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Economic appraisal of ecosystem services and restoration scenarios in a tropical coastal Ramsar wetland in India

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Abstract

Valuation of ecosystem services can play an important role in guiding decision-making concerning the restoration of natural ecosystems. This is particularly important in tropical coastal wetlands due to their widespread deterioration. This study investigates the environmental status and provision of ecosystem services of the Ashtamudi lake Ramsar site in Kerala, India, and explores the feasibility of wetland restoration scenarios through a multi-year program involving stakeholder workshops, primary market data collection, and stated preference non-market valuation. Relying on the input of local stakeholders, we apply a choice experiment to estimate the willingness to pay for wetland restoration scenarios with a focus on water quality, mangrove conservation and sustainable fisheries. Results indicate that local stakeholders attribute the greatest value to mangrove conservation, followed by water quality and sustainably managed fisheries. Furthermore, we show that the local residents' willingness to pay for modest and moderate wetland improvement scenarios may outweigh the potential cost of the restoration projects, especially for modest restoration objectives and even under conservative assumptions regarding the benefits and costs of restoration. We discuss how such results can inform local policy in the development of sustainable management practices and act as a benchmark for the extensive network of wetlands in Kerala.

Keywords: Choice experiment; coastal wetland; mangroves; ecosystem restoration; India

1. Introduction

Coastal wetlands are rich and biologically diverse ecosystems which support important ecological functions and play a vital role in providing a range of services for stakeholders at local, regional and global scales (Barbier et al., 2011; Chaikumbung et al., 2016; Lavoie et al., 2016). Such ecosystem services (ES) include provision of raw materials, habitats for biodiversity, water purification, climate regulation, flood protection as well as a host of cultural services by offering spaces for recreation, promoting public health, inspiring culture, catalysing tourism and providing a sense of place (Millennium Ecosystem Assessment, 2005a,b; TEEB, 2010; de Groot et al., 2012). Despite the vast range of benefits accrued to humans by coastal wetlands and the growing research interest (Barbier et al., 2011; Vélez et al., 2018; Hanley and Czajkowski, 2019), these ecosystems experience increasing anthropogenic pressure and are at high risk of conversion to different land use (Meng et al., 2017; Vélez et al., 2018; Barbier et al., 2011), threatening their status as functioning ecosystems and limiting their ability to provide critical ES for the present and future generations. Coastal wetlands are particularly at risk, being exposed to multiple natural and anthropogenic pressures, both from the sea and the land (Mitchell et al., 2015).

The public good nature of many of coastal wetlands' benefits makes their deterioration and overexploitation difficult to prevent. Partly, this is due to a lack of adequate valuation and accounting of the benefits they provide to society, which is often compounded with the lack of integrated management, e.g., from a central wetland or basin authority. The true value of many wetland benefits is not captured by market mechanisms which makes them difficult to measure with accuracy (especially in data-scarce regions) and exposes them to the risk of being underrepresented in the decision-making process (Vélez et al., 2018). Poor management practices often result in natural capital depletion because of unsustainable resource extraction, land use conversion, and deterioration in quality and productivity (Ghermandi et al., 2010). The economic valuation of wetland ecosystem services and of the benefits of their conservation and/or restoration can be a helpful tool in assisting decision-makers and stakeholders involved in the management of such ecosystems (Ghermandi et al., 2016; Sun et al., 2018). Non-market valuation techniques are often implemented to explore local perceptions and value the benefits provided by natural ecosystems (Groot et al., 2012). Stated preference techniques are one commonly adopted approach which use surveys to obtain value for a range of ES (Christie et al., 2012; Cerda et al., 2013). Among them, the choice experiment (CE) has recently gained in popularity due to its ability to extract information about the marginal willingness to pay (WTP) for individual environmental attributes under alternative management scenarios and in a rigorous econometric framework (Hanley et al., 1998; Hanley and Czajkowski, 2019). This can be utilised for estimating the value of ES and changes in their provision under different environmental or anthropogenic conditions (Turner et al., 2010). Choice experiments and other non-market valuation tools have been frequently used to value wetlands (Milon and Scrogin, 2006; Westerberg et al, 2010; Petrolia et al, 2014; Ndebele and Forgie, 2017), though fewer studies exist for developing regions (Chaikumbung et al., 2016).

Valuation of the market and non-market benefits of wetland ecosystem services is, however, only one step toward better informing environmental policies and the sustainable use of natural resources. Limiting the analysis to the estimation of the benefits of the preservation of ecosystems in their current status or restoration to a previous, less degraded status hides some of the trade-offs that are involved in such decisions, notably the costs of restoration, including the opportunity costs of forfeiting the returns from ecosystem development, even though these might be short-termed and fundamentally unsustainable in the long run (de Groot et al., 2013; Sathirathai and Barbier, 2001). The cost-benefit ratio and internal rate of return for restoring wetlands, especially coastal wetlands, can be low in comparison to other ecosystems types, however, restoration is often economically viable (de Groot et al., 2013; Cao et al., 2018). Its viability largely depends on the spatial extension of the wetland (Yang et al., 2016), the time period over which costs and benefits are assessed (Vázquez-González et al., 2017), the rate of discounting applied (de Groot et al., 2013; Turpie et al., 2016) and the level of restoration considered in the analysis (Pattison-Williams et al., 2018). In some wetland restoration projects, the costs outweigh the benefits (Pattison et al., 2011) while in others, the benefits can far outweigh the costs (Birol et al., 2006). Ecosystem services valuation results that are not set in the proper broad context of restoration costs, especially when they include non-market or intangible benefits such as cultural ecosystem services, can be met with suspicion or as a purely academic exercise by policy makers, especially in developing countries where the urgent need to promote economic and social development entails that environmental policies are often more oriented toward the preservation of direct use and provisioning services rather than immaterial and long-term benefits of nature (Martinez-Alier, 2003). While protocols and methods for estimating the economic benefits of ES are increasingly standardised (TEEB, 2010), the estimation of restoration costs still lacks a standardised approach (de Groot et al., 2013). The costs of restoration projects are often difficult to obtain in developing and/or data-scarce regions, especially when there is an absence of comparable sites where projects have been implemented.

India has a notable lack of research on the valuation of wetland ecosystem services (Ghermandi et al., 2016; Chaikumbung et al., 2016). This is particularly troublesome in states like Kerala, which is the focus of the present study, given the local abundance and importance (both economic and ecological) of wetlands and the challenges they face. Kerala state in the South of India is an example of the dangers and, by converse, the potential benefits of the (lack of) sustainable management of coastal wetlands (Sinclair et al., 2019). A developing state, Kerala is covered by wetlands for 5% of the state's land area, with the local wetlands and backwaters representing some of the world's most unique ecosystems (Abraham, 2015) and playing a crucial role in a growing tourism industry. These coastal wetlands, however, have been experiencing increasing deterioration due to growing populations serviced by inadequate facilities, natural resources overexploitation and a general lack of adequate environmental management (Banerjee and Dey, 2017; Bassi et al., 2014; Parikh and Datye, 2003). Such conditions have led to water quality degradation, land encroachment, mangrove disappearance and overfishing practices which threaten the capacity of Kerala's wetland ecosystems to provide goods and services (Kokkal et al., 2007; WISA and CWRDM, 2017; Shiji et al., 2016). In this study, we investigate the Ashtamudi lake, one of Kerala's three Ramsar wetlands of international importance. It is a vital source of ES for more than half a million beneficiaries residing nearby, but has experienced substantial environmental degradation in recent years.

This paper summarizes some of the main results of an international research project focusing on the valuation and mapping of the ecosystem services provided by Kerala's wetlands. The main objectives are: (1) to investigate the environmental status and current provision of ES by the Ashtamudi lake Ramsar wetland; and (2) to evaluate how the willingness to pay of local residents for various environmental attributes and restoration scenarios compares to restoration costs, especially the opportunity costs involved in forfeiting some of the short-term, economic returns that would derive from the continuation of the current trends of mangrove conversion and overfishing. To this extent, we implemented a multi-year program of field surveys, stakeholder workshops, and, to the best of our knowledge for the first time in the context of Kerala's wetlands, a non-market valuation of wetland ecosystem services through a choice experiment. Field surveys and seasonal water quality monitoring were undertaken to characterize the present condition of the lake in terms of water quality and its current supply of ES to the surrounding residents. Through two stakeholder workshops, we identified priority ES and scenarios for their restoration, which were subsequently evaluated by the local population through a choice experiment. Finally, using market data collected we were able to estimate the cost of restoration scenarios, which combined with the locals' willingness to pay for restoration obtained through the choice experiment, enabled us to provide insights into the economic sustainability of wetland restoration for the Ashtamudi lake.

2. Materials and methods

2.1 Study site

The study was carried out in the Ashtamudi lake wetland and its adjacent administrative regions, which are locally referred to as "panchayats" (see Figure 1). Designated as one of Kerala's three Ramsar sites of international importance in 2002, Ashtamudi is a shore-perpendicular, brackish lake located in India's South-West state of Kerala, occupying a land area of approximately $56km^2$. The banks of this estuary lake are densely populated (659,360 inhabitants in 2018), with the adjacent lake area split into 13 regions, including the heavily populated city of Kollam (367,107 inhabitants in 2018) to the south. Residents are provided a range of direct and indirect benefits from the lake, which provide a livelihood to many. These include capture fisheries, clam fisheries, aquaculture, tourism, flood control, storm protection, among others.

Over the last decade, the lake has been increasingly subjected to exploitation beyond its supportive capacity due to increasing anthropogenic pressures from urbanization, overfishing, mangrove destruction, tourism development and land reclamation (Sitaram, 2014; WISA and CWRDM, 2017). The lake is also subject to the disposal of industrial and municipal wastewaters, especially from Kollam city (Figure 1), which has greatly contributed to the water quality degradation and the environmental deterioration of the lake (WISA and CWRDM, 2017; Sagar et al., 2020). Currently, Ashtamudi lake fisheries are not part of any systematic monitoring or management and there is no restriction for fish catch in terms of quantity, age or size. However, there are regulations against small mesh sizes, dictated by the Kerala Fisheries Department. Despite this regulation and voluntary guidelines set out from The Food and Agriculture Organization's Code of Conduct for Responsible Fisheries, the fishing industry continues to operate using, to some extent, banned methods which deplete the fishery and biodiversity of the lake. In terms of mangroves, an investigation conducted by Sumesh et al. (2014) revealed that the luxuriant growth of Ashtamudi mangroves has been rapidly diminishing due to loss of habitat, cattle grazing, harvest for medicine, harvest for timber, fuel wood collection, over fishing and destructive fishing practices, pollution (from industrial effluents, thermal, oil, pesticides and mercury), coconut husk retting, reclamation and sedimentation.

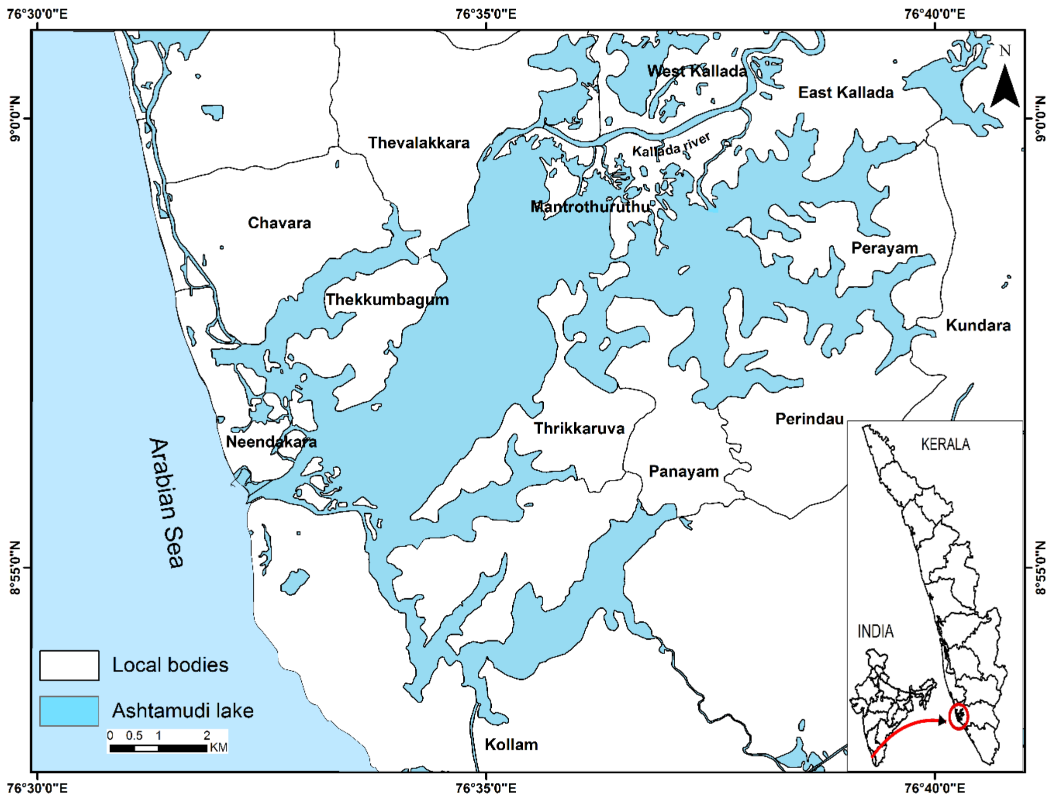

Figure 1: Ashtamudi lake and administrative divisions in the study area

2.2 Identification of ecosystem services and restoration scenarios

Extensive field surveys were carried out during 2017 and 2018 to investigate the environmental situation of the Ashtamudi lake, including the key ES provided by it. Data collected included fisheries landings, aquaculture, tourism, mangrove location and abundance, as well as extensive water quality sampling. Fisheries landing data was collected in 2018 through a monthly sample of six fish landing centres adjacent to the Ashtamudi lake. A water quality monitoring program assessing various measures of quality was conducted at 58 locations throughout the lake during the non-monsoon (May) and monsoon (September) season and measured different physico-chemical water attributes using standard methods (Sagar et al., 2020). Mangrove location and species were mapped through on-site field surveys, while aquaculture data, including spatial extent, yield and cost data, was collected through site surveys and communication with locals. Stakeholder workshops were carried out in Kollam (2017) and in the state's capital city Thiruvananthapuram (Trivandrum) (2020). They were attended by official representatives of all the local regions ("panchayats") as well as local experts, policy makers, local residents, and academics from several key disciplines including clam, prawn and fisheries, and tourism which are among the main economic sectors depending on the lake. The workshops were organized as a series of presentations, followed by open discussions with the participants. The first workshop was focused on the status of ES, perceived problems experienced by the lake, and identification of priority ES and potential restoration scenarios. The second workshop presented the collected field data, results of the choice experiment, and generated feedback from local stakeholders, particularly with regard to the elaboration of the restoration scenarios.

Representing the full range of ES provided by the lake, and various levels of improvement, is infeasible in the context of a choice experiment, with past studies showing that including more than four or five attributes can affect the quality of the data obtained (Alpizar et al., 2001). Therefore, based on the stakeholder feedback from the data collected, we limited the attributes for the choice experiment to three: water quality improvements; sustainable fisheries; and mangrove conservation (Table 1). A status quo was determined for each attribute based on the ES assessment and considering projections of future decline extrapolating from the current trends, i.e., in the absence of additional policy intervention. Technically feasible improvement scenarios were then developed for each attribute using the collected data and in collaboration with local stakeholders.

2.3 Experimental design and generation of choice cards

Figure 1 shows an example choice card from the study. Despite high literacy levels in Kerala, we used images to represent the attribute levels (Table 1), to reduce the cognitive burden on the respondents and ensure the survey was inclusive to those who could not read or only read with difficulty. Interviewers would explain the images using a text legend which was also given to respondents. Cards consisted of the status quo and two alternatives plans which considered combinations of the three selected attributes at different levels (Table 1). Weakly informative priors were used to generate a D-efficient design for the pilot study using Ngene software (ChoiceMetrics, 2018). Priors from the pilot study were then used to generate a D-efficient design for the main study. Constraints were included to ensure that at least one of the non-price attributes in the alternative plans were improved compared to the status quo. The Modified Federov algorithm was applied to generate 24 choice cards which were blocked into two versions. Two choice cards in each version were randomly selected as practice cards, followed by ten choice cards that were presented to respondents as part of the survey.

Table 1: Summary of the selected attributes and attribute levels

Attribute	Level	Description
Water quality management	Status quo	Water quality continues unmanaged and deteriorates based on current trends
	Intermediate	Visible pollution and bad odour are removed. Lake water is suitable for non-contact activities.
	High	Water quality is improved and managed to levels which support contact activities such as boating
Fisheries management	Status quo	Fin fisheries catch continue unmonitored and without management
	High	Fin fisheries catch are monitored and fish catch is managed within the maximum sustainable yield
Mangroves management	Status quo	Mangrove destruction continues at current rates (leading to complete loss of mangroves by 2027)
	Intermediate	Mangrove area is maintained and managed at the current level (64 hectares)
	High	Previously lost mangrove area is restored and current area is conserved (80 hectares)
Payment	50, 100, 150, 200, 300, 400, 500, 600	One-time payment per household (in INR)

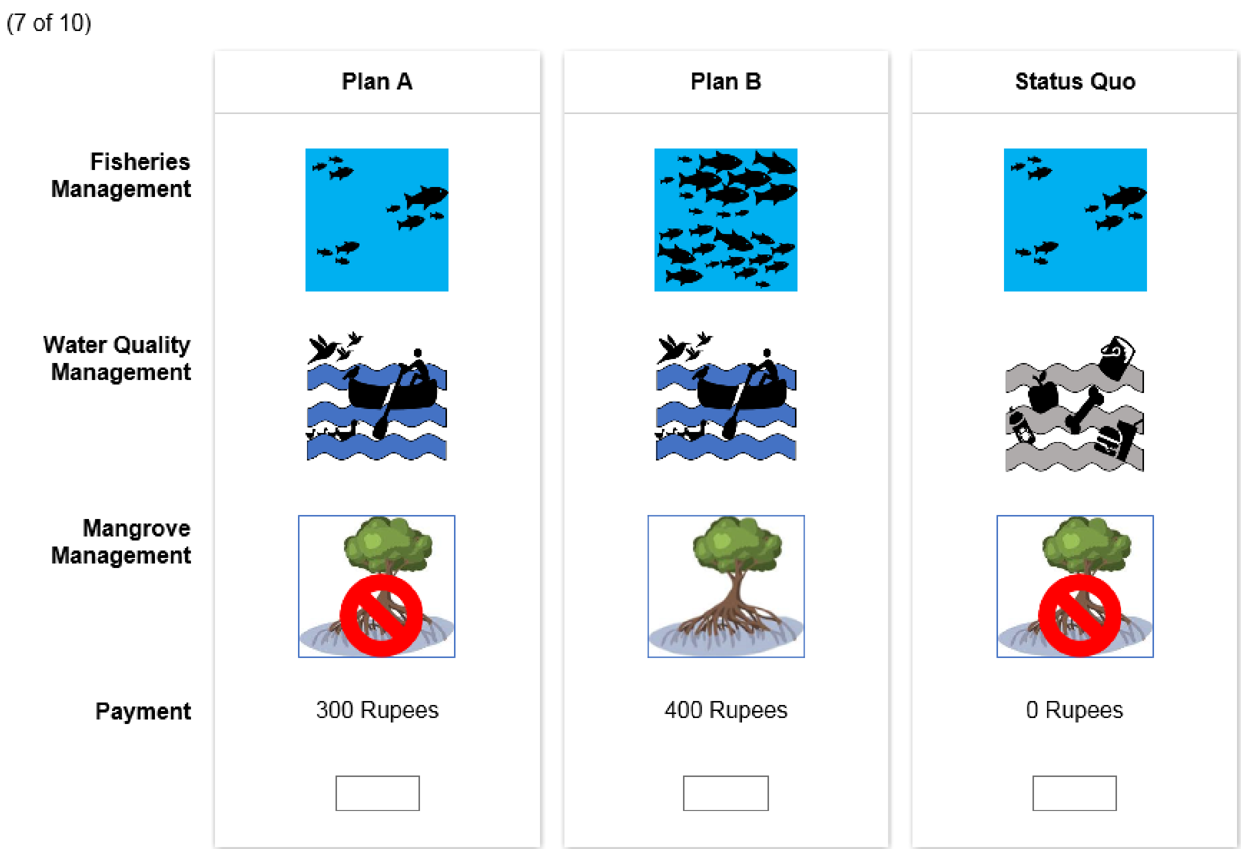

Figure 2 Sample choice card generated for the study

2.4 Questionnaire and sampling

The questionnaire was designed in four sections. The first section offered an introduction and explanation of the ecosystem status quo before presenting socio-demographic questions; the second gathered information on respondents' uses of the lake and gauged their perceptions related to environmental issues using a five-point Likert scale ranging from strongly agree (1) to strongly disagree (5); the third comprised of a warm-up exercise for the choice experiment in the form of two choice cards; the last section was the choice experiment.

Before piloting the first version of the survey, a draft was tested on a focus group in July 2019, consisting of local stakeholders including panchayat residents, social science staff from the University of Kerala, and members of Kerala's Pollution Control Board. Feedback from this session guided amendments to the pilot survey, which was undertaken in August 2019 by one interviewer in the city of Kollam (n = 40)[1]. Guided by the findings of the pilot study, the final survey was design before being carried out by a team of 21 interviewers during October and November of 2019 (n = 450). Sampling across administrative units was proportional to the local population (see appendix S1) and the questionnaire was administered at the household level, whereby respondents from randomly selected households were interviewed directly at their home. Sampling was split between Kollam city (n = 244), the major urban centre located adjacent to Ashtamudi lake, and the other lake-adjacent administrative regions, or panchayats (n = 206)[2], leading to a total of 4500 observations. The sample sizes were deemed sufficient to separately assess each group and identify potential urban-rural divides or issues related to more or less intense uses of the wetland (Hassan et al., 2019).

2.5 Econometric model

The analysis of the data was based on random utility theory. The utility *U* gained from alternative *j* by individual *n* is a linear and additively separable function of the attributes describing the alternative X_{nj} and an error term ε:

$$U_{nj} = X_{nj}\beta + \varepsilon_{nj}$$

[1] In order to guide our decision on the final price levels to include in the choice experiment, we included an open-ended contingent valuation question which asked respondents to state their maximum household willingness to pay for the sustainable management of the Ashtamudi lake. The maximum stated willingness to pay of 600 INR from the 40 respondents of the pilot survey was used as an upper boundary for the price attribute to be used in the final survey.

[2] Due to resource limitations which restricted sampling in all the lake-adjacent regions, four panchayats were selected as representative of all 12. Surveys were carried out in the four panchayats proportionally to the population of each (see appendix S1).

The vector of attributes describing alternative *j* is accompanied by a vector of utility weights β indicating the desirability of the attributes. The probability that individual *n* chooses alternative *i* can then be written as:

$$P_{ni} = P(X_{nj}\beta + \varepsilon_{nj} < X_{ni}\beta + \varepsilon_{ni}) \text{ for all } j \neq i \in J$$

A standard assumption in the literature is that the error terms follow a type I extreme value distribution which leads to the conditional logit (CL) model (McFadden, 1974):

$$P_{ni} = \frac{\exp(X_{ni}\beta)}{\sum_{j=1}^{J} \exp(X_{nj}\beta)}$$

The CL model assumes that individuals are homogeneous, but it is well known that choice behaviour varies across individuals and researchers are increasingly interested in identifying ways to model different sources of heterogeneity. The generalised multinomial logit (G-MNL) model by Fiebig et al. (2010) is one such model which accommodates both taste and scale heterogeneity:

$$P_{ni} = \frac{\exp(X_{ni}\beta_n)}{\sum_{j=1}^{J} \exp(X_{nj}\beta_n)}$$

As indicated by the subscript *n*, the vector of utility weights is individual-specific and defined as:

$$\beta_n = \sigma_n\beta + \gamma\eta_n + (1\text{-}\gamma)\sigma_n\eta_n$$

β_n depends on a vector of mean utility weights β, an individual-specific scale parameter of the random error σ_n, a scalar parameter γ and a random vector η_n. The scale parameter σ_n is inversely related to the variance of the error term while also being confounded with the deterministic component of utility. Estimated utility weights will thus be larger (smaller) for individuals with smaller (larger) error variance. This kind of heterogeneity is referred to as scale heterogeneity because all utility weights are scaled up or down in tandem. Following Fiebig et al. (2010) and Gu et al. (2013), the scale parameter σ_n is assumed to be lognormally distributed with mean $\bar{\sigma}+\theta Z_n$ and standard deviation τ where $\bar{\sigma}$ is a normalising constant, Z_n is a vector of individual-specific characteristics and θ and τ are parameters to be estimated.

The random vector η_n identifies individual-specific deviations from the mean utility weights and is thus a measure of taste heterogeneity. The standard deviation of η_n is independent of scale when $\gamma=1$ and proportional to σ_n when $\gamma=0$. Following Keane and Wasi (2013), γ will be allowed to take any value including $\gamma<0$ and $\gamma>0$ (Gu et al., 2013).

If utility weights are estimated as fixed parameters then the G-MNL model reduces to the so-called scale multinomial logit (S-MNL) model and if the scale parameter is parametrised as $\exp(\theta Z_n)$ then the S-MNL model reduces to the heteroscedastic conditional logit (HCL) model (Hole, 2006). All models were estimated with Stata 14.0.

2.6 Feasibility of restoration scenarios

To gauge the feasibility of attending to the improvements to the lake ecosystem developed in the stakeholder workshops and outlined in the choice experiment, it was important to understand the perceived benefits in terms of the potential costs associated to them. To facilitate this comparison, we collected available costs related to their implementation. For water quality, we assessed the cost in terms of direct costs for the construction of wastewater treatment facilities to meet the two improvements scenarios. For the costs to achieve these improvements we relied on the estimates produced in a management plan published by Wetlands International (WISA and CWRDM, 2017). For mangrove conservation and restoration, we estimated the opportunity cost in terms of the unit net income loss to the shrimp aquaculture industry and the loss of yield associated with the forfeited area under conservation and restoration (given the expected depletion of mangroves by 2027). For fisheries, the shift to a sustainably managed fishery, where fishing is only permitted within the maximum sustainable yield (MSY)[3], we measured the cost as the opportunity cost derived from the reduced fish landing to the local fishing community[4]. Costs for fisheries and aquaculture were calculated over a 5-year time horizon using a 7% discount rate. For benefits, to avoid double counting, we only considered the welfare estimates from the choice experiment, with the understanding that they likely represent a lower boundary of the benefits obtained as a result of the proposed improvements to the lake, given that a range of other direct and indirect benefits which we do not explicitly account for in the choice experiment are expected to be accrued also (e.g., carbon sequestration and habitat services).

[3] The MSY has not been calculated for Ashtamudi lake or any lake in Kerala. Therefore, we estimated this at a conservative 90% of the current catch based on the most available data from the marine fisheries sector in Kerala (advised as the best alternative by the India's Central Marine Fisheries Institute), with estimates of the MSY between 85.1% and 87.9% (Sathianandan and Jayasankar, 2009; Sreekanth et al., 2015).

[4] Although attempts were made to collect cost data for Ashtamudi fisheries, it was not possible to do so accurately because of the scale of the operations and wide range of fishing practices employed. Therefore, the opportunity costs used is in terms of lost revenue, rather than lost net income. Conservatively, this leads to an overestimation of the opportunity costs of wetland restoration.

3. Results

3.1 Ashtamudi lake ecosystem service assessment and stakeholder workshops

Findings from the first workshop highlighted key areas of ecosystem deterioration, including: mangrove conversion to alternative land uses, primarily aquaculture; unregulated overfishing; and concern over deteriorating water quality, especially in terms of a rapid increase of the lake water's salinity and degradation due to insufficiently treated solid and liquid waste flows especially in areas located in proximity of the city of Kollam. The Manrothuruth panchayat, which is located in proximity of the deltaic plain of the Kallada river in the northern part of the lake and is an attractive area for tourists, has been experiencing particularly severe issues with water salinity increase and ground subsidence, the latter probably caused by a combination of eroded shoreline, reduced sediment deposits and sea-level rise (Jha et al., 2016; Thallak et al., 2019). The dialogue from this workshop guided much of the data collection process.

After analysing the field data, findings re-enforced the concern highlighted by participants of the workshop. Figure 3 shows the water quality, in terms of dissolved oxygen, of the Ashtamudi lake, as collected in the framework of the project (Sagar et al., 2020). Much of the lake exhibits oxygen deficiency, especially the zone adjacent to Kollam city which is hypoxic (dissolved oxygen levels between 2-4 mg/L). Zones of the lake which are spared the worst effects of pollution are those furthest from the estuary. The Manrothuruth panchayat is the region which is home to a large portion of Ashtamudi's remaining mangroves (see figure 4 for the spatial location of mangroves and appendix S2 for detailed mangrove data). Mangroves have been subject to conversion over the past decade to aquaculture (Table 3), much of it illegal. While there used to be 80 ha of mangroves in the lake, extrapolating the current rate of conversion to shrimp aquaculture and other land uses suggests that the present 64 ha (Figure 4) of area would be lost by 2027 without policy intervention. With the possible exception of mangroves in the bar mount, due to the limited accessibility (Figure 4), all the remaining mangroves are exposed to the risk of being lost due to conversion to aquaculture. Finally, inland fisheries landing data and revenue is presented in Table 2. Data was collected from the lake's fish landing centres whose location is disclosed in Figure 4.

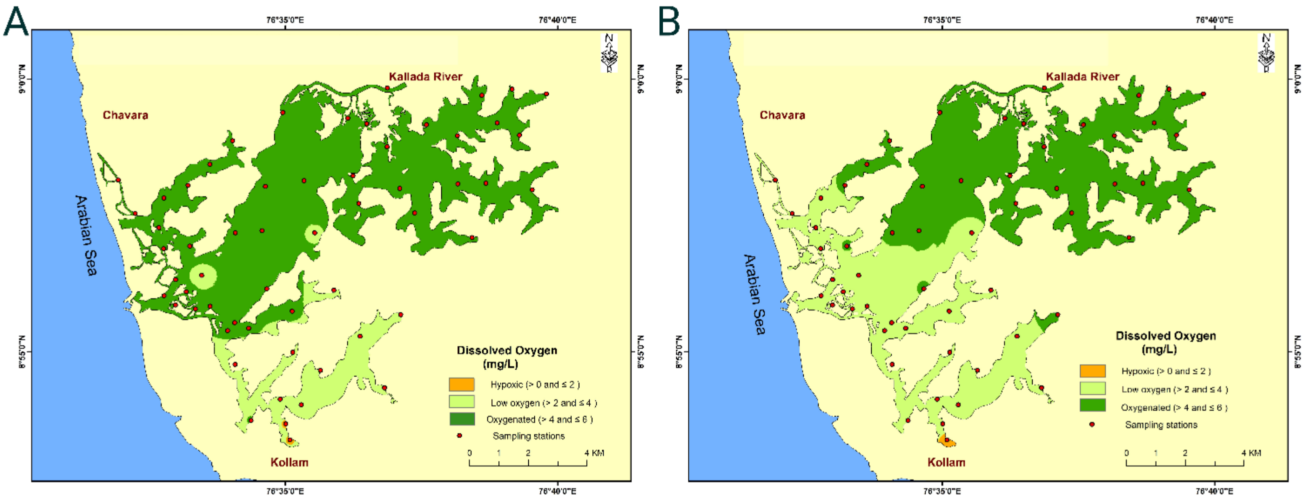

Figure 3: A, Dissolved oxygen in the Ashtamudi lake during monsoon season (A) and non-monsoon season (B) (source: Sagar et al., 2020)

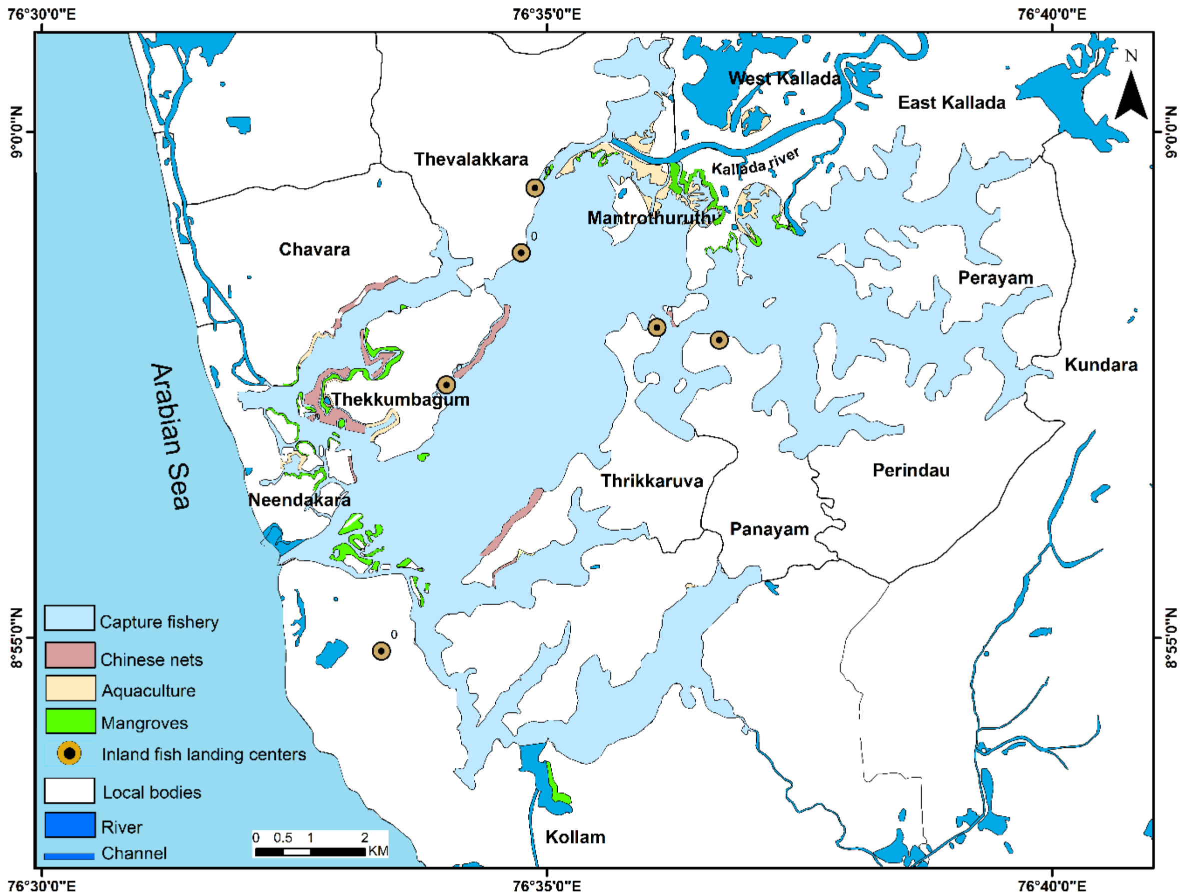

Figure 4: Distribution of mangroves and fisheries-related activities in the Ashtamudi lake. Source: field data collected Field data collected in 2017-19.

Table 2: Ashtamudi lake fisheries landing data 2018

Species	Landing (tonne)	Price per tonne	Revenue
Prawn	1,080	550,000	594,000,000
Etroplus	936	720,000	673,920,000
Murrels	768	94,000	72,192,000
Mullets	984	350,000	344,400,000
Cat fish	1,116	200,000	223,200,000
Tilapia	1,584	120,000	190,080,000
Barbus	2	500,000	1,000,000
Crabs	240	400,000	96,000,000
Common Carps	24	75,000	1,800,000
Catla	24	450,000	10,800,000
Chamos	8	75,000	600,000
Eels	4	200,000	800,000
Labeo Rohita	36	180,000	6,480,000
Edible Oyster	368	200,000	73,600,000
Total	7,640		2,288,872,000

Notes: data was sampled monthly from six fish landing centres; Source, prices and revenues are in INR; Source: Field data collected in 2018.

Table 3: Shrimp aquaculture net income 2018

			Net income	
Region	Revenue	Cost	Total	per ha
Neendakara	12,849,534	7,516,017	5,333,517	607,171
Chavara	2,294,981	1,371,851	923,130	588,395
Thekkumbagam	3,598,813	2,236,569	1,362,244	553,708
Thevalakara	2,064,893	1,271,308	793,585	562,187
Westkallada	1,188,515	913,780	274,735	391,490
Manrothuruth	177,060,277	138,672,000	38,388,277	367,188
Eastkallada	1,017,751	877,488	140,263	233,406
Perayam	0	0	0	0
Kundara	0	0	0	0
Perinadu	0	0	0	0
Panayam	67,730	55,000	12,730	870,850
Thrikkaruva	416,318	367,000	49,318	179,826
Kollam	16,701,700	9,810,000	6,891,700	626,379
Total	217,260,513	163,091,013	54,169,500	412,357

Notes: Source = field data, 2017-19.

3.2 Sample descriptive statistics and respondents' perceptions and attitudes

Sixty six percent of the respondents were female, though this number was higher for the Kollam sample (73%) than non-Kollam (57%). The higher level of female respondents is likely because male family members are more often engaged in employment in the region. The Kollam sample is more educated, higher paid, less employed in fisheries and more in government services. The respondents report substantial differences between Kollam and non-Kollam subgroups insofar as the dependence of their household's livelihood on the lake (figure 5B). The fraction of non-Kollam respondents who affirm to be very dependent is substantially larger (19% compared to 2% in Kollam), while 48% of Kollam respondents declare not to be dependent at all from the lake compared to 38% in non-Kollam. This suggest a higher direct dependence from those living in the lake surrounding areas and perhaps more indirect benefits on the lake's services on the part of city dwellers. Results showed that 90% of respondents were not satisfied with the current water quality of the lake. Of the two groups, the lake-dwelling regions have a higher portion of respondents who felt very strongly about conservation of the lake (19% compared to 2% in Kollam), which was especially true in Thekkumbam and Munrothuruth (41% and 25% respectively), however, 94% of Kollam residents and 93% of non-Kollam residents agreed that conservation of the lake was important to them. Regarding the local government's action on the conservation of wetlands in the region (Figure 5A), the responses were polarised, with 28% responding negatively to the action and 30% responding positively. Lake-dwelling respondents were more negative and Kollam respondents were more positive on this matter (see appendix S4). Related to mangroves conservation and the development of aquaculture, results highlighted the conflict in competing land uses, with 87% of respondents believing shrimp aquaculture in Ashtamudi lake to be an important source of income for the economy, yet 55% of respondents being dissatisfied about the conversion of mangroves to aquaculture.

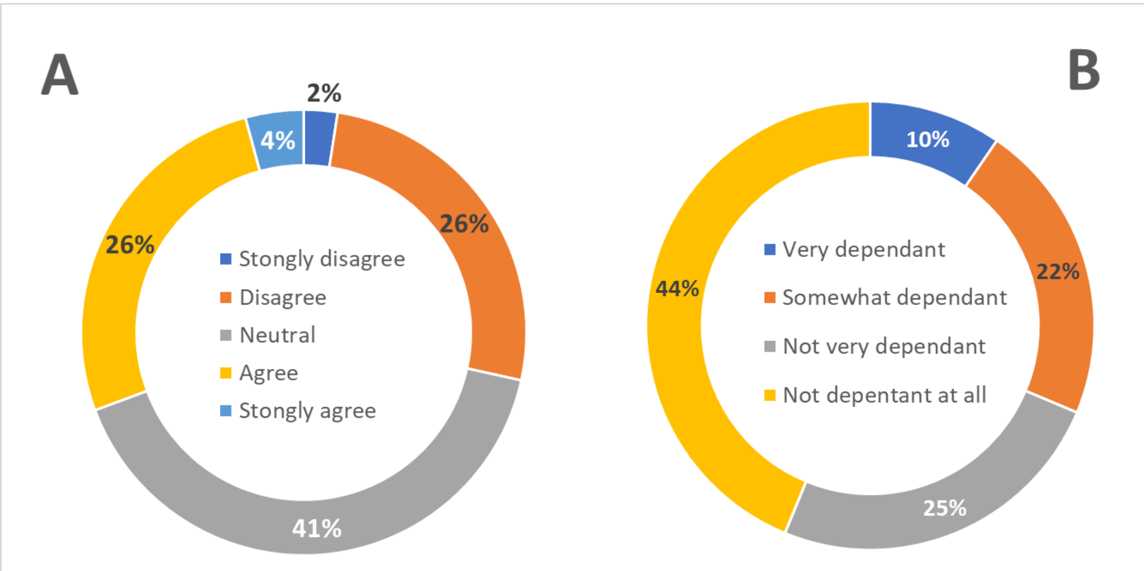

Figure 5: responses to survey questions for the full sample of respondents

Notes: 5A, "Government-funded projects for the conservation and management of lakes, reservoirs and rivers are currently executed in a good manner in Kerala"; 5B, "How dependent is your household's livelihood/income on the Ashtamudi lake?".

3.3 Utility estimates and willingness to pay for wetland restoration

Four choice models are estimated (see Section 2.5) and the results are presented in Table 4. As expected, the utility parameters for the conservation attributes in all models are significant and positive with coefficient magnitude increasing for higher levels of conservation for each attribute. The payment parameter is negative, as expected, but only significant at the 10% level meaning WTP estimates should be interpreted with caution (as indicated by the wide confidence intervals in Tables 6 and 7).

The alternative-specific constant (ASC) for the status quo is negative and significant indicating that respondents are dissatisfied with the status quo and generally prefer an improved scenario. The ASC captures unobserved aspects of the status quo that are not captured by the experimental attributes.

In the HCL model, the scale term is normalised to 1 for male respondents who went to primary school or are illiterate[5], earn an average income, and reside in non-Kollam regions. The scale term for secondary education is insignificant indicating that there is no difference in error variance (choice consistency) between illiterate respondents / respondents with primary education and respondents with secondary education. The scale term for degree or above is positive and significant indicating that this subgroup has a lower error variance, as would be expected. None of the other scale terms are significant and only the education variables are thus included in the S-MNL and the G-MNL models where a statistically significant τ confirms the presence of scale heterogeneity.

All but one of the estimated standard deviations in the G-MNL model are significant indicating preference heterogeneity in the data and γ=0.2386 indicates that the variance of preference heterogeneity to a large extent varies with scale.

Table 4: Choice model results

	CL		HCL		S-MNL		G-MNL	
Water Quality Management								
Intermediate	0.9012	***	0.8411	***	1.7033	***	2.1719	***
	(0.0637)		(0.0812)		(0.4481)		(0.4650)	
High	1.1113	***	1.0444	***	2.6932	***	3.4862	***
	(0.0614)		(0.0878)		(0.7191)		(0.7371)	
Fisheries Management								
High	0.4402	***	0.4105	***	1.0566	***	1.1452	***
	(0.0424)		(0.0481)		(0.3223)		(0.2861)	
Mangrove Management								

[5] Only 1% of the sample are illiterate so this subgroup is merged with the subgroup who went to primary school.

Intermediate	0.7971	***	0.7478	***	1.5404	***	1.7330	***
	(0.0556)		(0.0707)		(0.4108)		(0.3837)	
High	1.1944	***	1.1156	***	3.0159	***	3.1055	***
	(0.0658)		(0.0954)		(0.8547)		(0.6774)	
Payment	-0.0003	*	-0.0003	*	-0.0008	*	0.0003	
	(0.0002)		(0.0002)		(0.0004)		(0.0003)	
ASC SQ	-0.9948	***	-0.9120	***	-1.2562	***	-3.1344	***
	(0.0926)		(0.1056)		(0.0938)		(0.3586)	
Scale (θ)								
Female			-0.0104					
			(0.0499)					
Higher Secondary			0.0310		-0.0667		-0.0894	
			(0.0553)		(0.1449)		(0.2195)	
Degree or above			0.2400	***	0.4959	***	0.5136	**
			(0.0619)		(0.1467)		(0.2117)	
Income below average			0.0231					
			(0.0567)					
Income above average			-0.0946					
			(0.0720)					
Kollam			0.0172					
			(0.0499)					
Standard Deviations								
Water Quality Management								
Intermediate							0.9870	***
							(0.2444)	
High							0.6882	***
							(0.2158)	
Fisheries Management								
High							0.9697	***
							(0.2052)	
Mangrove Management								
Intermediate							0.3919	
							(0.3172)	
High							1.4344	***
							(0.3712)	
ASC SQ							2.7316	***
							(0.2992)	
τ					1.5808	***	1.6498	***
					(0.2403)		(0.1761)	
γ							0.2386	**
							(0.1131)	
Observations	4500		4500		4500		4500	
LL	-3257		-3248		-3228		-2912	

Notes: Standard errors in parentheses; * p<0.10; ** p<0.05; *** p<0.01; CL = conditional logit, HCL = heteroscedastic conditional logit, S-MNL = scale multinomial logit, G-MNL = generalised multinomial logit.

Location-specific estimates are presented in Table 5. To avoid potential issues with overfitting, we rely on S-MNL estimates and present also basic CL estimates for comparison. Consistent with the findings for the whole sample (Table 4), both Kollam and non-Kollam return utility parameters for the conservation attributes which are positive and significant. Coefficient magnitude is also increasing for higher levels of conservation for each attribute across both groups indicating higher utility for higher levels of conservation. As with the results shown in Table 4, the ASC for the status quo is negative and significant indicating that both groups are dissatisfied with the status quo. Differentiating between Kollam and non-Kollam, it appears that respondents in Kollam have ignored the price attribute in their choices, as emerges from the positive payment parameter for this group. This will be further explored in the discussion.

Consistent with utility maximisation and demand theory (Bateman et al., 2003), the CE can obtain measures of welfare, in terms of a marginal WTP. Household WTP for the environmental improvements to the lake is shown in Table 6. Overall, WTP ranges from 1329 to 3764 INR with water quality improvements and mangrove conservation showing higher WTP than a policy of sustainably managed fishing, likely due to the perceived loss in fishing benefits from enforcing a reduced catch. Mangrove protection has a higher WTP at both levels than water quality management. For regions other than Kollam, WTP ranges between 337 and 1058 INR. Because of the counter intuitive results of the respondents in Kollam insofar as price is concerned, we cannot generate meaningful measures of WTP for this sub-group. This implies that the WTP values elicited for the entire sample are likely overestimated due to results of the Kollam sub-group and therefore should be treated with caution.

Table 5: Location-specific choice model results

	CL		S-MNL	
Water Quality Management				
Intermediate (Kollam)	0.8682	***	1.7744	***
	(0.0894)		(0.2847)	
Intermediate (non-Kollam[a])	0.9437	***	1.0550	***
	(0.0919)		(0.1612)	
High (Kollam)	1.2359	***	3.0992	***
	(0.0874)		(0.4465)	
High (non-Kollam)	0.9946	***	1.6134	***
	(0.0876)		(0.2410)	
Fisheries Management				
High (Kollam)	0.4877	***	0.7893	***
	(0.0602)		(0.1448)	
High (non-Kollam)	0.3992	***	0.5999	***
	(0.0603)		(0.1181)	
Mangrove Management				

Intermediate (Kollam)	0.9251	***	1.5498	***
	(0.0778)		(0.2040)	
Intermediate (non-Kollam)	0.6740	***	0.7402	***
	(0.0808)		(0.1253)	
High (Kollam)	1.1724	***	2.5389	***
	(0.0922)		(0.3340)	
High (non-Kollam)	1.2523	***	1.7089	***
	(0.0955)		(0.2706)	
Payment (Kollam)	0.0005	**	0.0010	**
	(0.0002)		(0.0004)	
Payment (non-Kollam)	-0.0012	***	-0.0001	
	(0.0002)		(0.0003)	
ASC SQ (Kollam)	-0.4707	***	-1.7577	***
	(0.1224)		(0.1401)	
ASC SQ (non-Kollam)	-1.6205	***	-0.6821	***
	(0.1478)		(0.1193)	
T			1.3142	***
			(0.1104)	
Observations	4500		4500	
LL	-3217		-3051	

Notes: Standard errors in parentheses; * p<0.10; ** p<0.05; *** p<0.01;
[a] Represented by Munrothuruth, Neendakara, Perinad and Thekkumbagam

Table 6: Willingness to pay for wetland restoration (INR per household)

	Non-Kollam[a]	Full Sample
Water Quality Management		
Intermediate	337	2126
	[192,482]	[503,3749]
High	797	3362
	[511,1084]	[595,6128]
Mangrove Management		
Intermediate	569	1923
	[328,811]	[318,3527]
High	1058	3764
	[684,1432]	[662,6866]
Fisheries Management		
High	840	1319
	[556,1124]	[224,2414]

Notes: 95% confidence interval in square brackets; WTP estimates for the full sample are based on the S-MNL model show in table 4; WTP estimates for the location-specific subsamples are based on the CL model from table 5; [a] Represented by Munrothuruth, Neendakara, Perinad and Thekkumbagam.

3.4 Feasibility of wetland restoration scenarios

One strength of the CE technique is that coefficient results can be used to estimate the compensating surplus for improved wetlands management scenarios over the present situation (status quo). In order to estimate the respondents' WTP for potential restoration, three restoration strategies were proposed which represent modest, moderate and ambitious policy interventions (Table 7). As expected, benefits increase as we move from the status quo through scenarios of ecological improvement. The mean WTP for the modest scenario is 5910 INR per household, while for the moderate and ambitious scenarios the WTP estimates are 7140 INR and 8503 INR, respectively. The WTP for the non-Kollam group are 1400, 1898 and 2236 INR for the three restoration plans. Using the estimated costs of improving the different attributes, we can compare aggregate benefits to design more efficient wetland management policies (Birol et al., 2006; Pattison et al., 2011). Table 8 compares aggregated costs and benefits. In order to avoid potential double counting, benefits in Table 8 only reflect the locals' WTP for restoration as elicited in the choice experiment and therefore are assumed to act as a lower boundary. This likely underestimates additional benefits of environmental improvement (such as for instance mangrove carbon sequestration and protection of endangered species), which the respondents were not reminded of in the questionnaire, as well as benefits accrued to non-locals (e.g., from tourism activities). Cost data are also incomplete which limit a comprehensive cost benefit analysis; however, results for the full sample indicate feasibility for modest and moderate scenarios. The aggregate WTP as a one-time contribution for modest restoration is 1.2 billion INR, while moderate and ambitious scenarios are 1.5 billion INR and 1.8 billion INR, respectively. Results should be considered in the context of the wide confidence intervals which are a result of the unexpected findings from the Kollam sub-group. Taking the non-Kollam group only as a conservative lower boundary of the benefits, moderate and ambitious scenarios would potentially be rendered infeasible, however, the costs of the modest scenario are comparable with the benefits (B/C ratio = 0.98) and fall well within the confidence interval of benefits.

Table 7: estimated willingness to pay for Ashtamudi restoration scenarios per household

Restoration scenario	Description	WTP	
		Full sample	Non-Kollam
Modest	Water quality is improved to intermediate level, and mangroves conserved to intermediate level	5910 [225,11594]	1410 [921,1899]
Moderate	Water quality is improved to intermediate level, and mangroves restored to high level	7140 [348,13932]	1898 [1266,2530]
Ambitious	Water quality is improved to high level, and mangroves restored to high level and fisheries are sustainably managed	8503 [406,16600]	2236 [1486,2985]

Notes: 95% confidence interval in square brackets; WTP estimates are based on the CL models in tables 4 and 5; values are in INR.

Table 8: Comparison of aggregated benefits from choice experiments and cost estimates for implementation of proposed restoration scenarios

Restoration scenario	Cost	Benefit[a]	
		Full sample	Non-Kollam
Modest	0.304	1.245	0.297
		[0.047,2.442]	[0.194,0.400]
Moderate	1.008	1.504	0.400
		[0.073,2.934]	[0.267,0.533]
Ambitious	2.012	1.791	0.471
		[0.086,3.496]	[0.313,0.629]

Notes: [a] value in billion INR; 95% confidence interval in square brackets; WTP estimates aggregations of data in table 7 (see appendix S1 for household data used in the aggregation); Fisheries and aquaculture opportunity costs are estimated using a 5-year time horizon and a 7% discount rate; see appendix S5 for further details on cost-benefit data.

4. Discussion and Conclusion

Kerala has an abundance of wetland ecosystems which have traditionally played a central role in its society and economy. The anthropogenic changes witnessed in the last decades have applied pressure on these ecosystems, with the consequence that the provision of their environmental services can no longer be taken for granted for future generations. Despite wetlands being legally protected in the state, a lack of enforcement and effective environmental management practices have resulted in severe deterioration for wetlands such as the Ashtamudi lake Ramsar site. Characterizing the environmental situation of the Ashtamudi lake and providing a quantitative evaluation of ES and public preferences for environmental improvements can spark a better-informed and participated discussion regarding the future of the lake, and translate into more efficient environmental policy. This study is the first to value wetland ES and explore the costs and benefits of restoration options including non-market values in Kerala. It is the outcome of a comprehensive, multi-year primary data collection and stakeholder engagement, which set the foundations on which the CE and analyses of costs and benefits of various restoration scenarios are built. We believe that the process and analyses performed can act as a useful benchmark for future analyses in other wetlands in the state.

The importance and urgency of improved management of the Ashtamudi wetland were generally shared by the stakeholders, as emerges both from the workshops and the stated preference valuation. The feedback from the stakeholder workshops highlighted a series of concerns for the current trends experienced in the lake, particularly regarding the rapid deterioration of water quality in recent years, both due to salinity increase and waste discharges, the loss of mangrove ecosystems, and the general overexploitation of the wetlands productive and assimilative capacity. During the workshops, hotspots for specific issues were identified (e.g., Munroe island for ground subsidence, Kollam city for water quality). The results of the CE confirmed that such concerns are not limited to the participants in the workshops, but rather widely felt across the local population. Almost the entire sample of respondents (93%) agreed about the importance of conservation of the lake, and residents of lake adjacent regions felt stronger than those of the nearby Kollam city. All three restoration scenarios delivered high levels of utility for respondents. In particular, the positive sign on the ASC coefficient implies that a perceived improvement in quality to the wetland, compared with the status quo, has a positive impact on the respondent's utility, holding all other variables constant. Such finding is observed also in other studies on wetland restoration, including in Canada (Dias and Belcher, 2015), Vietnam (Do and Bennett, 2009) and Greece (Birol et al., 2006). In terms of the individual attributes, the conservation and restoration of mangroves returned the highest levels of utility, followed by improvements in water quality. Sustainably managed fisheries are also important but delivered less utility perhaps given the large number of people dependent on the fishing industry and the expected restrictions on catch if this policy was realised (Feyisa and Bersisa, 2019).

Insofar as the econometric estimation is concerned, the study offers mixed results. Although the signs, magnitude and statistical significance of the coefficient of the full sample regressions are largely as expected based on theoretical considerations, closer inspection of sub-groups of respondents reveals that while the sub-group represented by non-Kollam regions exhibits negative marginal utility for price, Kollam residents have a positive marginal utility for price, i.e., the more a Kollam resident is asked to pay for improving attribute the more he/she is likely to choose this option. This counterintuitive result is presumably responsible for the inflation of the WTP estimates derived from the full sample, which are 1.5 to 6 times larger than those estimated for the sub-group 'non-Kollam' and outside of the range of price levels given to the respondents. Although this finding is not consistent with the notion that urban dwellers generally show stronger support for nature conservation (Bandara and Tisdell, 2003; Badola et al., 2012; Datta et al., 2012; Mbaiwa and Stronza, 2011), despite having less use of the environmental asset (Bandara and Tisdell, 2003), it has been observed in other studies (Kragt and Bennet, 2011; Hassan et al., 2019). As for the reasons, one could hypothesise that urban respondents believe the payment is for a good cause (i.e., charitable giving, warm glow effect, or a Veblen good), or that hypothetical bias is at play (i.e., they see the payment as something purely hypothetical). Kollam residents could also have simply ignored price (attribute non-attendance), possibly because the upper price boundary was not set high enough for some respondents of this group, in view of their higher than average earnings, and despite the fact that the price levels were chosen based on the pilot study which was undertaken within Kollam city. At any rate, such findings suggest that one should treat WTP estimates for the full sample with considerable caution.

For the evaluation of the feasibility of restoration scenarios, rather than looking at the full range of short- and long-term environmental costs and benefits of interventions (or inaction), in this study we adopt the perspective of a short-sighted decision-maker, who only considers the immediate investment costs (for water quality improvement) and short-term opportunity costs of restoration in the form of lost returns from mangrove development and overfishing. In other words, rather than pursuing a theoretically comprehensive environmental cost-benefit analysis, whose results could be met with suspicion or indifference by the policy-maker, our aim is to make a pragmatic argument for the immediate viability of restoration interventions, at least at a modest level. Such conclusion is supported by the economic analysis, whereby the aggregated WTP by the local residents for the modest restoration scenario is comparable, even if slightly lower (B/C ratio = 0.98), than the present value of the costs over a five-year time horizon. Such result should be evaluated in the context of (1) the relatively ample extension of the 95% confidence interval around the WTP estimate (see Table 8), (2) the substantially higher aggregated WTP estimates obtained for the whole sample (B/C = 4.09), albeit with the aforementioned limitations, and (3) the exclusion from the analysis of a range of habitat, regulating and cultural services that were not explicitly included in the analysis partly so that the choice exercise could be more easily understood on the part of the respondents and partly because their valuation in monetary terms can be met with distrust on the part of the policy-makers.

The restoration of various coastal wetland attributes for the proposed modest, moderate and ambitious improvement scenarios, generated lower-boundary compensating surpluses ranging between 1410 and 2236 INR, which correspond to, respectively, $71 and $112 (international dollars, 2018) using the most recent PPP conversion factors for private consumption from the World Development Indicators (World Bank, 2020). While there are no studies from Kerala with which to compare, the WTP for water quality improvements is in the range of other recent and similar studies (Dias and Belcher, 2015; Tan et al., 2018). Dias and Belcher (2015), for instance, found a value of $91 (international dollars, 2018) as a one-time payment per household for water quality improvement in Canadian prairie wetlands. Comparing the benefits of the overall improvement scenarios, the benefits found here are comparable to those found in other studies (Dias and Belcher, 2015; Chen and Chen, 2019. Dias and Belcher (2015) found a shift to the most ambitious restoration scenario (which included improvements in water quality, increases in wetland area and increases in wildlife) found a value of $117 (international dollars, 2018) per household, which is comparable to what found in this study for the ambitious restoration intervention. For context, the WTP for this ambitious restoration as a one-time payment per household is comparable to the value of the average weekly wage in Kerala in 2019.

Given the complex and integrated nature of wetlands, their management requires a holistic approach. Projects to restore deteriorating wetlands have been launched in the USA, Europe, China and several other countries (Che et al., 2012; Clarke and Dalrymple, 2003; Pedroli et al., 2002) and CE have been widely used to inform the policy to support such restoration (Hanley and Czajkowski, 2019). In the context of developing regions, however, implementing sustainable environmental management policies is often challenged by lack of regulation or enforcement (Vélez et al., 2018). A strong institutional framework with the capacity to adequately implement and monitor changes may play a critical role in driving a successful restoration project (Vélez et al., 2018). Consistently with this observation, a recurring recommendation emerging from the stakeholder workshops regards the potential benefits from establishing a central Ashtamudi lake wetland authority, i.e., an institution which by centralizing the responsibilities and decision-making process which are now distributed among the 13 panchayats and the Kollam municipal corporation, can promote a more holistic approach in wetland development and conservation, in collaboration with the local stakeholders.

Following the models of river basin authorities as they exist in other countries, such organization would be better positioned to deal with the trade-offs inherent in development and conservation decisions. In the case of Ashtamudi lake, trade-offs exist, for instance, between mangrove conservation and the development of shrimp aquaculture, and water quality / fisheries and development in the surrounding settlements. Mangroves are limited to a few areas around the lake, however, residents of both sub-groups in our CE displayed positive utility for their conservation, suggesting that their importance does not decline with distance from the mangrove, which has been found before (Otieno, 2015). Past mangrove research has shown that an integrated approach, with development and conservation in mind, can be optimal (Barbier et al., 2008), however this may not be relevant in the case of Ashtamudi given the limited mangrove area. The current situation, essentially subsidises shrimp farmers in their operation by using the lake ecosystem to generate profit without internalizing the cost of environmental damage represented in the loss of mangroves services or in the deteriorating the waterbody through their practices.

Decision-makers and researchers interested in the present study should be aware of some limitations of the work. Some are limitations that are inherent in the chosen methodology. Firstly, in partitioning attributes, which represent complex and interconnected process and functions (Barbier et al., 2011) into definite categories, a CE necessitates reducing complexity and defining variable so respondent can easily comprehend them. Secondly, the number of attributes that can be included is limited. In the present case, this implies that other services such as support of tourism, flood control, storm protection, provision of habitats for (endangered) species, and support of biodiversity, which are also present in the Ashtamudi lake, were not explicitly included. Finally, due to limitations in the available data, including knowledge of the ecological processes occurring in the lake (e.g., lack of estimates of the MSY for fisheries), the range of restoration benefits had to be limited to a subset of the whole range of ecosystem services provided by a healthy wetland ecosystem, thus preventing the implementation of a proper environmental cost-benefit analysis.

In conclusion, by applying a combination of stakeholder consultation, field data collection, and stated preference valuation with the CE approach, the present study sheds some light on the complexities involved in the management and restoration of a tropical coastal wetland of international importance in the south of India. The insights provided in this research can help inform local policy and sustainable management of such natural resource. While the quantitative results are peculiar to the case-study under investigation, we believe that the methodological approach and the effort to acknowledge and account for the true value of the preservation of natural wetland ecosystems have wider applicability, especially in the context of developing countries, and may provide a useful benchmark for future valuation and restoration projects in the region.

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Supplementary material

Appendix S1. Survey sampling procedure

Table 1: number of households in 2018

Region	Households	Population
Neendakara	4087	15424
Chavara	10596	42655
Thekkumbagam	4388	16937
Thevalakara	10473	42977
Westkallada	4655	18176
Manrothuruth	2505	9000
Eastkallada	5505	21181
Perayam	5539	23752
Kundara	3750	14651
Perinadu	8448	35173
Panayam	6686	26895
Thrikkaruva	6307	25432
Kollam	137683	367107
Total	210622	659360

Appendix S2. Provision of mangroves in Ashtamudi lake

Table 1: area of mangroves in Ashtamudi lake (ha)

Region	A	B	C	D	E	F	G	H	I	J	K	Total
Neendakara	1.0	0.0	0.4	0.7	4.0	0.2	0.0	0.0	0.0	0.0	0.0	6.3
Chavara	0.0	0.0	1.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.1
Thekkumbagam	0.0	0.0	6.0	0.0	1.0	0.2	0.0	0.0	0.4	0.0	0.0	7.6
Thevalakara	0.0	0.0	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	0.2
West-Kallada	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Manro thuruth	2.0	8.2	5.4	4.2	2.0	2.0	0.0	0.0	0.2	0.0	0.0	24.0
Kollam	4.0	10.0	0.8	0.5	3.8	4.0	0.0	0.8	0.4	0.2	0.2	24.7
Total	7.0	18.2	13.6	5.5	11.0	6.5	0.0	0.8	1.0	0.2	0.2	64.0

Notes: A = *R. mucronata*, B = *R. apiculata*, C = *A. ilicifolius*, D = *A. aureum*, E = *A. marina*, F = *A. officinalis*, G = *B. sexangula*, H = *B. gymnorrhiza*, I = *E. agallocha*, J = *S. alba*, K = *S. caseolaris*; Source: Kerala Forest department, Department of Statistics & Economics-Kollam, ENVIS Centre, Kerala State Biodiversity board, CUSAT_Kochi, NCESS, Thiruvananthapuram, Kerala State Remote sensing Board, Thiruvananthapuram

Appendix S3. Shrimp aquaculture data for Ashtamudi lake

Table 1: Shrimp aquaculture revenue 2017

Region	Area (ha)	Yield (ton)	Revenue (INR/year)
Neendakara	8.74	23.60	12,034,759
Chavara	1.56	4.20	2,143,709
Thekkumbagam	2.38	6.42	3,276,653
Thevalakara	1.29	3.48	1,777,168
Westkallada	0.67	1.91	1,071,192
Manrothuruth	102.25	290.38	162,615,246
Eastkallada	0.58	1.64	917,248
Perayam	0.00	0.00	0
Kundara	0.00	0.00	0
Perinadu	0.00	0.00	0
Panayam	0.01	0.09	47,223
Thrikkaruva	0.25	0.69	363,130
Kollam	10.70	29.33	15,544,326
Total	128.43	361.75	199,790,656

Notes: Source = field data, 2017-19

Table 2: Shrimp aquaculture revenue 2018

Region	Area (ha)	Yield (ton)	Revenue (INR)
Neendakara	8.78	24.24	12,849,534
Chavara	1.57	4.33	2,294,981
Thekkumbagam	2.46	6.79	3,598,813
Thevalakara	1.41	3.90	2,064,893
Westkallada	0.70	1.97	1,188,515
Manrothuruth	104.55	298.56	177,060,277
Eastkallada	0.60	1.68	1,017,751
Perayam	0.00	0.00	0
Kundara	0.00	0.00	0
Perinadu	0.00	0.00	0
Panayam	0.01	0.12	67,730
Thrikkaruva	0.27	0.76	416,318
Kollam	11.00	30.37	16,701,700
Total	131.37	372.72	217,260,513

Notes: Source = field data, 2017-19

Table 3: Shrimp aquaculture costs 2018

Name of local body	Maintenance charges	Shrimp seed charges	Shrimp feed charges	Labour charges	Other charges	Total
Neendakara	349,594	489,431	436,992	5,040,000	1,200,000	7,516,017
Chavara	31,136	21,795	38,920	1,080,000	200,000	1,371,851
Thekkumbagam	59,489	35,693	71,387	1,620,000	450,000	2,236,569
Thevalakara	32,265	23,231	25,812	990,000	200,000	1,271,308
Westkallada	20,206	10,103	13,471	720,000	150,000	913,780
Manrothuruth	35,140,000	10,632,000	7,280,000	76,320,000	9,300,000	138,672,000
Eastkallada	17,302	8,651	11,535	720,000	120,000	877,488
Perayam	0	0	0	0	0	0
Kundara	0	0	0	0	0	0
Perinadu	0	0	0	0	0	0
Panayam	20,000	5,000	10,000	15,000	5,000	55,000
Thrikkaruva	60,000	30,000	25,000	192,000	60,000	367,000
Kollam	3,300,000	550,000	440,000	4,320,000	1,200,000	9,810,000
Total	39,029,992	11,805,905	8,353,116	91,017,000	12,885,000	163,091,013

Notes: Source = field data, 2017-19

Appendix S4. Summary statistics by location

	Kollam	Non-Kollam[a]	Full sample
Observations	244	206	450
Gender (% female)	0.73	0.57	0.66
	(0.45)	(0.50)	(0.48)
Education			
Illiterate	0.00	0.02	0.01
	(0.06)	(0.14)	(0.10)
Primary	0.38	0.50	0.43
	(0.49)	(0.50)	(0.50)
Higher Secondary	0.26	0.35	0.30
	(0.44)	(0.48)	(0.46)
Degree and above	0.36	0.14	0.26
	(0.48)	(0.34)	(0.44)
Occupation of head of the household			
Fisherman	0.04	0.19	0.11
	(0.19)	(0.39)	(0.31)
Agriculture	0.02	0.03	0.02
	(0.13)	(0.17)	(0.15)
Government services	0.26	0.09	0.18

	(0.44)	(0.29)	(0.39)
Private sector	0.16	0.19	0.18
	(0.37)	(0.40)	(0.38)
Self employed	0.29	0.30	0.30
	(0.46)	(0.46)	(0.46)
Unemployed	0.16	0.17	0.16
	(0.36)	(0.37)	(0.37)
Other	0.08	0.03	0.06
	(0.27)	(0.17)	(0.23)
Household income			
Much above average	0.05	0.03	0.04
	(0.21)	(0.18)	(0.20)
Slightly above average	0.17	0.09	0.13
	(0.37)	(0.29)	(0.34)
About average	0.26	0.25	0.26
	(0.44)	(0.44)	(0.44)
Slightly below average	0.27	0.30	0.28
	(0.44)	(0.46)	(0.45)
Much below average	0.26	0.32	0.29
	(0.44)	(0.47)	(0.45)
How dependent is your household's livelihood on Ashtamudi Lake?			
Very dependent	0.02	0.19	0.10
	(0.13)	(0.39)	(0.29)
Somewhat dependent	0.27	0.16	0.22
	(0.45)	(0.36)	(0.41)
Not very dependent	0.23	0.27	0.25
	(0.42)	(0.45)	(0.43)
Not dependent at all	0.48	0.38	0.44
	(0.50)	(0.49)	(0.50)
"Environmental issues are important to me"			
Strongly disagree	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)
Disagree	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)
Neutral	0.05	0.11	0.08
	(0.23)	(0.31)	(0.27)
Agree	0.94	0.71	0.83
	(0.24)	(0.46)	(0.37)
Strongly agree	0.01	0.18	0.09
	(0.09)	(0.39)	(0.28)
"The conservation of Ashtamudi Lake is an important issue for me"			
Strongly disagree	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)
Disagree	0.00	0.00	0.00
	(0.00)	(0.00)	(0.00)
Neutral	0.07	0.07	0.07
	(0.25)	(0.26)	(0.25)
Agree	0.92	0.73	0.83

	(0.27)	(0.44)	(0.37)
Strongly agree	0.02	0.19	0.10
	(0.13)	(0.40)	(0.30)
"Government-funded projects for the conservation and management of lakes, reservoirs and rivers are currently executed in a good manner in Kerala"			
Strongly disagree	0.01	0.04	0.02
	(0.09)	(0.20)	(0.15)
Disagree	0.23	0.29	0.26
	(0.42)	(0.46)	(0.44)
Neutral	0.45	0.36	0.41
	(0.50)	(0.48)	(0.49)
Agree	0.30	0.22	0.26
	(0.46)	(0.41)	(0.44)
Strongly agree	0.01	0.08	0.04
	(0.09)	(0.28)	(0.20)

Notes: Standard deviations in parentheses; [a] Represented by Munrothuruth, Neendakara, Perinad and Thekkumbagam (see appendices S1 and S2)

Appendix S5. Cost-benefit data

Table 1: Cost of each improvement component

Component	Cost (INR)
Water quality management	
Intermediate	257,200,000
High	931,920,000
Mangrove management	
Intermediate	47,297,957
High	76,243,513
Fisheries management	
High	1,004,176,500

Notes: water quality costs are taken from WISA and CWRDM (2017). A detailed report of the financing for the improved water quality can be found in the report; for cost of conservation/restoration for mangroves is in terms of the net opportunity cost to shrimp aquaculture of the potential converted area (see table 3 and appendices S3); the maximum sustainable yield for fisheries is estimated at 90% of the current level (table 2), in absence of cost data for the fin fisheries industry, gross opportunity costs of fishing within the sustainable yield is assumed. Fisheries and aquaculture opportunity costs are estimated using a 5-year time horizon and a 7% discount rate.

Table 2: Opportunity cost of intermediate mangrove management scenario

Year	t	Net income / ha	Ha lost to aquaculture compared to BAU	Lost net income	Discounted lost net income
1	0	412,357	9	3,711,213	3,711,213
2	1	412,357	18	7,422,426	6,936,847
3	2	412,357	27	11,133,639	9,724,551
4	3	412,357	37	15,257,209	12,454,427
5	4	412,357	46	18,968,422	14,470,918
				PV of opportunity cost:	**47,297,957**

Notes: Values in INR; conservation/restoration for mangroves is in terms of the net opportunity cost to shrimp aquaculture of the potential converted area (see table 3 and appendices S3). Costs are estimated using a 5-year time horizon and a 7% discount rate.

Table 3: Opportunity cost of high mangrove management scenario

Year	t	Net income / ha	Ha lost to aquaculture compared to BAU	Lost net income	Discounted lost net income
1	0	412,357	25	10,308,925	10,308,925
2	1	412,357	34	14,020,138	13,102,933
3	2	412,357	43	17,731,351	15,487,249
4	3	412,357	53	21,854,921	17,840,126
5	4	412,357	62	25,566,134	19,504,281
				PV of opportunity cost:	**76,243,513**

Notes: Values in INR; conservation/restoration for mangroves is in terms of the net opportunity cost to shrimp aquaculture of the potential converted area (see table 3 and appendices S3). Costs are estimated using a 5-year time horizon and a 7% discount rate.

Table 4: Opportunity cost of sustainably managed fisheries

Year	t	Income	Lost income	Discounted income
1	0	2,288,872,000	228,887,200	228,887,200
2	1	2,288,872,000	228,887,200	213,913,271
3	2	2,288,872,000	228,887,200	199,918,945
4	3	2,288,872,000	228,887,200	186,840,135
5	4	2,288,872,000	228,887,200	174,616,949
			PV of opportunity cost:	**1,004,176,500**

Notes: Values in INR; the maximum sustainable yield for fisheries is estimated at 90% of the current level (table 2), in absence of cost data for the fin fisheries industry, gross opportunity costs of fishing within the sustainable yield is assumed. Costs are estimated using a 5 year time horizon and a 7% discount rate.