteria is generally poor. This is evidenced by the fact that almost three quarters of the sample had no prior knowledge of the possible ill health effects of exposure to cyanotoxins. Moreover, while a minority of respondents perceived a risk of mild illnesses such as pruritic skin rashes and gastroenteritis, none were aware of some of the less common but more serious potential health outcomes such as the links to primary liver cancer (Svircev et al., 2009)} and neurodegenerative diseases (Ince and Codd, 2005;Metcalf and Codd, 2009)}. It might be expected that greater awareness of such health outcomes, notwithstanding the fact the actual risks are likely to be very low for the vast majority of individuals, would almost certainly lead to a significant increase in the perceived risk. This implies that the lack of adequate consumer information probably led to a downwards biasing of the WTP values elicited in this study. Indeed, Sukharomana and Suppala (1998) reached similar conclusions about the role of imperfect consumer information on WTP values for health risk reductions.

5.3. Implications for water resource management

The findings of this study have significant implications for the management of waterbodies affected by toxic cyanobacterial blooms. The magnitude, frequency, duration and geographic spread of cyanobacterial blooms, scums and biofilms in fresh, brackish and marine waters are increasing globally in response to eutrophication and climate change. This includes potable waters as well as those used for recreation. In the UK, for example, cyanobacterial blooms have recently led to the cancellation of two national swimming events – the Great North Swim in Lake Windermere (LDNPA, 2011) and the Great Scottish Swim in Strathclyde Loch – because of the potential health risks. The costs of such cancellations can be approximated directly through the revenue lost by the local economy. Similarly, the increased costs for drinking water treatment caused by increased cyanobacterial cell and toxin loads can be estimated relatively easily (Thorne and Fenner, 2011).

However, efforts to reduce the occurrence of toxic cyanobacterial blooms in recreational waters will also provide significant nonmarket benefits to society, not least because of the decreased risk to public health. Pretty et al. (2003) estimate that the environmental costs of eutrophication in England and Wales are approximately £75.0-114.3 million per year. This estimate was based upon an assumption that the health cost to humans from blooms of toxic cyanobacteria is effectively zero because reported incidences of ill health are rare (although one could argue the vast majority of cases of ill health resulting from human exposure to cyanotoxins are likely to go unreported or be misdiagnosed by health care professionals). Our study shows that the economic benefits of reducing these costs through measures to improve water quality are likely to be greatly augmented by a range of nonmarket benefits including reductions in the risks posed by toxic cyanobacterial blooms. We estimate the benefits of reducing the occurrence of toxic cyanobacterial blooms at Loch Leven by at minimum of 50% to be greater than £225,000 per annum when aggregated over the local population. Clearly, such welfare estimates should be taken into consideration when assessing costs and benefits of programmes for the restoration of waterbodies, such as those currently being developed under the auspices of the WFD, as they could make a significant contribution towards mitigation costs. However, there remains an urgent need for further studies on the nonmarket benefits of water-related health risk reductions. In particular, further research should be directed towards elucidating the relationships between the perceived and actual risks posed by cyanobacterial blooms (and other water-related health risks) and the extent to which possible public misperceptions of the risks lead to a biasing of benefit estimates.

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Tables

Table 1. Sample demographics.

	Sample (370)						Perth and Kinross (134 949)[1]
	n	**Mean**	**Median**	**St. Dev.**	**Min**	**Max**	**Mean**
Age (years)	360	52.8	53.0	15.1	17	92	
Residence (years)	363	21.4	16.0	17.4	1	83	
Commuting distance (miles)	241	24.6	12.0	83.4	0	1000	
Household (no. people)	363	2.79	2.00	1.29	1	7	2.24
Dependents (≤ 16 years old)	361	0.61	0.00	1.00	1	5	
Household income (£)	308	50 974	45 000	26 721	5 000	95 000	
Dogs	352	0.56	0.00	1.04	0	10	
Sex	***n***	**%**					
male	180	48.9					48.3
female	190	51.4					51.7
Occupation							
unemployed/student/retired	129	34.9					40.9
manual	80	21.6					24.0
non-manual	52	14.1					22.9
professional	98	26.5					12.2
Education							
school only	94	26.1					
College	118	32.8					
University	138	38.3					

[1]Data from 2001 Scotland Census

Table 2. The results of explanatory factor analysis of the responses to attitudinal questions regarding perception of environmental and health risk. Shaded boxes show items loading on each factor with loadings >0.4.

Variable	Factor 1	Factor 2	Factor 3
Level of concern regarding air pollution	74	-4	13
Level of concern regarding drinking water pollutants	82	-7	3
Level of concern regarding household waste disposal	74	-19	14
Level of concern regarding radiation from mobile phones and masts	64	6	10
Level of concern regarding blue-green algae	64	-28	24
Level of concern regarding pesticides in food	71	-24	11
There is more risk today than 10 years ago	13	-41	23
I feel comfortable with the level of risk	-8	65	-6
The risks are likely to be serious	24	-44	33
People who have contact with blooms know what the risks are	3	60	1
I can deal with the risks	-17	62	13
The risks are acceptable to me	-22	65	-1
There are no risks associated with blue-green algae	-3	63	-22
The health risks are managed by the relevant authorities	-1	46	-3
Having contact with blooms could harm people	13	-44	41
Awareness of the risk of skin rashes	-4	-31	66
Awareness of the risk of eye, ear and nose irritation	3	-24	74
Awareness of the risk of sore throat	4	-16	77
Awareness of the risk of nausea	24	-3	85
Awareness of the risk of vomiting	20	1	84
Awareness of the risk of abdominal pains	21	0	83
Awareness of the risk of diarrhoea	16	16	75
Variance explained by factor	**3.4377**	**3.1384**	**4.7484**

Table 3. Binary logistic model estimates for market participation.

Variable	**Coefficient**	**Standard error**	***p-value***
Constant for scenario 1 (a reduction from 90 to 45 RDs)	-3.4301	2.17450	0.1147
Constant for scenario 2 (a reduction from 90 to 0 RDs)	-3.5153	2.18135	0.1071
Factor 1 (Level of concern with environmental risks)	0.0625	0.16091	0.5563
Factor 2 (Attitude to risks associated with cyanobacteria)	0.0947***	0.18172	0.0001
Factor 3 (Awareness of potential health risks associated with cyanobacteria)	-0.7142	0.14299	0.6621
Household income (ln(GBP))	0.5019**	0.22084	0.0231
Frequency of visits to Loch Leven (1-7)	-0.1971**	0.10032	0.0495
Membership of environmental organisations (dummy)	0.4952**	0.21729	0.0227
Employment status (dummy)	0.8520**	0.34051	0.0123
Household size	-0.2672**	0.12411	0.0314
n	297		
Log-likelihood	-156.0800		
Akaike Information Criterion (normalized)	1.1180		

***, **, * – Significant at 1%, 5%, 10%

Table 4. The results of the spike model fitted to the bid function

Variable	Coefficient	Standard error	*p-value*
Constant for scenario 1 (a reduction from 90 to 45 RDs)	-6.4465***	1.6794	0.0001
Constant for scenario 2 (a reduction from 90 to 0 RDs)	-6.7870***	1.6729	<0.0001
Cost	-0.0869***	0.0058	<0.0001
Factor 1 (Level of concern with environmental risks)	0.2533**	0.1211	0.0365
Factor 2 (Attitude to risks associated with blue-green algae)	-0.3253**	0.1269	0.0104
Factor 3 (Awareness of potential health outcomes associated with blue-green algae)	0.0835	0.1170	0.4756
Household income (ln(UK£))	0.7915***	0.1602	<0.0001
Frequency of visits to Loch Leven (1-7)	-0.2568***	0.0784	0.0011
Membership of environmental organisations (dummy)	0.3746***	0.1312	0.0043
n	297		
Log-likelihood	573.0538		
Akaike Information Criterion (normalized)	-3.859		

***, **, * – Significance at 1%, 5%, 10%

Table 5. The mean WTP (in £/household/year) estimates for the scenarios of reduction from 90 to 45 and 0 RDs, respectively.

	WTP (£/household/year)	Standard error	95% confidence interval
Reduction to 45 RDs	7.91***	1.0269	5.90- 9.92
Reduction to 0 RDs	9.55***	1.3168	6.97-12.13

***, **, * – Significance at 1%, 5%, 10%