Highlights

- Although the causes are debated, increasing interactions between users of the marine environment and jellyfish blooms are being reported in the Northeast Atlantic (NEA).
- Future increases in jellyfish blooms across the UK have the potential to cause significant impacts to the coastal tourism sector.
- A decrease in the recreational use value of the coastal ecosystem to beach users under two bloom scenarios are projected in a case study location in the UK.
- Through stakeholder preferences, significant use value decreases were projected from the bloom scenarios.
- A hypothetical bloom management scheme was assessed, showing the potential to maintain some use value of the coastal ecosystem during blooms to certain beach users.

Abstract

Jellyfish bloom events in the Northeast Atlantic (NEA) are perceived to be increasing, based on a rise in reports of their interactions with human activities, including coastal recreation. However, few studies have assessed the potential impact of bloom events on coastal recreation in the NEA. This article reports findings of a questionnaire carried out with beach users to assess the possible impacts and potential management implications of an increase in jellyfish blooms at St Ives, Cornwall which is a popular seaside resort in the UK and was selected as the case study location. Impact to coastal recreation was estimated based on a revealed preferences valuation of beach visits and beach recreation that occurred using a travel cost model and its effect, based on projected change in overall visit patterns under jellyfish bloom scenarios. Under a scenario where blooms of jellyfish stingers cause beach closures, 42% of respondents reported that they would avoid the St Ives coasts entirely, resulting in an estimated use loss of £11,182.50 per day. Under a second scenario, where blooms of non-stingers occur on open beaches, 13% of visitors would avoid the beaches and coast, resulting in an estimated daily use value loss of £3,461.25. Through an estimated valuation of willingness of beach users to donate to a hypothetical bloom management scheme, 40% of respondents stated that they would be willing to contribute to anti-jellyfish nets to limit the impact of blooms, with a projected benefit of £6,000. Results suggest that jellyfish blooms could cause significant impact to coastal recreation in a UK seaside town. However, jellyfish management schemes have the potential to mitigate some of the impact. Further studies are required to determine whether the local impacts estimated in the present study are indicative of regional, UK-wide recreational behaviour change and losses in response to bloom events.

Key words: Hydromedusa proliferations; Beach tourism; Socioeconomic impact; Travel cost method; Contingent valuation

1. Introduction

Since the early 2000s, jellyfish blooms are perceived to be becoming more common globally, reflected by an increase in coverage of bloom events within the media and scientific literature (Condon et al., 2012; Vandendriessche et al., 2016). However, uncertainty exists as to whether the perceived increases are reflective of actual trends (Boero et al., 2008; Condon et al., 2012; Sanz-Martin et al., 2016), given the lack of routine monitoring for jellyfish species in many geographic regions. Some exceptions do exist, such as within Europe, where the Mediterranean Science Commission (CIESM) jellywatch and the MED-JELLYRISK programmes are providing consistent citizen science records of jellyfish occurrence, indicating that recent increases have occurred (Boero et al., 2009; Gatt et al., 2018; Marambio et al., 2021). Yet, there continues to be limited confidence globally regarding how future bloom events will compare to the present-day, more than two decades after increasing blooms were initially being noticed (Mills, 2001; Lynam et al., 2006; Attrill et al., 2007; Richardson et al., 2009; Kennerley et al., 2021). Evidence does suggest that increases in bloom events at regional levels are possible, driven by climate change, over-fishing of predators and competitors, eutrophication, the introduction of non-native species and increases in artificial hard structures placed on the seabed (Purcell et al., 2007; Richardson et al., 2009; Purcell, 2012; Collins et al., 2020). Concern has therefore been expressed in relation to the impacts of increased numbers of blooms in coastal marine systems, particularly where outbreaks occur in areas of high human activity (Purcell et al., 2007; Richardson et al., 2009; Doyle et al., 2007; Licandro et al., 2010; Pikesley et al., 2014; Ruiz-Frau, 2022).

Jellyfish blooms are known to negatively impact the use of coastal locations by humans (e.g., beaches) due to a reduction of ecosystem services such as recreation opportunities, fishing and aquaculture productivity, coastal biodiversity, and tourism activities (Purcell et al., 2007; Bosch-Belmar et al., 2020; Morandini, 2022). The impacts of blooms can be severe, ranging from human health concerns (Mariottini and Payne, 2010; De Donno et al., 2014), large scale disruption to coastal tourism (Ghermandi et al., 2015), finfish aquaculture (Purcell et al., 2007; Gershwin, 2013), and commercial fishing (Knowler, 2005; Bosch-Belmar et al., 2020). In the Mediterranean, where recurrent jellyfish outbreaks have been well documented (Canepa et al., 2014; De Donno et al., 2014; Marambio et al., 2021), tourism is known to be negatively affected in terms of human health hazards from stranded medusae (Burnett, 2001; Haddad et al., 2009), reduced recreation due to beach closures (Purcell et al., 2007), the reduction in the aesthetic value of coastal locations (Palmieri et al., 2015), and the envenomation of bathers

(Cegolon et al., 2013; Montgomery et al., 2016). For example, Ghermandi et al. (2015) assessed welfare losses associated with bloom events along the Mediterranean coast of Israel and reported monetary losses ranging €1.8 - €6.2 million per year within seaside resorts and a reduction in the number of seaside visits between 3-10.5%. More recently, Rui-Frau (2022) surveyed visitors to the Spanish Balearic Islands, with 24-40% of respondents reporting that they would choose not to return to the beaches under scenarios of increasing blooms of *Pelagia noctiluca* and *Physalia physalis* respectively.

Across the Mediterranean, strategies are employed to reduce the amount of contact between recreational beach users and jellyfish (Lucas et al., 2014). Anti-stinger nets are deployed to protect bathers, mostly in response to rises in *P. noctiluca* outbreaks (Piraino et al., 2016). Such schemes have been shown to protect beach users and promote a sense of safety, which has shown to decrease the number of beach users deterred from returning by 66% and 83% in response to increased protection from *P. physalis* and *P. noctiluca* respectively (Ruiz-Frau, 2022). In choice experiments in relation to jellyfish management, coastal tourists have also been shown to be willing to pay higher amounts for the greatest levels of protection from blooms (Ruiz-Frau, 2022). Additional measures also include temporary beach closures and the removal of stranded medusae by the authorities. Early warning systems based on spatial modelling of favourable ocean conditions, currents, and trade winds have been implemented so that coastal users are able to prepare for the impacts associated with blooms in high-risk locations (Lucas et al., 2014). Investment in such strategies is enabling adaptation to region specific challenges posed by increasing concurrent use of the marine environment by humans and jellyfish.

The Northeast Atlantic (NEA) is perceived to be experiencing increases in bloom events in terms of frequency, size, duration, and area covered, particularly within coastal areas where they are more likely to be noticed (Lilley et al., 2009; Licandro et al., 2010; Palmieri et al., 2015). Perceived increases are supported by reports of blooms in the area (Doyle et al., 2008), habitat suitability mapping (Collingridge et al., 2014; Kennerley et al., 2021) and continuous plankton recorder data sets (Gibbons and Richardson, 2008; Licandro et al., 2010). As well as the lack in confidence in future bloom trends (Collins et al., 2020), there is currently a lack of understanding of the impact on ecosystem service provision in the NEA compared to regions such as the Mediterranean, particularly with regards to cultural services such as tourism and recreation (Palmieri et al., 2015). Within the NEA, the UK has significant coastal recreation (Beatty et al., 2010) that could be heavily impacted by increases in bloom occurrence in the region (Palmieri et al., 2015), for example through beach closures, and negative interactions with jellyfish resulting in fewer beach visitors. Few studies have assessed the potential impacts of blooms in the UK, and to date, no study has provided cost estimation on coastal recreation or assessed the potential for management strategies based on the responses of beach users (Palmieri et al., 2015).

Despite manifestations of blooms off the UK coastline in the early and mid-2000s (Doyle et al., 2008; Palmieri et al., 2015), which have been perceived to be increasing, there has been a scarcity of direct management actions such as anti-jellyfish nets being deployed across beaches popular with tourists. The lack of management action may be due to the lack of socioeconomic assessments of bloom impact on coastal recreation assessing any need for action. Citizen science projects within the UK do monitor jellyfish occurrence (E.g., the Marine Conservation Society (MCS) jellyfish survey (Lucas et al., 2014)), that could be used to identify areas that may require management in a similar way to the monitoring schemes in the Mediterranean (e.g., the CIESM jellywatch programme) (Piraino et al., 2016; Marambio et al., 2021). When members of the public spot jellyfish on the coasts they are encouraged to state the species (and provide a photo), rough numbers and the GPS locations on the MCS website, providing indications of population trends and spatial distributions. If coastal areas of high recreational activity within the UK are identified as at increased risk or start experiencing more frequent blooms, a major benefit reported during the initial stages of the implementation of anti-jellyfish nets have included a 90% reduction in bather envenomation (Montgomery et al., 2016). Increased levels of safety perceived by users of the beaches associated with nets also result in the number of beach visits being maintained (Ruiz-Frau, 2022), which could contribute to the maintenance of the use value of UK beaches, it they were to experience increasing blooms.

This article reports the findings of a case-study used to estimate the expected impact on the use value of beach recreation in a UK coastal town, through estimates of per-visit value and expected changes in visitor patterns under hypothetical jellyfish bloom scenarios. The reduction in number of visits due to blooms can have direct and indirect (non-market) economic effects. The direct effects impact the coastal economy, with for example, a reduced number of tourist bookings, carpark payments and food and drinks expenditures. It also has indirect effects, which is the reduction in enjoyment value of coastal locations by visitors, independently of their expenditure. This second effect is under investigation in this study, and it is defined as the use value of coastal recreation services. Given the comparatively low frequency of bloom events that currently occur in the region, fewer mitigation measures, such as anti-jellyfish nets (Piraino et al., 2016) have been implemented in UK waters. This study therefore also assesses the potential for jellyfish nets to be used as an adaptation strategy to reduce the economic impacts of bloom events. This study provides a benchmark against which the economic impacts of jellyfish outbreaks on coastal recreation and potential adaptation policies can be evaluated.

2. Methods

2.1. Study Area

The study used St Ives, Cornwall (50.2084° N, 5.4909° W) as the case study location (Figure 1). St Ives is a popular seaside town with an economy that is heavily reliant on coastal recreation associated with beach visits, with recreational activity and seasonal visitors supporting a high proportion of local livelihoods (Beatty et al., 2010). Citizen science records within the MCS jellyfish survey also suggest that a number of species capable of impacting coastal recreation, if they were to bloom, occur in the area (Lucas et al., 2014). The south-western location in the UK is also susceptible to increases in jellyfish populations; with coastal waters reported to be the most suitable in the UK for a number of bloom-forming species under current and future climate scenarios, with conditions in the region being most favourable for *Aurelia aurita, P. noctiluca, Rhizostoma octopus and Chrysaora hysoscella* during the summer months when recreational activity along the coast peaks (Kennerley et al., 2021).

Figure 1. Aerial view of St Ives and the beaches where field work occurred. Source: ESRI - ArcGIS online basemap

Since the early 2000s, the NEA, including waters surrounding the southwest coast of the UK, is experiencing rapid warming (Philippart et al., 2011) and increased instances in plankton blooms that jellyfish prey upon (Licandro et al., 2010). A number of studies conflate the increasing temperatures with greater levels of reproduction associated with bloomed populations that can be supported by the increases in prey abundances. For example, under laboratory conditions, *A. aurita*, *C. hysoscella, R. octopus* and *P. noctiluca* are known to start reproducing, and at greater rates, in response to certain temperature and prey threshold thresholds (Purcell et al., 2012; Lilley et al., 2014; Kennerley et al., 2021). Increasing temperatures and plankton blooms in the region could therefore lead to a northern expansion of the conditions associated with increased reproduction at earlier times in the year, potentially enabling blooms of existing populations. Licandro et al. (2010) reported increasing records of gelatinous material in the annual continuous plankton recorder (CPR) surveys across the NEA since 2002 (specifically between 45° N to 58° N and 1° W to 26° W), which included outbreaks of *P. noctiluca* in 2007 and 2008. Species such as *P. noctiluca* are able to exploit the hydroclimatic changes that are occurring in the NEA, with outbreaks potentially increasing in intensity and frequency (Licandro et al., 2010). If such trends were to continue, the location of St Ives means that it will be one of the first UK seaside towns to start experiencing the northern expansion of increasing blooms of native populations and incursions of non-native species from more southerly latitudes.

2.2. Questionnaire Data Collection

A revealed preference questionnaire (Supplementary material) was administered face to face with beach users across the four main beaches of St Ives (Porthmeor, Porthgwidden, Harbour Beach, Porthmintser) (Figure 1), during three weeks in the summer months (27th July to 17th August) of 2016. The questionnaire was composed of three sections: Section A 'Activities' asked the respondents about their recreational activities in St Ives which included number of beach trips during their visit, Section B “Jellyfish” asked about previous experience of jellyfish, responses to hypothetical blooms on the beaches of St Ives and their preferences towards management, Section C “Socioeconomics” asked for demographic information which included travel cost to reach St Ives and the beaches. Interviewers approached recreational beach users at random. Respondents (all above the age of 18) were informed of the aim of the survey, the voluntary nature and confidentiality of their responses. Ethics approval was granted by the University of East Anglia (UEA) General Research Ethics Committee (GREC) for the study.

2.3. Revealed Preference

The initial section of the questionnaire collected data to generate the non-market use valuation of recreation per beach visit through revealed preferences of beach users. Questions were asked on the respondents' main recreational activities on the beach, number of visits in the last 12 months, the duration of each individual beach visit and the travel costs and time associated with journeys to access St Ives from their home address and the beaches from their holiday accommodation. Information was also collected on respondent demographics (age, gender, reason for visit, income, education level, employment status and if there were children in their group).

A single-site travel cost model (TCM) (Parsons, 2003) was built to estimate the per visit non-market recreational use value of the beaches of St Ives to act as a basis for the estimation of the potential hidden impact of jellyfish blooms. After data cleaning, a total of 151 complete responses were included in the analysis to derive a demand curve. The number of beach visits in the last twelve months was established as the dependent variable (quantity demanded) of the travel cost function (price to pay). Due to overdispersion of the dependant variable data (Kolmogorov-Smirnov = 6.336, n = 182, p= <0.001), the TCM was built on a negative binomial regression and dependent on the travel cost (TC), income (I) and the demographic variables (SC) (Parsons, 2003):

$$\text{visits}=f(TC, I, SC) \qquad (1)$$

Equation 1 describe the demand curve to be estimated using the observational data. Travel cost for each visitor, TCi was defined as the sum of the travel expenses required to reach the beach (TEi) and the time cost (tCi):

$$TCi=TEi+tCi \qquad (2)$$

The estimation of TCi was based on the total distance travelled, cost per unit of distance travelled (TEi) and the travel time (tCi) of respondents, which was collected during the initial section of the survey. Respondents specifically stated their tCi during the questionnaire. Distance was based on the origin of travel, which was stated to be the postcode of the respondent's home (or start point of their journey) and the postcode of their accommodation in St Ives, plus the distance to the beach from their accommodation. For those that drove to St Ives, the post codes were inputted into google maps and the distance was multiplied by the average cost of fuel type (petrol or diesel) used by the respondent at the time of study. To gain a full understanding of the direct travel cost, the distance was doubled to account for the return trip. For those that used public transport, the cost of the return ticket and the cost to get to the beach were used to estimate total travel cost. If the respondent was part of a group, total travel cost was divided by the number of people who had travelled together to avoid overestimating the per person daily travel cost.

Yearly individual income (I) and other demographic variables (age, gender, reason for visit, income, education level, employment status and if there were children in their group) were explored for inclusion in the TCM. Some of the demographic variables were transformed into dummy variables before incorporation into the TCM (Appendix A). To avoid multicollinearity in the regression analysis, all the demographic variables were tested against TCi, and Income with different statistical tests as follows; (i) Spearman's Rank correlation when the demographic variable was continuous or ranked-categorical; (ii) Mann–Whitney U Test, to compare TCi with dichotomous variables; or (iii) Chi-squared analysis, to compare Income with dichotomous variables. The variables that showed significant correlation were education level, children in group and employment status, leading them to be removed from further analysis, so that the number of beach visits and income could be treated as unique coefficients without additional influence. An economic demand curve is primarily a function of price and income but further demographic variables that did not show collinearity, were included in the model (age, gender, and the reason for visiting St Ives) to better reflect the heterogeneity of preferences.

The demand function for the beach visits was estimated for the negative binomial regression models using R v.3.6.0 (R core team, 2020). The estimation of use value per-beach visit using the travel cost function described by Parsons, (2003) was calculated as follows:

$$t = \frac{ƛ\mathrm{n}}{-\beta\mathrm{tcr}} \tag{3}$$

Where *t* is the revealed visit value, ƛn is the expected number of daily visits to the beaches (assumed to be 1 per day based on survey responses) and -βtcr is the coefficient of the TCi on the negative binomial regression. An aggregated use valuation of the beaches based on total beach visits was then calculated by multiplying the per-visit value per beach user in the TCM by the number of visitors estimated on a typical summer's day, which was 1,500 (estimated through conversations with RNLI lifeguards stationed on the beaches at the time of research).

2.4. Bloom Scenario Impact

The next aim of the questionnaire was to determine whether hypothetical bloom events may affect the recreational behaviour of beach users to determine potential impact. Respondents were introduced to two hypothetical bloom scenarios and asked how they would respond; 1) blooms of stinging species that pose a significant threat to human health (e.g., *P. physalis*) resulting in beach closures (Gershwin et al., 2014; De Donno et al., 2014), and 2) blooms of non or mild stingers (e.g., *A. aurita*) occurring on beaches that were assumed to remain open. The subsequent changes in the frequency in beach visits were then used to estimate the change in aggregated use value of the beaches under the bloom scenarios per day. The reported percentage changes in visitor frequency were applied to the aggregated use value to estimate impact under both scenarios. As blooms have been suggested to persist for roughly 14 days within the NEA (Palmieri et al., 2015), the daily decrease in use value was multiplied by 14 to estimate the total impact over the course of a single bloom event.

2.5. Jellyfish Management

The final section of the questionnaire collected data to assess the potential for hypothetical bloom management strategies. A hypothetical management scheme was described to respondents, based on the anti-jellyfish nets commonly deployed in the Mediterranean (Piraino et al., 2016). Respondents were then asked about their preferences towards the scheme (for or against) and their willingness to donate towards bloom managed beaches under the two scenarios. Specifically, respondents were asked if they would be willing to make a one-off donation to a non-governmental organisation (NGO) to set up jellyfish free pools in St Ives in the event of blooms, and if yes, how much they would donate and the payment vehicle. The average per respondent willingness to pay (WTP) for the alternative bloom management scheme was then multiplied by the assumed proportion of daily beach users that indicated they would donate. This was used to estimate the total daily contingent valuation of bloom managed beaches with jellyfish nets.

3. Results

3.1. Demographics

182 questionnaires were collected (of which 151 were fully completed) during the fieldwork. The majority (93%) of the fully completed questionnaires were administered on the two larger beaches (Porthmintser and Porthmeor). Respondent key demographic characteristics (including the dummy variables) are summarised in Table 1 (full data set displayed in Appendix A). The age range of respondents was between 18 and 75+. Respondents had a range

of education levels and individual incomes, but most stated that they were in fulltime employment. The gender of respondents was split between 46% male and 54% female. Most respondents had travelled relatively long distances across the UK to get to St Ives (72% travelled > 251 miles) with an average travel duration of just under 6 hours. Of the respondents, 7% identified themselves as local to the area and 2% had travelled from abroad to visit St Ives. Most commonly, visitors travelled in groups of at least four people (65%), with groups often containing children (74%). The primary reason given for visits to St Ives was for a beach holiday (84%). Of all respondents, 66% reported that they did some form of water activity as well as recreating on the beach, with 11% of these reporting to exclusively engage in water-based activities, despite the cool ocean temperature (around 14^0C) at the time of the surveys.

3.2. Revealed Preference

From the 182 questionnaires completed, 151 (Table 1) could be used in the travel costs analysis after data cleaning. Three of the independent demographic variables were significantly correlated to income (education level ($X^2 = 9.3267$, $p = 0.009$), children in group ($X^2 = 25.469$, $p = <0.001$) and employment ($\rho = 0.278$, $p = <0.001$)), so were removed from the analysis to avoid multicollinearity.

Table 1 Income and demographic factors (including dummy varibles) considred for the travel costs model

Variable	Type	Categories	Code	Frequency	Percentage
Gender	Dichotomous	Male	0	70	46%
		Female	1	81	54%
Income	Categorical	0-30K	1	54	36%
		31-60K	2	58	38%
		61K	3	39	26%
Age	Dichotomous	18-44	0	79	52%
		45-75+	1	72	48%
Education	Dichotomous	Secondary or lower	0	53	35%
		Higher education	1	98	65%
Employment	Dichotomous	Unemployed	0	31	21%
		Employed	1	120	79%
Children	Categorical	No children	1	39	26%
		1 child	2	28	19%
		2 or more children	3	84	56%
Reason for visit	Dichotomous	Beach holiday	0	127	84%

	Other holiday (cultural, family, etc)	1	24	16%

No variable showed a significant relationship with the estimated per person travel expense per beach trip. The demographic variables that were kept in the definitive negative binomial regression were income, gender, age, and the main reason given for visiting St Ives (Table 2). The mean number of beach visits was 7 trips per person over the last 12 months with each visit stated to last most of the day on average (average of 5 hours per visit, resulting in an assumption of 1 beach visit per day). The average per person travel expense to St Ives was £13.84 (+/- £0.78). In the negative binomial regression model, the number of visits to the beaches of St Ives significantly decreased as the travel expense increased (Table 2). As both income and age increased, the number of beach visits decreased. However, the influence of all factors, apart from travel expense, within the model had no significant relationship with the number of St Ives beach visits in the last 12 months (Table 2).

Table 2 Negative Binomial Regression Model Output

	β Coefficient	SE	Z- value	*P*-Value
Intercept	2.71323	0.22716	11.944	<0.001
Average Daily Travel Cost	-0.05633	0.01080	-5.217	<0.001
Income	-0.05429	0.17713	-0.306	0.759
Gender	-0.18426	0.15176	-1.214	0.225
Age	-0.06122	015269	-0.401	0.688
Reason for visit	0.18651	0.20078	0.0929	0.353

The estimated use value of the beaches per beach visit (t) per person per day (equation 3) that was revealed based on travel costs was £17.75 (assuming one beach trip per day, per person and a $-\beta$tcr of 0.05633). The estimated total use value of the beaches per day was £26,625 when the per person use value per visit was multiplied by the assumed typical number of visitors expected on the beaches on a summer's day (1,500).

3.3. Behaviour Change

In scenario 1, where beaches close due to the presence of a bloom event of a stinging species that pose a threat to human health, there would be a 100% decrease in beach visits, resulting in a direct loss of £26,625 in access value per day and £372,750 loss if a bloom was to persist and cause beach closures for 14 days (Table 3). When asked to state how their visit patterns would change under scenario 1, 42% of respondents indicated that they would no longer recreate in the St Ives coastal area and move further afield because they cannot directly access the beach. However, 58% of respondents indicated they would stay in the vicinity of the beaches and continue to recreate close to the St Ives coastline. Based on the reported hypothetical visit patterns under scenario 1, it was assumed that there would be a 42% decrease in the aggregated use value of the St Ives coastline due to the decrease in visitors. The subsequent use value decrease was therefore estimated to be a loss of £11,182.50 for each day a bloom persisted and a £156,555 loss in the event of a bloom persisting for 14 days (Table 3).

Under scenario 2, where beaches remain open in the event of a bloom of a non-stinging species, 13% of respondents reported that they would avoid St Ives completely and 2% would avoid the beach but would still recreate along the coastline, resulting in 15% of beach users changing their visit patterns to the beach in some way (Figure 2). The remaining 85% of respondents reported that they have a variety of alternative recreational options on the St Ives coastline if the beaches do not close, particularly if blooms do not wash up on land and would therefore not change their visit patterns. Of these respondents, 18% would not change their recreational activities at all, with 27% stating that they would generally be more cautious (Figure 2). The remaining 40% of respondents would still recreate on the beach but would avoid the water. In terms of a direct decrease in visits to the beach, there would be an assumed access loss of £532.50 per day and £7,455 per 14-day bloom from the 2% or respondents who would avoid the beach but would still recreate along the St Ives coastline. From the 13% of respondents who would avoid the St Ives coastline and would move further afield, there would be an equivalent loss of £3,461.25 per day and £50,977.5 over a 14-day bloom period along the St Ives coastline (Table 3). Of those that stated they were local to the area, 90% reported that they would just avoid the beach in response to both scenarios.

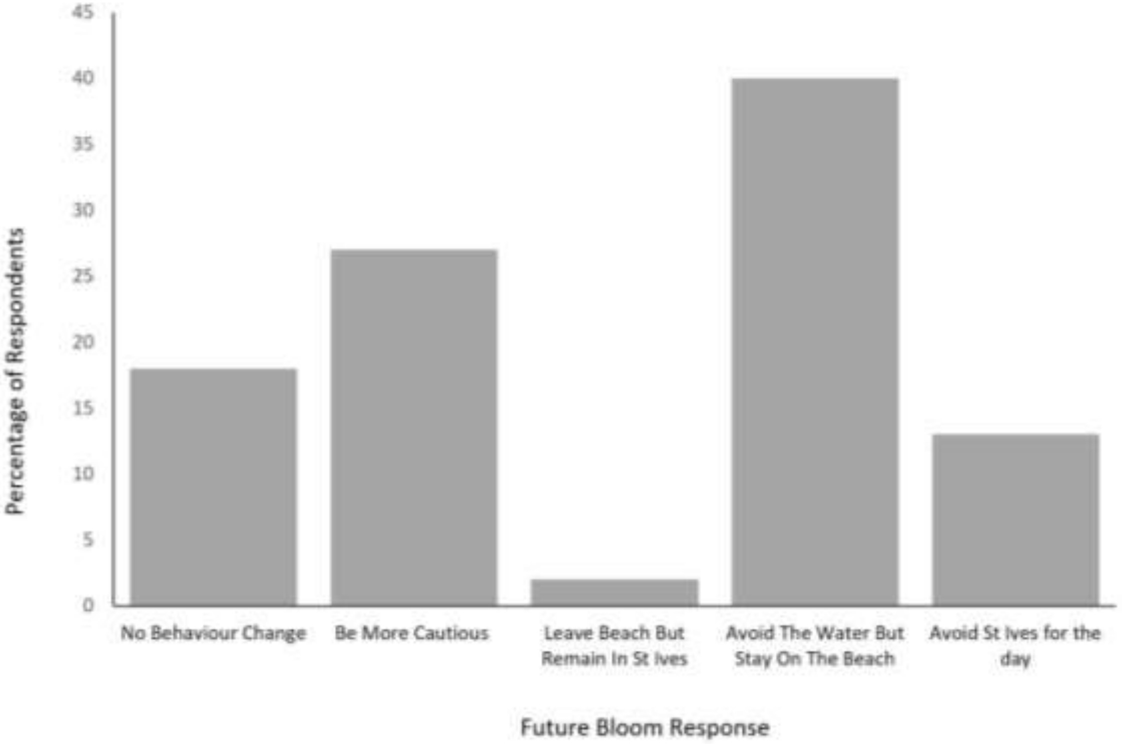

Figure 2 The frequency of responses (%) to future non-stinging blooms on the beaches of St Ives (where these remain open)

Table 3 Estimated decrease in aggregated use value of the beaches and coastal area under the bloom scenarios per day and over the assumed typical duration of a bloom (14 days)

	Per day	14-day bloom
Scenario 1: reduced coastal visits	£11,182.50	£156,555
Scenario 1: no beach visits	£26,625	£372,750
Scenario 2: reduced beach / costal visits	532.50	£7,455
Scenario 2: no beach visits	£3,461.25	£50,977.50

3.4. Bloom Management

Of the 151 respondents, 40% stated that they would be willing to donate towards an NGO management scheme such as anti-jellyfish nets. The average amount stated was £10 per person with upper and lower ranges (falling within 95% confidence intervals) being £7 and £14 respectively. A range of payment vehicles for the donations were suggested by the respondents including increased car parking fees (10%), taxes (20%), donating at a display area (35%) and putting money in collection buckets (35%). When scaling up the average per person donations by the total predicted daily number of visitors (1,500) to the beaches in St Ives, 600 (40%) were assumed to be willing to donate to a jellyfish management scheme. The average donation of £10 was multiplied by the 600 people, resulting in a valuation of £6,000, ranging between

£4,200 (lower limit), and £8,400 (upper limit) from one-off payments from all payment vehicles. This suggested that some access and recreation could be maintained under the bloom scenarios, assuming that safety could be ensured by the jellyfish nets, particularly in the event of blooms of stinging species.

4. Discussion

To the authors' knowledge, this is the first study to undertake an economic valuation of recreational losses associated with hypothetical jellyfish bloom events for a UK coastal town. The socioeconomic assessment done in this study is significant in terms of management needs (Morandini, 2022; Frau-Ruiz, (2022) since there is a perception that jellyfish populations are increasing in the area, as supported by survey records (Licandro et al., 2010), and the possibility that a number of species could potentially bloom more often due to changes in the environment (Kennerley et al., 2021), including incursions of non-native populations in response to climate change (Dissanayake et al., 2021). The results of the present study indicate that jellyfish blooms could result in significant losses to the recreational use value of the beaches along the southwest coast of the UK. The projections in reduction in value were due to behaviour changes in seaside visitors that results in reduced recreational activity in the area, due to avoidance of beaches and coastlines on which jellyfish blooms and strandings occur, or due to the closures of affected beaches. The projections were made in relation to hypothetical bloom scenarios, based on the quantification of data provided by respondents using a TCM, combined with assumptions about behaviours, and longevity of blooms. The study also reports willingness to pay for hypothetical anti-jellyfish nets and the potential for management schemes to maintain coastal recreation opportunities of a UK beach resort experiencing blooms, as well as initial understanding of public support for such interventions similar to what has been reported in other geographical regions including the Mediterranean where blooms are more common (Morandini, 2021; Frau-Ruiz, 2022).

4.1. Recreation and Tourism

Many of the impacts and interactions between beach users and jellyfish projected in the present study is consistent with previous studies that have assessed the impact of blooms on recreation in other geographical regions. For example, Ghermandi et al. (2015) report observations of bloom occurrence on beaches along the Israeli Mediterranean coasts that do not close, directly resulting in 3.5-10% decreases in beach visits. Similarly, in the present study, a 2-15% decrease in beach visits was projected in response to the scenario of blooms of non-stingers on beaches that remain open (Scenario 2). A greater proportion of respondents in the present study reported that their recreational activities would be affected by jellyfish outbreaks (55%) compared to Mediterranean coastal users (41%). The higher reported projections of impacts to recreation in the UK are likely due to the lower levels of experience that UK beach users have of jellyfish, with Mediterranean users being more familiar with blooms that occur annually. It has been shown that risk associated with jellyfish influences perceptions of a beach resort but does not significantly alter travel plans to that area from home locations (Crowley-Cyr et al., 2022), potentially resulting in greater conflict when bloom manifestations occur. However, it must be acknowledged that visitors may have mobility and are potentially willing to move elsewhere leading to a diversification of recreation, engaging in alternative activities in the vicinity or spill over to bloom free beaches.

An additional impact that was identified in the present study is that people local to the area would avoid the coastal ecosystem during the bloom scenarios. Local people had little travel cost compared to summer visitors, but the loss in access to the ecosystem that they would experience requires acknowledgment, particularly as they make many more trips. The impact associated with blooms on local people living in coastal locations popular with beach tourisms is rarely considered in the wider literature and requires further study. In addition to the assessment of recreational and welfare losses experienced by locals, the effect on their perception of changes to the environment and on their sense of place is worthy of further study.

The economic losses reported in the present study are based on hypothetical single bloom events assumed to last for 14 days (Palmieri et al., 2015), whereas annual economic impact is reported in other studies that have assessed impact of blooms on tourism, making it challenging to compare the total losses calculated. A key difference is the temporary nature of the losses that would occur in the scenarios reported in this study. Presumably, when the bloom is gone, people will resume recreating on the beach. Although for some, perhaps the experience of not being able to use the beach for a certain amount of time may have a more lasting effect, which is also a finding stated by Frau-Ruiz, (2022). This study therefore acts as an initial insight into the potential impact of bloom increases on UK beaches. If blooms were to become more common and persist for longer than the scenarios used in this study, it is conceivable that similar impacts to those observed in the Mediterranean could also be incurred in UK seaside towns.

4.2. Study Approach

In this study, a case-study approach was applied, which focussed on a tourist location on the south coast of England, where recreation is a prominent source of income. This potentially makes the results of this study highly localised. However, it could be argued that St Ives is characteristic of an English coastal town that has strategic importance (as defined by Fryberg, 2006: 230-231) and thus the effects could be similar to other coastal locations that are mainly geared towards seaside tourism. When scaled, the effect of blooms on a national level will likely vary depending on the importance of recreation in the area, the perceptions of beach users to jellyfish as well as local geographical characteristics and other recreation opportunities. Generating bloom costs over larger geographical areas, across more than one location and over a longer time period will result in more robust conclusions on the actual impact to recreation and the subsequent management implications, particularly in relation to detail on variation in effects of blooms. At the same time, economic direct costs could also be assessed through the use of local economy GDP statistics. For example, Tomlinson et al. (2015) assessed the impact of jellyfish blooms to the key sectors of tourism and fisheries in Girona, Barcelona, and Tarragona, using social-ecological input-output models informed by regional GDP statistics to aid management. Using regional and national tourism statistics would also improve impact projections made in this study as the total daily use losses were scaled up to a case study level using simple estimations of the total number of beach users on a typical day. Such expansions in economic data collection would improve upon the limitation that this study was based on surveys carried out in 2016, as trends in bloom occurrence and economic impact could be generated over time, enabling more robust management decisions. It must also be acknowledged that a valuation of substitute locations was not possible within the collected data set in this study. However, the potential for widespread distributions of blooms to neighbouring locations (Kennerley et al., 2021) means that the value of other locations cannot be guaranteed, highlighting the need for high level regional assessments. Monitoring of jellyfish populations using resources such as citizen science databases may therefore play a significant role in understanding where interactions between beach recreation and blooms (similar to what has occurred in the Mediterranean (Marambio et al., 2021, Frau-Ruiz 2022)), and how locations at risk across the UK compare with the case study location selected in this study, to aid regional management actions.

This study has provided *ex ante* projections of bloom impact in relation to hypothetical bloom scenarios that could potentially occur in response to a changing environment. The use of a questionnaire, a TCM and scenario approach has enabled the development of future projections in this study, whereas all previous assessments of bloom impact on recreation have been retrospective. The application of a TCM assessed the value of beach recreation that would directly be impacted by blooms in the absence of other economic data sets. The TCM provided a baseline valuation of the beaches based on a methodology that follows conventional empirical techniques that generate valuations based on market prices using data on behaviours and expenditure directly collected from respondents. The valuations then acted as baseline data for impact projections based on responses to hypothetical bloom scenarios provided by respondents. The data and projections generated from this methodology can be used to identify and support the management strategies that may be required to mitigate future impacts before they occur. Such approaches can also be adapted to assess future socioeconomic impacts of additional environmental changes to ecosystems with a use value, widening the toolkit of potential methodologies for other studies.

Furthermore, consideration should be given to how respondents engaged with the hypothetical scenarios of blooms outlined in the questionnaire. Most people initially respond to elicitations about uncertainty and risk emotionally (Slovic et al., 2004), using deep seated heuristics, which Slovic et al. (2004) defined as an experiential mode of thinking. Experiential thinking is an automatic response to risk based on images and associations that link to positive or negative emotions, which are then subsequently combined with more analytical modes of thinking (Slovic et al., 2004). When bloom scenarios were introduced to respondents, most considered blooms to be negative, with the most immediate association being the stinging capacity of jellyfish, even though many of the species considered in the survey do not possess potent stings. It is possible that heuristic responses to scenarios outlined in the questionnaire resulted in a higher number of respondents associating blooms with ‘high-risk’ compared to studies that assess impact in locations where blooms are more common. These heuristic responses to jellyfish and bloom scenarios are acknowledged as an important component of this study and one to consider in further work.

It has to be acknowledged that the survey for this study took place prior to the COVID-19 pandemic and Brexit; events that may have changed the user profile of the beaches of St Ives and potentially their responses to blooms. It can be argued that due to the pandemic and Brexit, there has been a rise in the number of tourists engaging in “staycations,” choosing to visit places like St Ives in the UK as opposed to going on foreign holidays (Reitano et al., 2021). A majority of respondents in the survey data in the present study had visited St Ives from the UK, travelling significant distance by car to get there. It can therefore be argued that there may be similarities in the profile of beach user in the present day compared to when the survey was administered. It is also possible that greater numbers are now visiting seaside locations such as St Ives from the rest of the UK with an aim of engaging in beach recreation. Although, the frequency of jellyfish occurrence and bloom manifestation still remains inconsistent, the perception of increasing interactions between jellyfish and users of the environment, also based on current citizen science, remains (Kennerley et al., 2021). If a greater number of beach users are visiting UK coastal towns wishing to make use of the marine environment, then conflict between these and jellyfish blooms may occur, highlighting a greater need and support for bloom management such as anti-jellyfish nets.

4.3 Adaptive Management

The methodology developed in this study allows for user perceptions to be considered to inform and underpin decision making, adaptation and management actions. The contingent valuation showed a willingness of some beach users to pay for the separation of blooms from designated bathing areas. Deployment of anti-jellyfish nets, such as those by MedJelly in the Mediterranean (Piraino et al., 2016) may limit the non-market use value losses associated with future blooming events in the UK, by ensuring the beaches remain open during certain types of bloom events (e.g., scenario 1) and maintaining perceptions of safety amongst beach users (Ruiz-Frau, 2022). For example, Nunes et al., (2015) estimated that beach users across the Catalonian coast are willing to pay an additional €3.20 per trip to visit beaches with fewer jellyfish, which is equivalent to €423 million/year. Despite the support for jellyfish management schemes in St Ives, a lower proportion of respondents were willing to donate (40%) compared to those reported by Ghermandi et al., (2015) (56%) in the Mediterranean. Perhaps, if blooms were to become a more common occurrence off the coasts of UK seaside resorts, more users would be willing to donate to management schemes than reported herein, resulting in greater benefits than predicted in this study.

However, whether such adaptive management options are viable remains unknown. Further research as to whether UK visitors would remain on beaches knowing jellyfish were in the vicinity of the nets is needed. Safety, in particular, would have to be ensured as there are examples of jellyfish nets that have been unsuccessfully implemented in Australian waters. In these instances, medusae have slipped between the mesh and entered jellyfish free pools, resulting in the stinging of bathers (Nimorakiotakis and Winkel, 2003). Studies could assess whether it is physically possible to create jellyfish free pools in certain areas and whether donations would cover the costs. Another challenge would be to develop management strategies that protect all users of the coastal environment from blooms. For example, jellyfish nets may hinder some activities such as surfing, which is popular across Cornwall. Such considerations highlight the possible challenges associated with the management of recreational locations if increases in blooms were to occur.

5. Conclusions

Despite the exact causes being debatable, the apparent increase in interactions between jellyfish blooms and users of the marine environment in the NEA could potentially cause increased socioeconomic impacts to the tourism sector in the UK. This study has assessed the potential indirect effects of two hypothetical bloom scenarios through potential reductions in the use of the coastal ecosystem. The scenarios and associated impact projections mirror what has occurred in other geographic locations (e.g., the Mediterranean) and allows the consideration of early responses to blooms to limit losses on UK beaches. The study was able to make the *ex-ante* projections of impact in relation to each scenario based on the preferences of beach users and developed a methodology applicable to other similar cases. This study showed that there would be a significant decrease in the use value of the coastal ecosystems for each day that a bloom persisted. The mechanisms of the projected decrease in use value were similar to that which is currently experienced in locations where blooms are currently more frequent, such as the Mediterranean. Such impacts included beach users avoiding the coasts during blooms and avoiding the case study location as a result. The projected changes in visitor patterns allowed for estimations of the socioeconomic impact relating to reduced recreational opportunity and also suggested the potential subsequent economic loss that would be incurred by the local economy in the case study location. Specifically, businesses in the area would also experience costs if visitors were deterred from coming to beach resorts such as St Ives. However, it is also possible that some local business could benefit from those who remain in St Ives during blooms and engaging in alternative recreational activities in the town, similar to activities engaged in on rainy days. Projections of such costs and benefits incurred within seaside towns in response to changes in visitor activity and the number of visitors due to blooms requires further consideration when total impact and management implications are considered. Subsequently, preparation for changes in beach quality and tourism losses could help regional economy to be resilient to a changing climate, particularly if blooms became more predictable in the future.

This study also considered the potential to mitigate the impacts of blooms using hypothetical anti-jellyfish nets that are currently deployed in regions where blooms are more common. The support of beach users for such interventions and their potential to minimise economic losses, highlights a need for investment in such management strategies if consistent increases in bloom occurrence is to become a reality. When this study was undertaken, bloom increases were seen as an emerging phenomenon. Since then, monitoring of populations has continued, data on the physiological responses of jellyfish to the environment is being assessed and some studies have started to map the spatial distributions of suitable locations (Kennerley et al., 2021). However, the appearance of blooms in regions such of the NEA remains inconsistent and their spatial distribution is difficult to predict year on year. Further monitoring of blooms and the associated environmental conditions is required to provide longer term population trends to understand the locations at greatest risk from experiencing the sort of socioeconomic impacts to coastal tourism projected in this study and to understand the required management specific to that location. Greater understanding is also required of the most appropriate management options on UK beaches. Anti-jellyfish nets were explored in this study, but there are a number of different types of beach user (e.g., surfers), who may have different requirements for bloom management to successfully maintain their recreational activity. Further studies should therefore assess the specific requirements of all the different types of beach user to mitigate bloom impact through choice experiments so that targeted management actions can occur. Also, initial indications in this study suggested that people local to the case study location with minimal travel cost would also experience impact from blooms. Stated preference methods could therefore be used to estimate the value of the coast for local residents, possibly combined with qualitative studies on their responses to blooms that may reveal additional management implications not recorded in this study.

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Appendix A: Overall demographic characteristics of respondents from 182 surveys

Respondent Characteristic		Frequency (%)
Gender	Male	48
	Female	52
Age	18 – 24	9
	25 – 34	13
	35 – 44	25
	45 – 55	31
	56 – 65	13
	66 – 75	7
	75+	2
Highest Education Level	GCSE	24
	A Level	12
	CertHE	4
	DipHE	15
	BSc / BA	22
	MSc / MA	19
	PhD	1
	Refused	3
Employment Status	Employed	36
	Unemployed	3
	Retired	6
	Student	2
	Self Employed	3
	Part Time	1
	Refused	49
Purpose of Visit	Visit Family	8
	Beach Holiday	83
	Cultural Holiday	2
	Activity Holiday	4
	Passing Through the Area	3
	Work	0
Individual Income	Up to £10K	8
	11K to 20K	13
	21K to 30K	12
	31K to 40K	10
	41K to 50K	12
	51K to 60K	9
	61K to 70K	5
	71K to 80K	3
	81K+	11
	Refused	17
Number in Group	1 – 2	18
	3 – 4	51
	5 – 6	19
	7 – 8	5
	9 – 10+	7