Jellyfish Blooms and Management Implications in the Northeast Atlantic

Adam Stuart Kennerley

Chrysaora hysoscella in St Ives Harbour, 2016 ©Adam Kennerley

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ABSTRACT

Jellyfish blooms are known to impact adversely a variety of industries, including fishing and tourism. A review of scientific literature indicates that blooms and their impacts may intensify in the Northeast Atlantic. There are also indications that the public perceive that blooms are becoming more common in this region. This research aimed to identify whether blooms and their increases across the Northeast Atlantic are a possibility, and, if so, generate an understanding of the potential economic impacts to fishing and tourism. GIS based maps of jellyfish presence and bloom occurrence were developed using current understanding of physiological thresholds for a variety of jellyfish species. The maps indicated that increases in bloom occurrence in the future is a possibility for several species, particularly in waters to the southwest of the UK. Based on these results, case study locations associated with coastal tourism (St Ives) and fishery activity (Brixham and Newlyn) were selected to assess whether and how blooms could cause impacts to these, applying an ecosystem services approach to measure potential economic and welfare changes. Survey responses from fishers and tourists were used to explore future hypothetical bloom scenarios, and quantitative indications of how the industries would operate and respond were derived. Fishers envisaged displacement effort as the main impact, with additional operational costs coming from increased fuel use while fishing during blooms. Tourists reported blooms would impede leisure activities, resulting in less beach visits. These findings enabled quantification of welfare impact due to loss of recreational activities, as well as subsequent decreases in holiday expenditure that impacts the local economy. Management options were explored during the tourism survey (anti-jellyfish nets) and mitigation considerations

were made in relation to the fishery findings (informing skippers of the costs certain bloom responses). Based on the study results, policy and management recommendations, as well as future research opportunities, are discussed.

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CHAPTER 1

INTRODUCTION

1.1 Introduction and Rationale

A jellyfish bloom is when intense congregations of medusae occur within a specific geographic location (Mills, 2001; Brotz *et al*. 2012). When jellyfish bloom in waters where anthropogenic activity occurs, they are known to cause socioeconomic benefits and impacts to users of the marine environment (Graham *et al.* 2014). In a modelling study, Graham *et al*. (2014) showed that under a variety of scenarios where bloom increases occur, the economic value of their benefits will increase, but at a much lower rate than the increases in economic costs that they are known to have. The scientific literature summarises a range of ways in which blooms cause impact through interactions with several anthropogenic activities (e.g. Graham *et al.* 2014). Such impacts include jellyfish decreasing the ability of humans to gain provisioning services from ecosystems such as food, including jellyfish hampering the operations of fishermen by clogging their nets (Palmieri *et al.* 2014) and stinging jellyfish causing the death of farmed finfish (Doyle *et al*. 2008). Blooms also impact cultural services such as tourism, which can include them forcing the closure of beaches and decreasing visits to the coastal environment (Ghermandi *et al.* 2015). The impacts blooms have, are of importance because studies have attributed significant socioeconomic impact to them (e.g. Knowler, 2005; Palmieri *et al*. 2014; Ghermandi *et al.* 2015) and reports of interactions between blooms and people appear to have increased over the last couple of decades (Purcell, 2005). A perception exists that jellyfish blooming events are becoming more common worldwide, with jellyfish blooms gaining significant attention within the media when they occur (Condon *et al.* 2012). However, this perception is debatable as increases in interactions could simply have occurred due to increased use of the marine environment by humans (Condon *et al*. 2012; Sanz-Martin *et al*. 2016). Few records exist of long term population trends to confirm whether jellyfish are becoming more common and that the oceans maybe heading towards a more gelatinous future (Condon *et al*. 2012).

The Northeast Atlantic is an example of an area where evidence has been gathered that suggests that blooms could potentially be on the increase (Lilley *et al.* 2009; Licandro *et al.* 2010; Palmieri *et al*. 2015). However, there is uncertainty associated with jellyfish populations in the area with few attempts in existence to map their distributions and the locations of potential blooms or projections of what future populations will be like in the area (one of the few examples includes a study by Collingridge *et al*. 2014 who assessed the North Sea for potential invasions of the ctenophore *Mnemiopsis Leidyi*). Also, compared to locations where blooms are typically more common (e.g. the Mediterranean), understanding of how anthropogenic activities in the marine environment respond to blooms and quantifications of subsequent socioeconomic impacts are lacking, apart from quantifications in lost aquaculture revenue as result of bloom induced die offs of farmed salmon (caused by blooms that occurred off the coasts of Ireland in 2007 and 2008 (Doyle *et al*. 2008)). There is therefore a need to understand jellyfish populations in areas such as the Northeast

Atlantic so that impacts can also be understood and potentially managed. Information on the causes of blooms exists, that could potentially be applied to this area to assess what jellyfish populations may be like, so that projections of their potential impacts can be made. The overarching rationale of this thesis is to therefore generate an understanding of jellyfish in the Northeast Atlantic, including potential blooms, of locations that may be impacted, of the magnitude of any socioeconomic consequences that blooms could cause and any management considerations.

1.2 Aims and Research Questions

This section of the chapter defines research questions to be addressed in relation to the rationale of the study (discussed above), focusing on the impacts that jellyfish could have within the Northeast Atlantic so that management and policy implications can be considered. For this, an understanding of jellyfish populations is paramount because distributions of potentially large populations will determine any socioeconomic impacts that could be incurred. Knowledge of the spatial distribution of locations of possible blooming events across the Northeast Atlantic and how they coincide with anthropogenic activity in Northeast Atlantic waters is required to recognise the ecosystem services and benefit / beneficiaries that could be impacted.

Based on these considerations, the following research questions were developed to encapsulate the main foci of the research:

1. What does existing knowledge of changes in the marine environment reveal about potential future jellyfish blooms across the Northeast Atlantic, based on their physiological thresholds / responses to the marine environment?
2. What would be the magnitude of the socio-economic impacts related to the tourism and fishing industries in the event of increased jellyfish bloom occurrence across the Northeast Atlantic?
3. What are the possible management and policy options that would address the socio-economic impacts of future bloom changes in the Northeast Atlantic?

As indicated by these three research questions, this research aimed to identify whether blooms and their increases across the Northeast Atlantic could occur, and, if they are, then generate an understanding of the potential socioeconomic impacts in coastal and marine locations. The locations of fisheries and tourism activity that coincide with areas that could support bloomed jellyfish became the focus of this study, because of the activities the literature suggests could be impacted; furthermore, no quantifications exist of bloom impacts for these two industries in the Northeast Atlantic, only suggestions of what could occur. Understanding of the ways blooms could change these activities and the cost projections then enables the consideration of management implications.

1.3 Thesis structure

Due to the range in scope of the research questions developed, it became apparent that this study would require interdisciplinary research to access the interface between the natural and social worlds, and draw upon these, to examine jellyfish population changes, blooming events and how they impact society. A combination of natural and social science methodologies was therefore required to generate and bring together data to answer the three research questions. In terms of research question 1, a natural sciences approach was applied to develop an understanding of the physiology of jellyfish and how suited the Northeast Atlantic is to populations in relation to the locations of anthropogenic activity. For research question 2, understanding of societal responses to blooms was required, involving social science methodologies to develop an understanding of the impacts of bloom induced changes to the environment so that economic projections of impact could be made. An ecosystem services approach underpinned these aspects of the research, which enabled a conceptualisation of changes to the environment resulting in changes to ecosystem services and benefits. The findings from the natural and social questions that were posed in relation to jellyfish bloom increases and anthropogenic activity then allowed for consideration of the third research question as to whether management is required and what the options are. Throughout this thesis, well established techniques and frameworks from the natural and social sciences were applied to the emerging field of jellyfish bloom impact research.

The remainder of this section describes how the thesis is set out in relation to the investigations and field work that was undertaken. Chapter 2 reviews the literature from which the rationale for the study described in Chapter 1, was coined. It also reports the current knowledge on the physiological thresholds of jellyfish in the marine environment; these formed the bases of the investigations into the locations where blooms and anthropogenic activity could coincide within the Northeast Atlantic. The chapter then outlines an ecosystem service approach framework to develop an understanding of the interactions with blooms that could occur and how subsequent impacts can be quantified. Chapter 3 then discusses the methodology of the research, describing how potential jellyfish populations across the Northeast Atlantic were visualised and the stages of the approach that was used to understand and quantify any bloom impacts that could occur on both the fishing and tourism industries. In Chapter 4, the results of visualisations of potential blooms are displayed, identifying the spatial extent of anthropogenic activity that could be impacted. Chapter 5 and 6 then discuss output from the ecosystem services approach, reporting the responses of the fisheries and tourism industries in the Northeast Atlantic to blooms as well as projecting the subsequent socioeconomic impacts in case study locations identified in in Chapter 4. Chapter 7 then concludes the thesis by discussing the research, outlining policy and management implications of the work as well as future research recommendations.

CHAPTER 2

JELLYFISH BLOOMS AND THEIR CONSEQUENCES TO COASTAL INDUSTRIES

2.1 Introduction

This chapter reviews the literature on the nature of jellyfish blooms, and the potential for future changes in bloom frequencies because of environmental change. The choice to focus on blooms and potential increases in bloom frequencies is based on the fact that they are known to cause a number of socioeconomic impacts to coastal communities. The impacts are due to the interactions blooms have with several anthropogenic activities, such as coastal tourism, finfish aquaculture and fisheries, each of which are discussed during this review. The evidence as to whether increases in bloom occurrence are actually happening, as well as the areas that may experience increasing blooms in the future, are also reviewed and discussed. The review opens at a global level, looking at blooms occurrence across the world's oceans, their socioeconomic impacts and the potential consequences where interactions between jellyfish and people are being reported more often. The review then focuses on blooms in the Northeast Atlantic, as an example of an area where evidence exists that jellyfish populations are increasing. Issues associated with jellyfish blooms on coastal communities are discussed in section 2.2, based on the review of reports on how and the degree to which blooms are known to impact fisheries, finfish aquaculture and coastal tourism. The perception (within society, the media and the scientific literature) of bloom increases worldwide and potential for future blooming event increases are then reviewed (evidence for and against are discussed in section 2.3.1). Focusing again on the Northeast Atlantic, gaps in knowledge about where potential future blooming event increases may occur, as well as previous studies on their spatial distribution, are investigated in section 2.3.2, introducing the Northeast Atlantic as the focus of this research.

To answer the three research questions set out in Chapter 1, a welfare benefit valuation is proposed based on the ecosystem services / benefits approach, in relation to human activities that could be impacted by future blooms (section 2.4). An ecosystem services approach is presented and suggested for this research as a framework to consider the importance of understanding the spatial scale of potential impacts and the variety of methods available to value the benefits derived from coastal and marine waters that could be impacted by blooms.

2.2 Jellyfish Blooms and their Impacts

Gelatinous medusae (members of the Cnidaria (subphylum: Medusozoa) and Ctenophora (for more information on taxonomy see Hayward and Ryland, 2008)), hereafter referred to as jellyfish, are known to bloom as part of their life cycle (Mills, 2001; Purcell *et al.* 2007; Hamner and Dawson, 2009; Richardson *et al.* 2009; Brotz *et al*. 2012). A bloom occurs when large numbers of jellyfish congregate in a specific geographic location, often over a relatively short period of time (Mills, 2001; Brotz *et al*. 2012). Blooming is a natural phenomenon that is described as an evolutionary advantage to gregarious jellyfish, enabling them to out compete other more mobile marine organisms (Shiganova and Bulgakova, 2000; Hamner and Dawson, 2009). Bloom sizes in terms of numbers, biomass, and duration can vary between species and location, with regional reports existing of several thousand individuals occurring in single events (Graham *et al.* 2003). There are a range of negative impacts that blooms have been reported to have on human populations when they occur within inshore waters ranging from generally being detrimental to public health (Mariottini and Payne, 2010; De Donno *et al.* 2014) to causing disruption to human activity such as to coastal tourism (Ghermandi *et al.* 2015), finfish aquaculture (Purcell *et al.* 2007; Gershwin, 2013), and commercial fishing (Knowler, 2005). However, it needs to be acknowledged that not all interactions between large jellyfish populations and people are negative. For example, in some parts of Asia, jellyfish are exploited commercially for consumption by people (Hsieh and Rudloe, 1994; Hsieh *et al.* 2001); some argue that jellyfish have aesthetic value (Graham *et al.* 2014); and in other cases, jellyfish are known to act as prey and havens for commercially important fish species (Bonaldo *et al.* 2004). Most reports however, suggest that blooms within coastal areas have an overall negative impact, which is focussed on in this review. A large proportion of the literature focuses on blooms occurring within the Mediterranean, as well as a few examples in Australasian and Southeast Asian waters, whereas studies are lacking in some areas where jellyfish are known to occur (which includes the Northeast Atlantic). The studies include attempts to quantify the socioeconomic impacts of blooms and provide descriptions of how blooms have negative impacts. The impacts that blooms have on various aspect on fisheries, aquaculture and tourism are discussed, as they are most commonly reported in the literature, and the focus of studies which have attempted to quantify (in economic terms) such impacts. Other industries are known to be affected adversely by blooms, including the nuclear power industry, but there is a lack of specific studies assessing these impacts. Much of the literature reviewed describes the impacts of blooms on coastal human populations in areas where blooms are a common occurrence, such as the Mediterranean where blooms are known to interact with fisheries (Palmieri *et al*. 2015) and tourism (Ghermandi *et al*. 2015) (in most examples discussed in this review, they are an annual occurrence during the summer months).

2.2.1 Fisheries

Many of the impacts reported within this section that are noted within the literature come from the varying locations within the Mediterranean. When occurring within fishing grounds, jellyfish blooms can impact the fishing industry in different ways, including blooms hampering fishing equipment and interfering with the fishing processes, making it less likely that fishermen are able to achieve their quotas, simply because there are too many jellyfish in the water acting as a barrier to target fish species (Uye, 2007; Kim *et al.* 2013; Nastav *et al.* 2013; Palmieri *et al.* 2014). Blooms are also known to damage catch when jellyfish bycatch is concurrently hauled aboard the fishing vessel, decreasing the value of each haul (Nastav *et al*. 2013; Palmieri *et al.* 2014). A survey conducted in the Adriatic Sea, reports that bloom bycatch decreases the amount of catch per haul as the nets are clogged with jellyfish (Palmieri *et al.* 2014), with the fishermen forced to make more hauls, adding to operational costs and time out at sea. Reports also exist that suggest there is an overlap in prey preferences between commercially important fish and jellyfish that leads to competition, which decreases the numbers of fish available for fishermen to catch, which is heightened during blooming events (Purcell and Arai, 2001), although, quantifications of actual decreases are not currently available. Other studies suggest that jellyfish prey upon juvenile fish (Purcell and Sturdevant, 2001), potentially decreasing potential catch further as fewer species are reported to prey upon jellyfish (described as trophic dead ends by Richardson *et al.* 2009). The decreases in fish as a consequence of blooms can be increased further if the target species are already in decline (i.e. as a result of overfishing prior to the occurrences of blooms) (Knowler, 2005). Finally, some jellyfish species can be hazardous to fishermen when they are hauled aboard vessels due to their ability to sting humans (Palmieri *et al.* 2014).

As a result, jellyfish blooms are known to reduce catch, cause fishermen to spend more time out at sea to achieve quotas, as well as impacting the welfare of the crew (Palmieri *et al.* 2015). The invasions of *Mnemiopsis leidyi* across the Black Sea in the 1980s (probably introduced via ballast water), were suggested to be a significant factor, together with overfishing, in the fishery crashes that occurred there (Knowler, 2005). The economic model developed by Knowler (2005) suggests that the blooms of the ctenophore contributed significantly to the population crashes in anchovy that was targeted by the fishery. The model attributed annual catches dropping by 90% during the *M. leidyi* blooms, culminating in losses of around $16.7 million per year which amounted to a 98%

decrease in total profits. In a more recent study, Palmieri *et al*. (2014) assessed the effects of annual blooming events within the northern Adriatic, a location of one of the most heavily exploited fisheries in the Mediterranean. A survey of fishermen's perceptions of blooms in the area revealed that they had suffered negative effects on their fishing activity (described above), with estimated economic losses for the Italian trawl fleet at €8.2 million per year due to blooms forcing alterations to fishing operations, damaged fishing gear, and impacting the health of fishermen. The study revealed increased annual fuel costs (€460,000) as fishermen have had to travel further given traditional fishing grounds had succumbed to blooms, but also because additional trawls to achieve quotas were required as a consequence of bloom bycatch which decreased the fish caught per trawl. Damage to nets caused by bloom by-catch resulted in estimated 89,000 extra man hours a year in equipment maintenance. In fact, annual blooms of *P. noctiluca* and *A. aurita* in Mediterranean waters are known to clog fishing nets and foul fishing apparatus, resulting in costs for replacing and repairing damaged gear (reviewed by Purcell *et al.* 2007; Purcell, 2012). Also, reviews of the primary literature that summarise the interactions between users of the marine environment and blooms, state that blooms are hazardous to fishermen when stinging jellyfish bycatch is hauled onto the deck of vessels with crew reporting health issues when sorting catch, forcing them to use extra safety gear (Purcell *et al.* 2007; Brotz *et al.* 2012; Gibbons and Richardson, 2013).

There appears to be few responses available to fishermen to mitigate the impacts caused by bloom disruption. One example, provided by Palmieri *et al.* (2014), suggests that fishermen should move to other grounds upon witnessing blooms before deploying their fishing gear, but this does not guarantee bloom avoidance because of the distance the fishermen have to trawl across bloom prone waters. It only takes one bloom within the large distance trawled to cause the issues described above. On top of this, there is added fuel costs of moving to alternative fishing grounds, which may also be compromised by blooms. Other responses available to fishermen that enable them to achieve their catch include: spending more time out to sea, as a result of having to do more trawls due to jellyfish clogging nets and leaving less room for catch as well as the greater time needed to sort bloom bycatch; wear protective gear to avoid stings; and having to repair / replace damage to nets caused by jellyfish (all reported by Palmieri *et al.* 2014). All of these responses highlighted above result in added welfare and economic costs even if the fishermen still achieve their quotas, with consequent reduced profits.

2.2.2 Finfish Aquaculture

In terms of finfish aquaculture, jellyfish bloom presence has been reported to result in economic impacts as jellyfish are known to trigger gill disorders and mortality in penned finfish (Sammes and Greathead, 2004; Purcell *et al.* 2007; Doyle *et al.* 2008; Baxter *et al.* 2012). This happens because jellyfish are planktonic and are unable to swim against water movements, which pull them towards aquaculture pens due to the micro-currents created by penned fish all swimming in unison (Gershwin, 2013). It could also be the case that blooms simply coincide with the locations of finfish pens (Doyle *et al.* 2008). Jellyfish in the vicinity become entangled to the structures of the enclosures and break up when forced against the mesh (Gershwin, 2013). Stinging cells remain active when they break up and enter the fish pens and inevitably enter the gills of penned fish. This causes haemorrhages that leads to suffocation and death (Sammes and Greathead, 2004). Also, biofouling of pens as consequence of the presence of some hydrozoan have been reported to also lead to gill disorders, resulting in mortality and harvest spoiling (Baxter *et al.* 2012). Some reports also suggest that jellyfish harbour pathogens that trigger fish kills (Delannoy *et al.* 2001). Jellyfish are also known to be a health hazard for people who work in the industry due to their ability to sting and can increase maintenance requirements of aquaculture apparatus (Bosch-Belmar *et al.* 2017).

Doyle *et al.* (2008) reported a record blooming event of *P. noctiluca* (encompassing a 10 square-mile area) off the coast of Ireland, to which the death of 100,000 farmed salmon was attributed directly, resulting in around £1 million in lost aquaculture revenue. Other examples of this phenomenon include severe blooms between 2001–02 where extensive occurrences (11 recognised bloom events) of *Cyanea capillata* off the Isle of Lewis, Scotland, caused the death of around 2.5 million farmed salmon, resulting in estimates of £5 million worth of economic costs (Johnson, 2002). In the Mediterranean, a survey of the impacts of blooms revealed that a single event in 2011, caused a fish kill that cost a Spanish company €50,000 as well forcing them to either replace net cages (€4000 per time) or apply cleaning treatments to pens using formalin baths (€ 3000 per time) (Bosch-Belmar *et al.* 2017). Additionally, the study reports that the Tunisian aquaculturist company incurred economic losses of a bloom-induced fish kill in the year 2009 that almost bankrupted it (Bosch-Belmar *et al.* 2017). There is a paucity of suggestions for the aquaculture industry in terms of mitigating the impacts of blooms.

However, during the 2012 annual PICES meeting, Doyle *et al.* (2012) described several suggestions as to what the industry (specifically within the Northeast Atlantic) could do to mitigate and prevent further mortality and gill disorders in the event of bloom increases. The initial suggestion was to develop an early warning system when blooms are forecast to occur in the locations of pens so that mitigation actions can be enacted, such as emergency harvests or boarding up pens. Other suggestion included the development and implementation of bubble curtains, but this requires testing as to whether it actually stops bloom induced fish kills and needs further development to make it less expensive. Another suggestion was to force farmed fish lower in the water column to avoid blooms, however a better understanding of vertical distribution of blooms is required specific to the location of the pens and the species that are may to increase in an area. Understanding if blooms occur offshore and placing pens there instead of nearer the coast was the fourth suggestion, but because of the potential relocation of the pens, if the technology was available, could be expensive.

There are therefore a number of physical changes to operations that could mitigate the impacts of future bloom increases, but these are either expensive or require further research as to whether they would work before they could be implemented. Generating better understanding of the preferences of those who actually farm penned fish may provide indications of which may be effective solutions were blooms to become more common. The suggestion of increased engagement is supported by a study by Bosch-Belmar *et al.* (2017), whose investigations with the industry suggested that different aquaculturists have varying knowledge of the impacts of blooms across the Mediterranean and therefore a varied understanding on how to adapt (e.g. Italian and Spanish fish farmers were better informed about the potential impacts of blooms compared to their Maltese counterparts). In any areas where bloom increases may interact with the industry, informing aquaculturists that they are operating in locations that could experience future blooms may lead them to engaging in behaviours that result in less severe socioeconomic impacts selecting less expensive preventive and / or mitigation techniques should the blooms appear. The literature therefore highlights a need for improvements in technology and further engagement with the industry in the event of the impacts of blooms becoming more substantial in areas that currently experience them less or not at all. However, forecasting bloom locations appears to be the most popular suggestion to reduce the magnitude of an unavoidable impact and should be a focus of future research into controlling the impacts of future blooms increases (Doyle *et al.* 2012).

2.2.3 Coastal Tourism

The most commonly reported effect of blooms on coastal tourism is the stinging of beach users, particularly as Scyphozoa, Cubozoa and some Hydrozoa stings can cause severe discomfort and even death in humans (Burnett, 2001). Most of these reports describe health issues when blooms impact water-based activities (e.g. bathing), but they can also impair land-based recreation when mass strandings occur (Palmieri *et al.* 2015). This can include the large amount of jellyfish biomass washing up and acting as a barrier to recreation by the sea (e.g. sunbathing and walking), spoiling the scenery and when they decompose, they produce odours that discourages beach recreation (Palmieri *et al.* 2015). Also, as long as the stinging mechanisms remain wet on dead jellyfish that have washed ashore, they are still capable of delivering sting to humans, resulting in further health issues (Haddad *et al.* 2009). When large aggregations of jellyfish occur in coastal zones the stinging interactions with bathers can reach epidemic proportions and essentially result in beach closures (reviewed by Purcell *et al.* 2007). This was the case in the 1960s when *Physalia physalis* was attributed to the stinging of 1,500 swimmers in 1961 in the Kanagawa region of Japan (Yasuda, 1988). During the mid-1980s in the French Riviera, 2,500 people were treated for *P. noctiluca* stings (Bernard *et al.* 2011). Blooms are considered an annual occurrence in some waters (particularly around tourist destinations within the Mediterranean), with the widest scale impacts attributed to *P. noctiluca* (Bernard *et al.* 2011). The most recent records state 45,000 stinging cases are regularly reported across the Mediterranean coasts over a summer season (Bernard *et al.* 2011). There are also examples of highly dangerous species (often Cubozoa) occurring in Australian, Asian and Indo-pacific waters that annually kill recreational water users (Fenner and Williamson, 1996; Burnett, 2001; Palmieri *et al.* 2015).

All of these interactions serve to decrease the number of visitors to coastal resorts, either through beach closures or bloom presence discouraging visitors from an area (Ghermandi *et al.* 2015; Nunes *et al.* 2015). However, although estimates of costs exist, and welfare impacts are reported, few studies specifically state how much blooms decrease recreational activities along the coasts, particularly across the Northeast Atlantic (Palmieri *et al.* 2015). Quantification or predictions of the actual economic costs of blooms to tourism are also uncommon, possibly due to the fact that monitoring who visits coastal areas is difficult and there are several indirect effects caused as a result of jellyfish presence (discussed below) that may impact the accuracy of models that estimate costs (Palmieri *et al.* 2015). However, one attempt to quantify economic loss in a location of high coastal tourism is reported off the coast of Queensland, Australia, where the summer presence of the Irukandji jellyfish (highly venomous) deterred tourists from visiting resorts across the coastline, costing the tourism industry an estimated AU$65 million (Macrokanis *et al.* 2004; Gershwin *et al.* 2009). A more recent quantification of the impacts of blooms is reported by Ghermandi *et al.* (2015), who assessed the impacts of blooms on beach recreation along the Mediterranean coast of Israel by means of beach user surveys. The responses to blooms that were reported led to predicted monetary losses of €1.8 - €6.2 million per year to seaside tourism in Israel (estimations of monetary losses based on two case study locations along Israel's Mediterranean coast line). As well as the costs, Ghermandi *et al*. (2015) demonstrated decreases in recreational visits to coastal resorts during blooms. Based on responses to the survey, the study estimated that beach visits decreased by between 3% and 10.5% when blooms were present with 41% of respondents stating that their recreational activities were impacted by bloom presence. This contributed to decreases in tourism expenditure and associated impacts to the local economy. The reasons and motives behind such decreases in beach visits have been investigated. One hypothesis is that tourists hold a negative perception towards jellyfish. However, studies on public knowledge about jellyfish indicate that publics are not well informed about jellyfish (Dolch and Schernewski, 2004; Kessler, 2009), which includes the belief that most species are dangerous, leading to reduced beach visits regardless of the type of the species that is occurring (Baumann and Schernewski, 2012).

The main measures to mitigate jellyfish impacts on tourists have been aimed at keeping visitors within a coastal resort, maintaining their recreational activities whilst at the same time, reducing interactions with jellyfish (specifically stinging species). This has been achieved in the Mediterranean by the Med-Jelly Risk project where pools were created that separate small sections of the beach from blooms in the water and nets were used to protect sections of the coast from jellyfish washing ashore. On the project website (jellyrisk.eu), reactions to the nets have been reported to be positive in a number of locations where they have been installed. For example, in Italy bathers praised their effectiveness, and beach side hotel owners have requested more nets to be put in place (MED-JELLYRISK, 2017). However, there are no evaluations or investigations as to whether the benefits of such schemes are greater than the costs of setting the nets up. Also, it can be argued that this is not a faultless measure because nets deployed throughout the summer period foul due to them being deployed throughout the stinger seasons. The nets are also unnecessary during times when blooms are not present, potentially hampering some recreational activities.

Education of beach users about blooms is another potential avenue for mitigating the negative impacts of jellyfish blooms on tourism. A study by Baumann and Schernewski, (2012: 555) reports that coastal users “are less bothered” when they know about the species that are occurring. Information can be delivered through social media or phone applications (Marambio *et al* 2013), or through beach signage urging people to avoid the water at times of blooms of the more dangerous species (Cegolon *et al.* 2013; De Donno *et al.* 2014). The Med-Jelly Risk project, for example, developed a mobile phone application that indicates when there is jellyfish risk on certain beaches. Success associated with the applications is also reported on their website, as it was nominated for a Maltese communication award in 2014. However, there are again no estimates or quantifications of the benefits that the App has generated. The notion of a net separating bathers from jellyfish seems to have traction. Via a contingent valuation study, Ghermandi *et al*. (2015) found that 56% of the survey respondents (the recreationalists on the beaches of Tel Aviv) were willing to donate to schemes similar to the MED-JELLYRISK projects. They also suggested that investment in public information about jellyfish would mitigate bloom impacts, referring to the Med-Jelly App and social media as a valuable tool, despite the lack of evaluation.

To sum up, the literature that describes the impacts of blooms on tourism are widely reported, but despite a few examples, specific quantifications of impacts are still rare (in particular, welfare impacts are still poorly quantified (Ghermandi *et al.* 2015)), indicating there is scope to develop such insights further.

Evaluation of costs of jellyfish blooms has concentrated to date, on areas that geographically have experienced them the most, thus offering the opportunity to explore the (economic) effects of jellyfish blooms in areas where they may occur in the future. Insights on how coastal tourists would react to blooms in areas where they are currently less common, would serve as a basis for projecting quantifications of economic and welfare costs. In terms of management there is scope to engage with different beach recreationalist to understand preferences towards nets, phone applications, social media and jellyfish information signage in locations where blooms could be future concern to understand how to apply similar projects to the ones reported above. Quantifying socioeconomic impacts on a consistent monetary scale might also provide indications of how much could be spent on a management scheme.

2.3 Are Blooms on the Increase?

Since the 1980s there have been increasing reports in both the media and scientific literature of conflict between humans and blooms worldwide (Lotan *et al.* 1993; Pagés, 2001; Uye and Ueta, 2004; Purcell *et al.* 2007), which has led to a perception that jellyfish are becoming more abundant and that blooming events are becoming more frequent, spreading to areas where historically they have not been recorded (Mills, 2001; Purcell, 2005; Licandro *et al.* 2010; Lehtiniemi *et al.* 2011; Purcell 2012). For example, Uye and Ueta (2004) describe that fishermen fishing in the inland seas of Japan, reported long term increases in *Aurelia aurita* blooms, which appear to have accelerated in the last 10 years. Other examples of evidence of increasing blooms can be found in Mills (2001), who discusses the role of environmental change on jellyfish populations, indicating that generally changes to the marine environment such as increasing temperature, favour jellyfish; and in Pauly *et al.* (2009), who describe general populations of jellyfish using online databases, reporting a general increase. There may be several explanations for why this trend appears to have occurred. Purcell *et al.* (2007), Richardson *et al*. (2009) and Purcell (2012), suggest environmental and anthropogenic contributors, such as climate change which provides conditions that favour jellyfish (such as temperature increases), overfishing which reduces competition and predation of jellyfish, species translocation, eutrophication and increasing development of hard structures such as windfarms which provide more locations for polyp recruitment. Other explanations include, increasing anthropogenic presence in the oceans leading to more interactions with jellyfish, which has resulted in an unsupported perception of bloom increases (Condon *et al.* 2012; Condon *et al.* 2013).

However, as each of these factors increases, the chances of humans and blooms interacting in coastal locations (at least in the short term), it might be argued that the socioeconomic impacts discussed throughout section 2.2 will escalate if the observed trends are confirmed and human responses are not modified substantially. Condon *et al*. (2012) suggest that media stories of increased blooms (underpinning heightened public awareness of blooms) and reports in the scientific literature, are not supported given the data currently available. There is a lack of long term datasets on jellyfish abundance and potential bloom increases is due to practical difficulties of researching them as medusae are difficult to sample because they are fragile (Hay *et al.* 2006; Purcell, 2009; Richardson *et al.*

2009) as well as them being classed until recently (Sullivan and Kremer, 2011) as trophic dead ends (Richardson *et al.* 2009). Sanz-Martin *et al.* (2016: 1039) tracked the evolution of the perception of bloom increases in the scientific literature through a citation network to reveal that “48.9% of publications misinterpreted the conclusions of the sources” that they had cited contributing to an over exaggeration of the trend. For example, within these misinterpretations there was a bias towards increasing jellyfish numbers, with one review becoming the main citation source. Condon *et al.* (2012:166) suggest that the existing paradigm of bloom increases needs to be redefined by examining “historical, current and future trends in medusae” where data are available, and by monitoring the impacts that they have on ecosystems and society. Many (>100) publications cite Condon *et al.* (2012), indicating that robust analyses must underpin statements about bloom increases, particularly when considering their future distributions and the socioeconomic impacts that could be incurred.

2.3.1 Causes of Blooms

It is suggested that physiologically jellyfish respond to favourable environmental parameters by blooming (Purcell, 2012). Several studies have tested how a combination of ocean temperature (Lotan *et al.* 1994; Purcell *et al.* 2012; Purcell 2012), prey availability (Decker *et al.* 2007; Lilley *et al.* 2014) and salinity (Hirst and Lucas, 1998; Ma and Purcell, 2005; Holst and Jarms, 2010) in the marine environment provides suitable conditions that can support large jellyfish populations (Purcell *et al.* 2007; Purcell, 2012; Collingridge *et al.* 2014). Purcell *et al.* (2012) recorded higher survival and strobilation rates at increasing temperatures in a number of Scyphozoa species under laboratory conditions, indicating that within limits, blooms could occur at higher temperatures. Correlations between increasing ocean temperatures and increasing jellyfish abundances has also been noted in the natural world (Purcell, 2012), with seasonal temperatures being reported to influence life cycle patterns (Lotan *et al.* 1994). Lilley *et al.* (2014) provided evidence to suggest that feeding rates on zooplankton alter survival and ephyrae development in the Scyphozoan *P. noctiluca,* showing increases in prey at the ephyrae stage of the life cycle is required, so that enough juveniles could survive to achieve the numbers of adult medusae associated with blooms. Increased jellyfish presence is also regularly recorded in areas of high zooplankton biomass, showing opportunism to preferable conditions (Decker *et al.* 2007). The suitability to different salinities for jellyfish has also been tested to show how it affects life cycles, with conclusions existing that it can be a limiting factor in organismal function and reproduction (Hirst and Lucas, 1998; Ma and Purcell, 2005; Holst and Jarms, 2010). Salinity is therefore a potential barrier that affects environmental suitability for jellyfish and therefore blooms. Jellyfish generally show high plasticity to salinity and this has enabled them to occur in places where other marine species are limited such as brackish environments (Holst and Jarms, 2010).

Relating increased bloom facilitation to a combination of these three factors could therefore generate understanding as to whether future bloom increases are a possibility and where future blooms may occur (Mills, 2001; Ma and Purcell, 2005; Collingridge *et al.* 2014). The information available on jellyfish physiology therefore provides scope for potentially highlighting locations more prone to blooms, as well as project if future bloom increases may occur. It must also be acknowledged that are other factors reported to contribute towards blooms such as wave and wind currents that transport jellyfish congregation into localised areas (Mills, 2001). Jellyfish are also reported to be able to survive conditions that their competition and predators can't, such as lower oxygenation (Condon *et al*. 2001) and lower water pH (Attrill *et al*. 2007), enabling them to achieve increased numbers of medusae associated with blooms. Hard structures (Duarte *et al*. 2013) such as windfarms (Richardson *et al*. 2009) and increased nutrients in the water column (Arai, 2001) have also been associated with greater recruitment. However, there is greater uncertainty and a lack of quantifications on how these factors influence blooms of individual species making assessment and examination of them on populations unachievable.

2.3.2 The Example of North East Atlantic.

The Northeast Atlantic has been offered as an example of a location where evidence exists of increasing jellyfish populations. In an ecological modelling study based on continuous plankton recorder (CPR) data, Licandro *et al*. (2010) described increased cnidarian occurrence in the Northeast Atlantic between 2002 and 2010. They specifically suggest that the warm temperate species, *Pelagia noctiluca,* is benefitting from hydrodynamic changes, with ocean currents transporting them from more southerly latitudes to the Northeast Atlantic, an area that has experienced warming in recent decades (getting closer to temperatures found in more southern latitudes where *P. noctiluca* is most common). The study suggests that a combination of productive waters in the Northeast Atlantic and water temperature are increasing the chances of blooms in the area. With predictions that the Northeast Atlantic will continue to warm (IPCC, 2013) and other hydro-climatic factors that benefit gelatinous medusae will continue, Licandro *et al.* (2010) conclude that outbreaks of *P. noctiluca* and other jellyfish may become more common than in previous years, including in the waters off the coasts of Britain. With the exception of a few anomalous events (e.g. the *P. noctiluca* blooms in 2007 and 2008 (Doyle, 2008)), Northeast Atlantic waters are yet to report the negative effects (such as the widespread stinging events of beach users (Ghermandi *et al.* 2015) and economic costs at the same level as other locations such as the Mediterranean (Licandro *et al.* 2010). However, if any increases do occur, the interactions between humans and jellyfish (sections 2.2.1 – 2.2.3) could become more common (Licandro *et al.* 2010). Northeast Atlantic waters are also within the northern range of a variety of species associated with more southerly and warmer waters, including blooming jellyfish which are occurring more frequently in shelf waters (Beaugrand 2009; Graham & Harrod 2009) and are expected to continue to expand northwards (Purcell *et al.* 2012; Collingridge *et al.* 2014). Some attempts exist to model jellyfish populations in the Northeast Atlantic based specifically on the levels of the environmental factors discussed above (temperature, salinity and prey availability). One example is Collingridge *et al.* (2014) who modelled the suitability of the North Sea for *M. leidyi*, to assess if invasions of this ctenophore are a possibility in responses to this species being discovered in the North Sea in the mid-2000s (Olveira, 2007). Based on the temperature, salinity and prey levels, the model found that large areas were suitable for survival with summer conditions being suitable for reproduction, citing ocean temperature and food availability as the main limiting factors for *M. leidyi*. However, less is known of how native jellyfish populations in the Northeast Atlantic may react to changes in the environment such as temperature, salinity and prey abundance and modelling them in a similar way to how Collingridge *et al.* (2014) modelled *M. leidyi* suitability would potentially provide evidence as to whether the perceptions of jellyfish population increases could have occurred within the last decade.

Painting *et al*. (2014) provided some evidence of native populations by correlating environmental conditions (temperature, salinity, turbidity, and chlorophyll levels) against the locations of jellyfish based on bycatch records. Presence of *Cyanea capillata* (and to a lesser extent *Aurelia aurita* and *Pelagia noctiluca*, but in lower numbers) appeared to be influenced mainly by suitable temperature and chlorophyll levels with salinity ranges and lower ocean turbidity also having an effect. Spatial locations of blooms of *A. aurita* also allowed Painting *et al.* (2014) to theorise that localised blooms could have been a result of hard structures placed in the water by man, acting as additional polyp nurseries. Pikesley *et al.* (2014), also highlight the value of citizen science data in increasing the knowledge on spatial and temporal patterns of jellyfish populations across the UK, based on sighting records submitted by citizens to the Marine Conservation Society (MCS) website. They suggest that with appropriate data collection and interpretation, public driven records can contribute towards the understanding as to whether jellyfish are increasing in a specific area as well as understand the conditions that support bloomed populations. Developing further suitability models for native and other invasive species in the area, combining them with sighting data (provided by scientists, fishermen and the public) will further contribute to the debate as to whether jellyfish blooms are on the increase. If they are, the same data gathered could shed light on where and how often issues associated with blooms could occur in the Northeast Atlantic and the specific locations most suitable.

2.3.2.1 Jellyfish of the Northeast Atlantic

Several native species that occur within Northeast Atlantic waters and seasonal visitors from more southerly latitudes can cause socioeconomic impacts to anthropogenic communities and could potentially bloom more frequently in the future (Purcell *et al*. 2007; Richardson *et al.* 2009; Doyle *et al.* 2007; Licandro *et al.* 2010 Pikesley *et al.* 2014). Most of these species are Scyphozoa with life cycles that contain both free swimming medusae stages and benthic polyp stages (Lucas, 2001). A typical example of a species with free swimming and dormant stages is *Aurelia aurita*, where sexual reproduction occurs between adult male and female medusae that produces a planula larva which descends to the sea bed where it attaches to a hard substrate and forms into a benthic polyp (Lucas, 2001). Polyps then bud and start strobilation (asexually), releasing free floating ephyra into the ocean that then develop into adult medusae (Lucas, 2001). The Northeast Atlantic Scyphozoa with both free swimming and benthic stages within their life cycles that were considered in this study are *Aurelia aurita* (the Moon jellyfish), *Cyanea capillata* (the Lion's Mane jellyfish), *Cyanea lamarkii* (the Blue jellyfish), *Rhizostoma pulmo* (the Barrel jellyfish) and *Chrysaora hysoscella* (the Compass jellyfish). However, there are also examples of Scyphozoa found within the Northeast Atlantic that only have a free swimming medusae stage within their life cycle such as *Pelagia noctiluca* (the Mauve Stinger) (Morand *et al*. 1987; Pikesley *et al.* 2014), as well as species that share similar morphological traits to jellyfish medusae (and subsequently cause similar socioeconomic impacts discussed earlier in this chapter) such as the Siphonophore *Physalia physalis* (the Portuguese Man O' War), which is a free-floating colony of symbiotic polyps that have a neustonic life style (Holdway and Maddock, 1983; Purcell, 1984).

A aurita is the most common of the species considered in this study and has a wide distribution across the entire Northeast Atlantic (and worldwide) as it can tolerate a range of environmental factors, including variable temperatures (Lucas, 2001). *A. aurita* is most commonly found in coastal waters (Doyle *et al*. 2007) with adult medusae typically reaching between 5 - 40cms in size (Hayward and Ryland, 2008). *A. aurita* feeds on small planktonic organisms which includes both zooplankton (e.g. copepods), phytoplankton (e.g. diatoms) and larvae of a variety of marine species groups which includes mollusks, pelagic fish eggs and crustaceans (Sullivan *et al*. 1994; Graham and Kroutil, 2001). *A. aurita* is a species that is known to undergo vast blooming events in coastal locations where it has been known to impact both the fishing and tourism industries, despite having a limited capacity to sting humans (Purcell *et al.* 2007; Richardson *et al*. 2009).

C. hysoscella is another Scyphozoa that occurs within Northeast Atlantic waters and has benthic and free-swimming stages within its life cycle; however, this species is a hermaphrodite, capable of both sexual and asexual reproduction (Russel, 1970; Lucas, 2001). *C. hysoscella* shares some characteristics that are similar to *A. aurita,* such as similar medusae size (typical diameter of an adult is around 30cms (Hayward and Ryland, 2008)) and diet (e.g. reported to feed on zooplankton, phytoplankton and planktonic larvae of other marine species (Dawson and Giordano, 2018). However, *C. hysoscella* has a smaller spatial range across the Northeast Atlantic (although is known to occur from the Bay of Biscay to Norwegian waters), as it is most is most commonly found in more southern regions, particularly to the south of the Celtic Sea, amongst the warmest waters within the Northeast Atlantic (Doyle *et al*. 2007). *C. hysoscella* has a more pronounced sting than *A. aurita*, but is not considered particularly dangerous to humans, causing only mild irritation (Del Negro *et al*. 1992).

Both *C. lamarkii* and *C. capillata* belong to the Cyaniidae jellyfish and are most commonly found in more northerly latitudes within the Northeast Atlantic where temperatures are cooler, and waters are generally more productive (Lynam *et al*. 2004; Hayward and Ryland, 2008; Doyle *et al*. 2007). The Northeast Atlantic can be considered within the more southerly regions of their range, with both species occurring in Arctic waters, northern regions of the Celtic Sea and across the North Sea, although they can be known to occur further south deepening on conditions and tidal movements (Lynam *et al.* 2004; Doyle *et al.* 2008). Both species have a similar life cycle to *A. aurita* (described above) but start appearing in the spring (compared to all the other medusae considered in this study, that are at their most common during the summer and autumn months) (Brewer *et al*. 1989; Haywards and Ryland, 2008). Despite both belonging to the same genus and having similar distributions, there are several morphological differences between these two species. For example, *C. capillata* is larger in size (medusae up to 2ms in diameter) than *C. lamarkii* (medusae around 30cms) (Hayward and Ryland, 2008), is more conspicuous and is generally recorded more regularly in the Northeast Atlantic (Doyle *et al.* 2007). Both species are capable of stinging humans, however, *C. capillata* has a more potent sting (Hayward and Ryland, 2008) and is reported to have interacted with anthropogenic activity more regularly in the Northeast Atlantic (Purcell *et al*. 2007). Both species have been reported to have similar diets to the other jellyfish within the Northeast Atlantic, however, due to its size and stinging capability, *C. capillata* is able to prey on larger organisms, including species of small pelagic fish and their eggs (Brewer *et al*. 1989).

R. pulmo is the other Scyphozoan jellyfish with both free swimming and dormant life cycle stages considered in this study. *R. pulmo* are the largest medusae that are found within the Northeast Atlantic, particularly when they are found in coastal locations (however, *C capillata* can grow to much larger sizes in more northerly latitudes within cooler, deeper and more productive waters (Naylor, 2018)). *R. pulmo* is most common in warmer waters and the Northeast Atlantic is considered within the more northerly reaches of its range, with ocean currents bringing it to the south Celtic Sea, southern North Sea and English Channel during the summer months (Houghton *et al*. 2006; Doyle *et al.* 2008). Medusae are bulky and can grow up to 90cms in diameter, which contain stinging tentacles, capable of leaving mild irritation on human skin (Hayward and Ryland, 2008). Despite its size, *R. pulmo* is reported to have a similar diet to the smaller medusae (e.g. *A. aurita*), mainly consuming microplankton (Lilley *et al*. 2009).

The only Scyphozoa without a benthic stage that was focussed on within this study was *P. noctiluca*. This species typically inhabits deeper, pelagic waters due to it not being constrained by a benthic polyp stage (Doyle *et al.* 2008), but ocean currents bring them into inshore areas within the Northeast Atlantic where they are known to impact fisheries, aquaculture and coastal tourism, particularly when they bloom (Purcell *et al*. 2007). This species is typically associated with warmer waters associated with more southerly latitudes but is known to occur within the Southern Celtic Sea and has even been recorded in more northerly regions of the Northeast Atlantic where it has been responsible for the deaths of farmed finfish off the costs of Ireland and Scotland (Lynam *et al.* 2004; Doyle *et al*. 2008). Despite being associated with warmer waters, this species shows plasticity to cooler temperatures and is capable of surviving starvation during times when sustenance is lacking, enabling it to survive conditions in the Northeast Atlantic and thrive when conditions become more favourable (Doyle *et al*. 2008; Licandro *et al*, 2010; Lilley *et al.* 2014). Despite having a relatively small medusae (typically around 10 cm in diameter (Hayward and Ryland, 2008), this species possesses one of the most potent stings out of the species that occur in the Northeast Atlantic (Hayward and Ryland, 2008, Licandro *et al*. 2010). Like other Scyphozoa, they prey upon a range of planktonic species and when they bloom, are known to apply significant predation pressure on Ichthyoplankton, particularly anchovy larvae (Gordoa *et al*. 2013; Tilves *et al*. 2016). Due to their potent stings and ability to digest food extracellularly and intracellularly, they are capable of consuming multicellular organisms (Morand *et al*; 1987; Lilley *et al*. 2014).

Although not a true jellyfish, *P. physalis* (a Siphonophore belonging to the Hydrozoa) was considered in this study due to it having a known ability to impact upon ecosystem services and the general morphological characteristics that it shares with the Scyphozoan jellyfish (e.g. marine species with stinging tentacles protruding from a bell like structure). They are colonies made up of several different specialised and symbiotic polyps, characterised by a pneumatophore gas bladder that persists on the surface of the ocean, attached to stinging tentacles that are submerged underwater to capture prey and a specialised digestive system (Purcell and Arai, 2001; Hayward and Ryland, 2008). *P. physalis* is carnivorous, feeding mainly on small and juvenile pelagic fish that get caught up amongst their stinging tentacles, as well as a range of planktonic organisms (mainly fish eggs) (Purcell and Arai, 2001). It uses the gas bladder like a sail for transportation, so the distribution of this species is determined by tides and trade winds, which can result in them occurring in large numbers within the Northeast Atlantic (Pikelsey *et al.* 2014). It is most likely to occur across the southern Celtic Sea, English Channel and Southern North Sea during late summer and early autumn, however occurrences are rare (once every few years) (Pikesley *et al*. 2014), as it is more common in tropical and subtropical waters (Purcell and Arai, 2011; Labadie *et al.* 2013). The sting of this species is very potent and can be fatal to humans (Labadie *et al*. 2013), enabling it to have significant impacts on a range of anthropogenic activities such as coastal tourism (Labadie *et al*. 2013).

Concern has been expressed in relation to future increases in the occurrence of these species and the impacts that they could have (Purcell *et al*. 2007; Richardson *et al.* 2009; Doyle *et al.* 2007; Licandro *et al.* 2010; Pikesley *et al.* 2014), so the following section highlights an approach to understand and quantify the impacts that each of these species could have in the event of them blooming more regularly within the Northeast Atlantic.

2.4 The Ecosystem Services Approach

Ecosystem services (ES) are “ecological characteristics and functions that are utilized (actively or passively) to produce human well-being” (Fisher *et al*. 2009; 645). The definition states that the services arise from ecological structures and processes utilized with the fundamental intervention of human capital, either directly or indirectly (Fisher *et al*. 2009). An example includes ecological processes such as primary production in the oceans contributing towards the growth of fish, which is then caught (intervention of human capital) to provide food for human consumption (Costanza *et al.* 1997). Aspects of ecosystems such as ecological processes and subsequent services can therefore be classed as goods that have value to humans, which can be assessed and quantified for a variety of purposes (Fisher *et al.* 2009). Therefore, the study of ES provides a “bridge between ecological and economic approaches” that can measure a variety of impacts associated with environmental change to the value of ecosystems that are of importance to anthropogenic communities (Costanza *et al.* 2017, p.13). In other words, ES approaches assess environmental benefits of ecosystems to human wellbeing and welfare, accepting that humans make up part of the ecosystem (MEA, 2005, UKNEA, 2011; Ingram *et al.* 2012), instead of focussing primarily on either the ecological or the monetary aspect of individual ecosystem services (Costanza *et al.* 2017). ES approaches do not assume a linear relationship between the environment and the variety of benefits that can be derived from them, allowing the often-complex relationships between the environment, the economy and society to be measured, specifically describing how the economy is linked to interactions between human communities and ecosystems (Costanza *et al.* 2017). Linking human welfare with how ecosystems function is becoming a common approach towards providing information for decision makers, particularly as environmental change is being acknowledged as altering how humans interact with the natural world (Fisher *et al.* 2009). In fact, the aim of an ES approach is to report, quantify and value the benefits that people derive from the natural world (Costanza *et al.* 1997), to provide information and insights for policy and decision makers, supporting them in developing measures to maintain healthy ecosystems that continue to benefit society (Ingram *et al.* 2012). It has been argued that for effective management decisions regarding ES at risk from degradation, the application of an ES approach must encompass all the complex processes of the ecosystem and all the associated services / benefits that human populations derive from them (Morse-Jones *et al.* 2011). However, when valuing changes in ecosystem services and benefits, Morse-Jones *et al.*

(2011) highlight important considerations to be made during the analysis including taking into consideration the location of the ES under investigation, and the issue of double counting ES, which may lead to an overestimation in welfare values. Since valuation is done on benefit derived from ecosystems, the estimation of the value is based on the change of one or few specific intermediate or final ES that are valued individually, avoiding double counting (Fisher *et al*. 2009).

The significance of investigating ecosystem services and the benefits they provide to humans was initially highlighted with the publication of the Millennium Ecosystems Assessment (MEA) in 2005 that described how wide scale declines in ecosystems causes, and will continue to cause, negative impacts on welfare because of the consequent decreases in human ability to derive benefits from degraded ecosystems. The MEA describes four different types of services: cultural services (the use of nature for human activity that provides welfare benefits; this includes recreation/tourism), provisioning services (resource production; e.g. food for human consumption), supporting services (general functions that enable an ecosystem to provide services; e.g. primary production) and regulating services (benefits gained from process that regulate and maintain the ecosystem; e.g. carbon sequestration and storage). As highlighted by Morse Jones *et al.* (2011), ES are context dependent and can be categorised as either intermediate or final services depending on benefits that are being investigated (Boyd and Banzhaf, 2007). ES are therefore different from benefits because it is the benefits that encapsulate changes in welfare, which require human capital and intervention for such benefits to be gained (Fisher and

Turner, 2008). The distinction between intermediate and final ecosystem services compared to benefits derived by humans using built and social capital and the four-different service categories within the Northeast Atlantic have been investigated in the UKNEA-FO (2014) and are displayed in Figure 2.1.

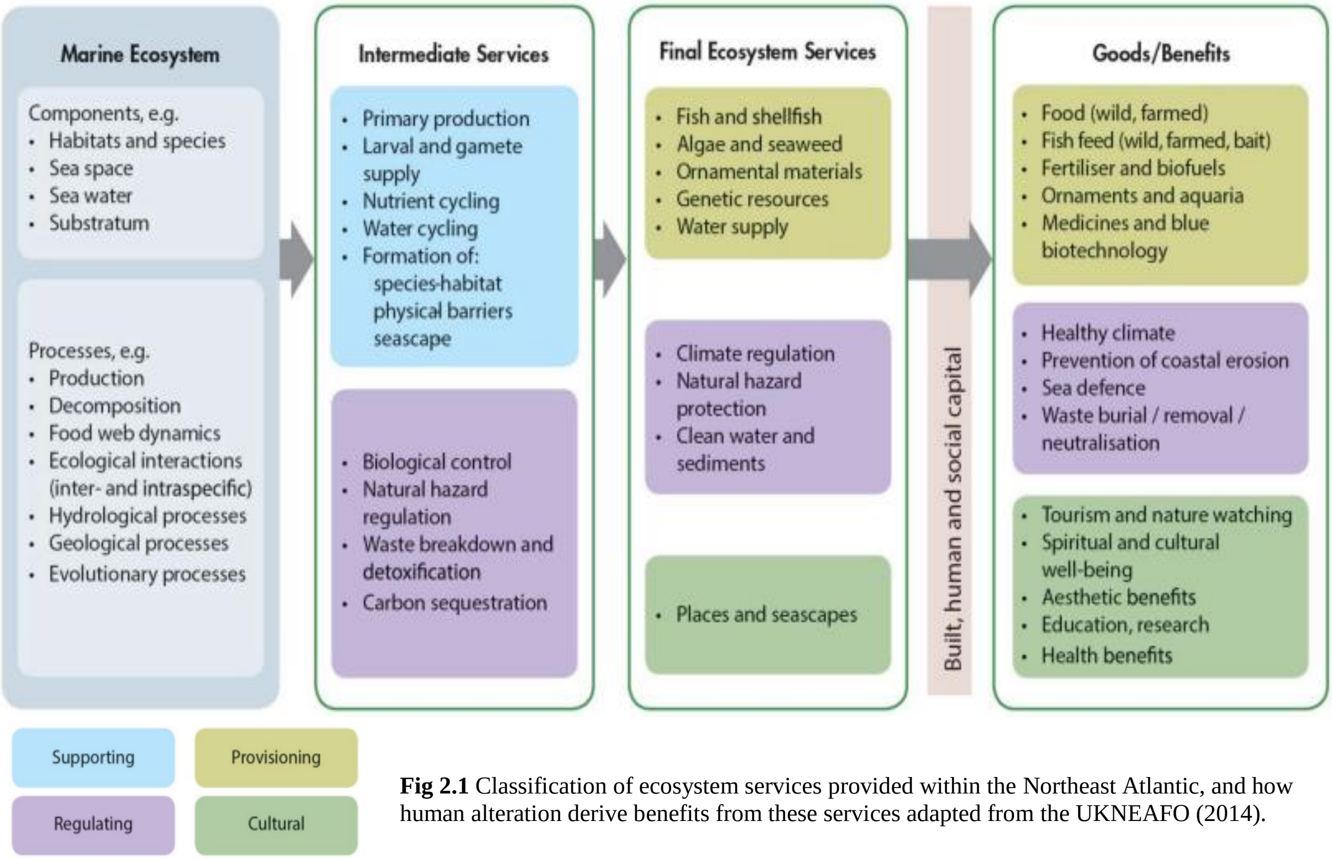


Fig 2.1 Classification of ecosystem services provided within the Northeast Atlantic, and how human alteration derive benefits from these services adapted from the UKNEAFO (2014).

The MEA classification is the most widely used and is very useful for providing scientific data. However, there is a range of different purposes that may need a different classification as it is accepted that the concept of ES is not a static one (Fisher *et al.* 2009). For example, Boyd and Banzhaf (2007) argue that for the purposes of accounting, standardized ecosystem service units, such as the measurement of ecological quantities and prices that can be aggregated are required. For the purposes of landscaping, Wallace (2007) argues that identification of the specific point when ecological processes deliver an ES is required. However, in terms of valuation of ES to be made to inform decision makers, Fisher and Turner (2008) state that the separation of intermediate services, final ecosystem services and benefits overcomes ambiguity (Fig 2.1).

The UK national ecosystem assessment (UKNEA, 2011) is an example of the application of an ES approach at a national scale for the purposes of valuation. The general procedure of the UKNEA is to 1) assess the services and benefits provided from ecosystems across the UK and their spatial scales, 2) identify drivers of change impacting the UK's ecosystems, 3) examine future scenarios of changes to services and benefits provided, 4) suggest responses to maintain services if ecosystem is impacted or degraded, 5) value ES contribution to wellbeing. A follow on of the UKNEA was published in 2014 (UKNEAFO, 2014), in which the UKNEA framework was specifically applied to coastal and marine ecosystems, highlighting a range of ecosystem services provided within the Northeast Atlantic from which fisheries, aquaculture and tourism derive benefit (Fig 2.1). Approaches such as the UKNEA appeal to policy makers, because it becomes clear that the concept of ES is an anthropocentric one and allows the ES to be measured working within an established economic paradigm, although the ES approach urges for a conceptual shift in the way natural capital is conceived and viewed. UKNEA is an example of valuing market and non-market service on a common monetary metric, which is becoming more acceptable among decision makers because it provides better information on a range of non-market benefits derived from the ecosystem, with approaches monetising them in a way that is comparable with market benefits and any management costs (Fisher et al. 2009; Morse-Jones *et al.* 2011). Such information can have a variety of applications such as enabling informed decisions about the potential returns from conserving a resource in relation to costs (e.g. how marine protected areas can result in greater future catches (Sanchirico and Emerson, 2002) or assess the damage certain activities could have on the environment and the subsequent impacts on welfare (e.g. human development impacting ecosystem processes and the associated loss of services and benefits (Wells and Ravilious, 2006)).

Depending on the ES / benefit under investigation, different economic methods and techniques can be employed to value a scheme, providing estimates of welfare benefit used in management and policy decision making (e.g. assessing whether the benefits of conserving an ecosystem and associated benefits are greater than their management costs) (Fisher *et al.* 2009). Economic values can be of use and of non-use (Fig 2.2). A non-use value is assigned to goods that may never be used directly and can include the simple knowledge that an ecosystem exists. Use values come instead from the direct use of an ecosystem, such as using a beach for recreation (Brouwer *et al.* 2013). There are a range of different welfare valuation methodologies of marine ecosystem services available that can include simple accounting of organisms harvested for consumption (an example includes catch statistic reports for the UK collected by the MMO (see Dixon *et al.* 2017a)) as well as getting users of the marine environment to state or reveal the value of certain services. Stated preference valuations are based on choices in response to hypothetical scenarios, whereas revealed preference valuations are based on actual behaviours (Adamowicz *et al.* 1994). The different techniques applied depend on the different concept of price and value. Price is a financial measure (Bateman and Turner, 1993) which can reveal the preference of individuals. However, the economic value is a quantification of what someone will trade (or give up) for a service or benefit (e.g. time or money) that has a positive influence on their welfare (Bateman and Turner, 1993) and can be measured by stated preference methodologies. The valuation methodologies applicable to this study are summarised in Figure 2.2.

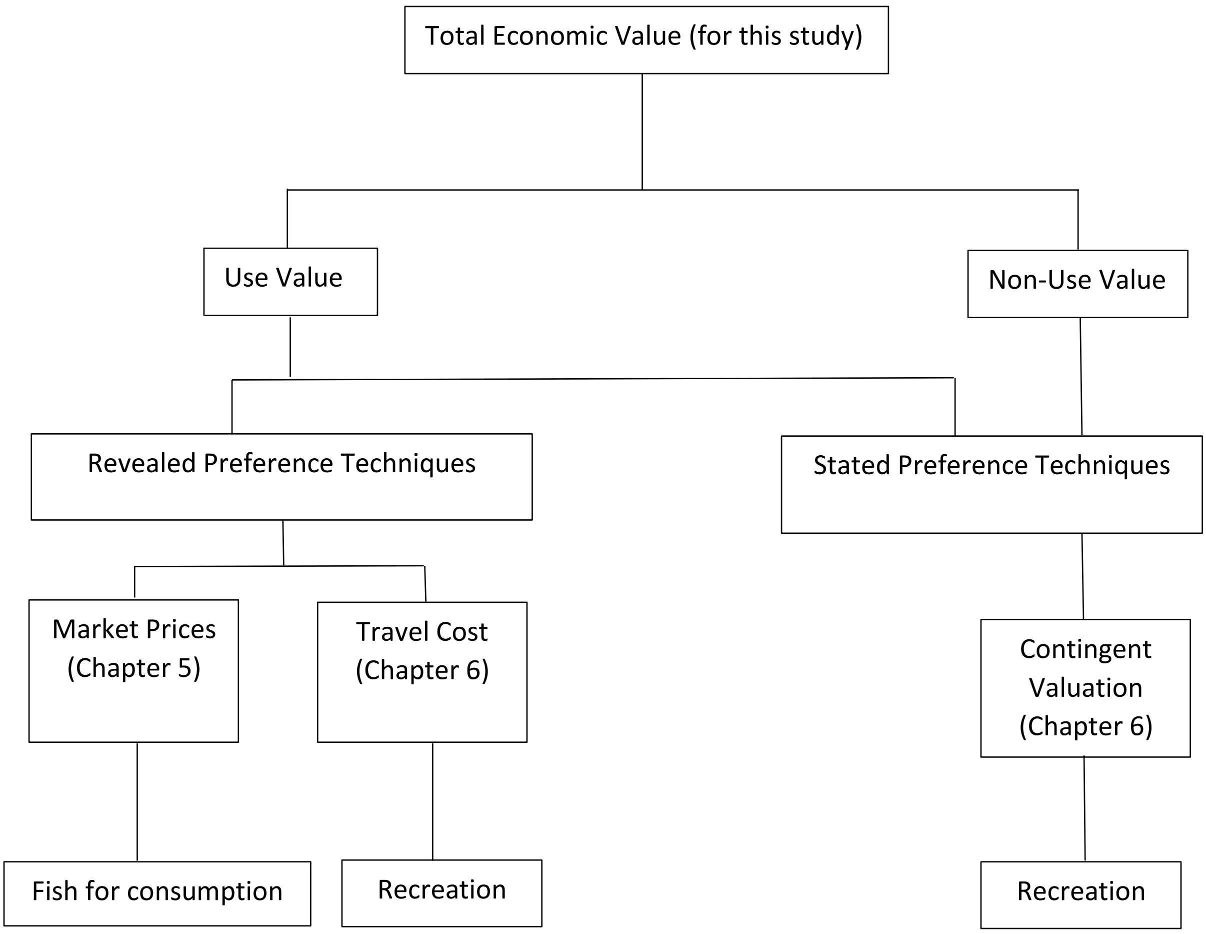


Fig 2.2 Valuation methodology techniques related to Northeast Atlantic ecosystems that could be impacted by blooms. Adapted from *Eftec (1999)*

Further information on the techniques displayed in Figure 2.2 relevant to this study and how they relate marine ES are summarised in Table 2.1. There are several valuation methods that could be used to value ES (see Brouwer *et al*. 2013 and Defra, 2007 for a review), but the techniques that would be considered to best serve the purposes of this study (i.e. generating an understating of jellyfish blooms perception and related magnitude of economic impacts in the Northeast Atlantic) were those reported in Figure 2.2 and Table 2.1.

Table 2.1 Table summarising valuation methodologies of ecosystem services identified as relevant to jellyfish blooms, adapted from Brouwer et al. (2013)

Valuation Technique	Valuation methods	Approach	Example of Marine ES	Limitation	Use in this study
Revealed	Travel cost	Estimate demand for a location based on user travel cost to access it	Recreation	Requires high amounts of data	Value of recreational sites at risk from blooms (see Chapter 6)
	Market Price	Observe changes based on market prices of goods and benefits	Fish for food consumption	Does not link to user preference	Value impacts of blooms based on changes in market goods such as amount of caught or harvested fish (see Chapter 5)
Stated	Contingent valuation	Ask users to state their willingness to pay for an ES using surveys	Beaches	Prone to bias if not administered properly	Willingness to pay for schemes that separates blooms from people along the coasts (see Chapter 6)

There are some limitations in the economic methods and techniques that can be used to value ES / benefits that must be acknowledged (see for example Table 2.1). Valuations made as part of stated preference techniques are often based on perceptions of users of the environment, which can be subjective and lead to inconsistent valuations (Costanza *et al.* 2017). Perception based valuations are also liable to include inaccuracies or miss information (i.e. biases) when they are in response to hypothetical situations. However, revealed valuation techniques, may not be referring specifically to the ES / benefit in question, since most ES do not have a market, and so are not traded using market prices (Brouwer *et al*. 2013). As mentioned above, there is not one standard way to assess and value ecosystem services, which could potentially lead to inconsistencies between studies of similar locations as well as overlook some of the relationships within an interconnected system which has led to some mistrust in the in the methodologies of the approach (Costanza *et al.* 2017). The techniques (Table 2.1) allow for the impacts of blooms to be quantified using well established methodologies, providing information pertinent to the second research questions (on the magnitude of bloom impacts on fisheries and coastal tourism in the Northeast Atlantic) and the following section will discuss how they will be applied throughout the rest of the thesis.

2.4.1 Application of ES Approach to Blooms in the Northeast Atlantic

With increased understanding of native and invasive jellyfish populations and the potential future distributions of their blooms across the Northeast Atlantic, the subsequent changes in the environment and the effects on individuals associated with fisheries and tourism can be conceptualised through an ES approach. Based on the literature that reports the impacts blooms can have on these activities (discussed in sections 2.2.1-2.2.3), the benefits within the Northeast Atlantic could potentially be compromised as a consequence of increasing jellyfish bloom occurrence because they are known to decrease the ability of humans to derive benefit from the marine and coastal ecosystems. Blooms can impact the built social capital of the fishing industry through bycatch decreasing the amount of target species catch per trawl due to clogging of nets and causing other additional overheads such as additional fuel moving to unaffected fishing sites (Palmieri *et al*. 2014) but is less likely to impact the intermediate (i.e. primary production) and final (i.e. fish production) ecosystem services. Any subsequent impacts could therefore be measured by applying the general framework of the UKNEA by investigating the spatial distributions of potential interactions between fishing vessels and blooms that may occur, generate understanding of how bloom scenarios could alter the way fishing vessels would operate and use pricing methodologies to quantify any subsequent changes in the market goods such as catch or base on the cost of altered fishing operations on overheads such as additional fuel usage or time spent out to sea. In terms of aquaculture, stinging jellyfish presence make finfish pens unsuitable for the process of rearing fish as the final ecosystem service of consumable fish that are either killed prematurely or made unsuitable for human consumption as they ingest stinging cells that enter pens (Doyle *et al.* 2008). A similar approach of valuing welfare implications as described for the fisheries could be applied by identifying farms that could experience blooms for the purposes of quantifying any losses in harvest based on the market prices of the species they farm in responses to bloom scenarios that could occur. In the case of coastal tourism, blooms become part of the seascape, impacting provisions such as clean water for recreational activities that includes bathing, decreasing the recreational value. Again, the general framework of the UKNEA (2011) can be applied by identifying locations that could experience blooms and investigating bloom scenarios that could cause welfare impacts could provide decision makers with information that could manage impacts. On this occasion non-market benefits could be impacted (e.g. recreational opportunity) so stated or revealed valuations could measure impact. For example, stated valuations could be achieved based on how much users would be willing to pay for the protection of recreational coast if bloom interaction were to be negative. Contingent valuations reveal the access value of a recreational location based on expenses such as travel costs of those benefiting from the location. The difference in valuations of beaches that contain blooms and hypothetical ones that contain blooms would provide indications of welfare impact based on benefit losses. An ecosystem service approach is therefore applicable to the study of future jellyfish bloom increases because it allowed for the development of information such as the locations of where blooms could cause impacts, what the impacts would be, quantifiable indications of the scale of such impacts and the resources required to maintain benefits that humans derive.

Graham *et al.* (2014) applied such an approach to investigate potential socioeconomic impacts of bloom increases in the Northeast Atlantic. Different ecosystems services (and benefits) impacted by jellyfish blooms were categorised, following the Millennium Ecosystem Assessment (2005) classification, into regulating, supporting, cultural and provisioning services in relation to human welfare. This categorisation allows thresholds to be identified where different levels of jellyfish occurrence causes trade-offs and social adaptation for anthropogenic communities. Graham *et al.* (2014) show that general welfare benefits associated with jellyfish (such as their contributions to an equitable climate for human use) increases linearly up until a saturation point where no further positive influence occurs. However, they also show that a negative impact has a non-linear relationship with jellyfish population size, as different thresholds were identified (e.g. when mortality rates in finfish aquaculture as a consequence of bloom presence alters operational practices of fish farms or the level of jellyfish biomass along the costs that triggers decreases in recreational activity), where anthropogenic populations are forced to either cope, adapt or transform their use of the coastal environment. The welfare impact of large-scale blooms that occur regularly would therefore outweigh any benefit that occurs.

Focussing specifically on the trade-offs that arise between jellyfish blooms and the cultural (e.g. coastal recreation associated with the coastal tourism activity) and provisional (e.g. food provision, associated with the fisheries and aquaculture activities) benefits stated by Graham *et al*. (2014), the costs discussed throughout this chapter are investigated under the lenses of an ecosystem services approach, which allows economic impact projections to be made across the Northeast Atlantic. Such projections are relevant to the Northeast Atlantic as this is an area where comparatively less is known about the interactions between people and blooms. Figure 2.3 is based on the framework of the UKNEA (2011) and summarises the general stages relevant to review the influence of potential bloom increases on cultural and provisional benefits across the Northeast Atlantic.

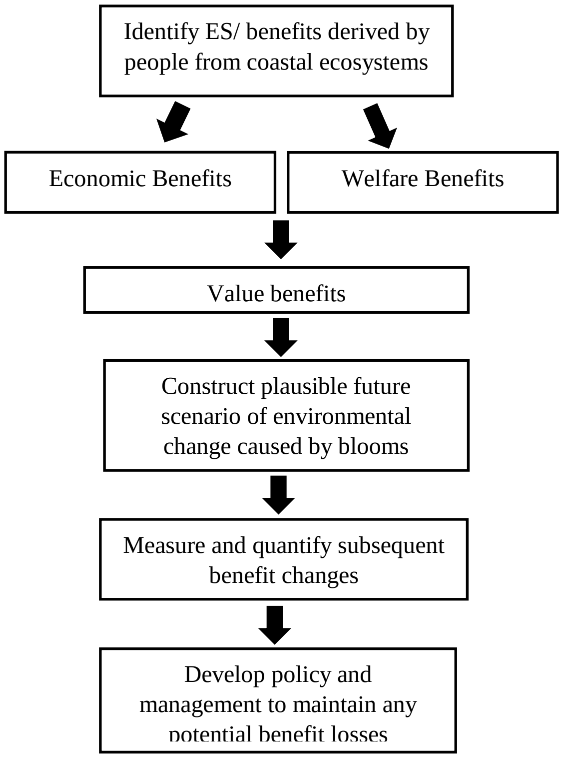


Fig 2.3 Stages of an ecosystem benefit valuation approach, applicable to the future interactions that are possible between coastal activities in the Northeast Atlantic and future jellyfish blooms.

2.5 Conclusion

To summarise, it can be concluded that there are many reports of instances when fisheries, tourism and aquaculture have been negatively impacted by blooms (as well as a few reports of when interactions have been positive for humans). Many of these reports provide estimations of the monetary impacts as well as suggestions of the welfare issues blooms are known to cause. However, fewer studies have specifically assessed impacts and subsequent responses of those affected by blooms to quantify both the economic and the welfare impacts, which could potentially provide decision makers with more robust information and insights to implement the most effective measures to mitigate bloom impacts. A few of the studies have quantified the socioeconomic impacts by engaging with coastal users and applied this information to economic data sets, but it is still suggested that these impacts remain poorly quantified for aquaculture (Bosch-Belmar *et al.* 2017), fisheries (Knowler, 2005) and tourism (Ghermandi *et al.* 2015). Even less is known about the social implications associated with blooms due to a lack of quantifications of the welfare impacts that blooms are known to have. Despite the suggestion that blooms are potentially increasing around the world, including areas that rarely experience them, there appears to be an absence of projections of the future impacts that blooms could have on each of the three activities this study is focussing on. Most studies have assessed the impacts to specific locations after or during a bloom has occurred and there is a need to project these impacts due to suggestions that blooms could be expanding into areas that experience them less. Also, apart from a couple of examples (including the MED-JELLYRISK scheme discussed in section 2.2.3), there are few responses and management schemes reported in the literature on how to effectively mitigate the impacts of blooms for diverse coastal and marine activities. Suggestions have been made, with the most common being forecasting the locations of future blooms so that certain waters can be avoided, or management can be put in place in anticipation of bloom emergence. There is therefore a need to provide quantifications of future impacts that could occur and suggest how to mitigate any future issues. However, before this can be done, the debate associated with future bloom increases needs to be addressed, as some suggest the trend of surges in worldwide jellyfish populations have been exaggerated in the media and the scientific literature. This requires further exploration, by examining which areas could support blooms in an area considered to be experiencing bloom increases and project how changes in the marine environmental factors (discussed in section 2.2.1.) may influence jellyfish populations.

Some studies within the literature suggest that the Northeast Atlantic is a location where jellyfish bloom increases could occur and there are a couple of examples of blooms being mapped in the area. However, they do not quantify how suitability for jellyfish could change in the future and only a couple of species have been represented. There is therefore scope to address these knowledge gaps by mapping the spatial extent of bloom in both the present day and based on future projections using the best data currently available on the environmental requirement of jellyfish that currently exists (i.e. at what level of temperature, salinity and prey levels different jellyfish suitability occurs). This could provide output that may challenge the perception of increasing blooms within the Northeast Atlantic and also provide an indication of the spatial distributions of future blooms (if it exists) for case study selection of specific locations where projection of socioeconomic implications can be projected. The review in this chapter has also considered how quantifiable projections of the impacts of bloom emergence within the Northeast Atlantic could be made. An ES approach has been suggested that can enable the valuation of the financial implications that blooms could have (e.g. any losses in catch they could cause the fishing industry) as well as welfare concerns (e.g. loss of recreational opportunities they are known to cause). As part of a potential approach a range of valuation methodologies have been proposed to project the impact of losses of market and non-market benefits that bloom increases could trigger in that could then be used to assess management and policy options.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter outlines the methodological approaches and tools used for this research, which explores the possibility of future jellyfish blooms in the Northeast Atlantic and applies an ecosystem services approach to assess the impacts and socioeconomic costs that could occur if blooms were to increase. Section 3.2 outlines my research positionality and how it relates to the questions the research sets out to answer. The chapter then sequentially presents and discusses the methods used to generate data pertinent to answering each of the research questions (outlined in Chapter 1). The first question considered what existing knowledge of changes in the marine environment reveal about potential future jellyfish blooms across the Northeast Atlantic, based on their physiological thresholds. The methods required to answer this question are discussed throughout section 3.3, including mapping techniques to identify the spatial extent of the locations where blooms of certain species changes could occur and potentially increase. Software selection (section 3.3), the collection and display of data representing environmental parameters (section 3.3.1) and of physiological thresholds that may affect jellyfish (section 3.3.2) are discussed, as well as how these were used to analyse the jellyfish populations in the Northeast Atlantic (section 3.3.3), followed by an assessment of whether these findings suggest that bloom occurrence could change and potentially increase (section 3.3.4). The methods used to validate this work are then discussed in section 3.3.5. The rest of the chapter then outlines the methods related to the second research question on the magnitude of the socio-economic impacts related to the tourism and fishing industry in the event of increased jellyfish blooms occurrence in the Northeast Atlantic. Section 3.4 describes how case studies were selected to assess the potential future impacts of blooms. Sections 3.5, 3.6 and 3.7 then describe how social science and economic methodologies were applied to produce quantifiable projections and valuations of the impacts that could occur for fishing and tourism in in the event of bloom changes, as well as considerations in relation to another activity (aquaculture) that the researcher had had an original interest in exploring (see section 3.6). Sections 3.8 and 3.9 refer to the safety training that was required prior to the field work as well as the research ethics. Section 3.10 then concludes the chapter by summarising the range of different methods used as part of an ecosystems services approach to analyse the impacts of future blooms in the Northeast Atlantic.

3.2 Research Positionality

Based on my background as a natural scientist, with an interest in examining the effects of environmental change on the physiology and distributions of marine organisms, as well as the exposure that I have had of the social sciences whilst studying in the School of Environmental Sciences at UEA, I would describe my philosophical research perspective as that of critical realism. This forms the basis of the perspective adopted in the research undertaken for this thesis. There are a number of philosophical perspectives; more ‘objective’ positionalities such as positivism maintain that the natural and social worlds exist independently from human understandings or knowledge of them and can be studied ‘objectively’. On the other hand, constructivism rests on the perspective that the world is socially constructed and exists only in relation to those whose knowledge is used to study it. There are multiple other perspectives that lie in between these two, which are generally considered to represent extremes of ‘ways of knowing’ (i.e. epistemologies) (Bryman, 2015). Positivism tends to be associated with natural scientists, who may undertake objective observations and records of the natural world, largely adopting quantitative methods (Guba and Lincoln, 1994). Constructivism is a perspective more commonly associated with social scientists, adopting qualitative methods to explore and understand the world (Guba and Lincoln, 1994). It is important to acknowledge this diversity of perspectives and reflect on which of these may represent the positionality of interdisciplinary researchers, which explore and examine both social and natural phenomena. They may adopt a critical realist perspective, in which the natural and social worlds are studied objectively, whilst acknowledging the difference between them. The research in this thesis examines how changes within the natural world (jellyfish blooms) may impact anthropogenic activities. It takes an interdisciplinary perspective adopting a critical realist stance: throughout this research measures and assessments of changes in natural phenomena (jellyfish) are undertaken objectively, and quantitative methods are applied to understanding social responses to changes in the natural world (jellyfish blooms).

3.3 Jellyfish Suitability Mapping

The initial stage in the valuation of benefits derived from an ecosystem is defining its spatial extent and geographic information systems (GIS) are increasingly being used to achieve this due to its ability to represent data spatially (Morse-Jones *et al*. 2011). ArcMap 10.3 (the most up to data GIS software available at the time of research) was therefore selected to map locations where blooms could occur and possibly increase within the Northeast Atlantic. This software has many visualisation options and a range of analyses that can be applied to environmental data sets which can be used to help understand the physiological responses of different jellyfish species. The software also allows for the separation of environmental parameters into individual data layers, allowing an understanding as to how individual factors influenced jellyfish dynamics prior to combining them to reveal overall area suitability. The GIS also enabled the quantification of predicted future changes to key parameters such as ocean temperature, salinity and prey availability, which are environmental factors thought to influence blooms and whether they will influence the occurrence of blooms and possible increases.

3.3.1 Jellyfish Prey and of Environmental Data

The responses of jellyfish life cycles and populations to ocean temperature, salinity and prey availability in the Northeast Atlantic was the focus of investigations into the potential bloom occurrences due to the literature (reviewed in chapter 2) that reports how certain levels of each factor influences jellyfish population growth. It must be acknowledged that there are other factors that influence whether a body of water can sustain or influence jellyfish populations which includes oxygenation (Lucas *et al.* 2014), pH (Richardson and Gibbons, 2008), nutrient levels (Richardson *et al.* 2009) and carbon levels (Pitt *et al.* 2013). However, indications of the physiological thresholds that dictate where certain populations can theoretically occur (discussed below), only currently exist for ocean temperature, salinity and prey abundance. The GIS maps therefore focussed on these parameters exclusively (however, it must be noted that there are also knowledge gaps associated with these environmental factors).

Data layers relating to ocean temperature and salinity were downloaded from the Met Office Hadley centre EN4.2.0 ocean data series[1] (Good *et al*. 2013) in the form of NetCDF files. Data layers represented sea surface temperature (SST) in degrees centigrade (converted from kelvin), and salinity in parts per thousand (PPT). The NetCDF files were displayed as raster data layers in ArcMap 10.3 using the multidimensional conversion tool (NetCDF to Raster), displaying two versions of each NetCDF (one displaying the SST and one displaying the PPT). Data layers contained a matrix of cells (1^{o}x1^{o} grid resolution) and represented the average SST and PPT for each month from the year 2000 until 2015 covering coordinates of 45^{o}N to 64^{o}N and 10^{o}E to 20^{o}W. The raster calculator function (spatial analyst tool: map algebra: raster calculator) was used to create data layers that display the average seasonal SST and PPT based on the monthly levels that occurred each year resulting in 15 annual winter (Dec-Feb), spring (Mar-May), summer (Jun-Aug) and autumn (Sep-Nov) averages. Final data layers that

[1] EN4 data series publicly available for research online

represented 15-year average SST and PPT that jellyfish may experience within Northeast Atlantic waters during the winter, spring, summer and autumn were then calculated from the corresponding 15 seasonal data layers (using the raster calculator).

Data on planktonic prey availability was obtained from the Sir Alister Hardy Foundation for Ocean Science (SAHFOS) continuous plankton recorder (CPR) databases[2] (SAHFOS, 2016). The CPR data sets are the most representative of any jellyfish prey item across the Northeast Atlantic (i.e. they are the only freely available data sets that includes the spatial occurrence of a known jellyfish prey item within the Northeast Atlantic) with samples being collected since the year 1931 that routinely analyse around 700 taxa, including an array of zooplankton and phytoplankton (SAHFOS, 2016). However, the review of the literature in Chapter 2, revealed a paucity of information on consumption rates of certain prey items by the jellyfish species in this study. For example, no specific quantifications exist of consumption rates and metabolic requirements of the majority of species in terms of level of microzooplankton, and phytoplankton (and in some cases pelagic fish species). This lack of data represented a challenge when endeavouring to define the spatial extent of jellyfish based on the environment they experience in the Northeast Atlantic and how suitability (including identifying locations more susceptible to blooming events) could change in the future. However, some indications exist of the levels of macrozooplankton that Northeast Atlantic jellyfish consume. Publications by

[2] SAHFOS CPR tow data is freely available for research purposes, by requesting it from their data team

Purcell, (1984), Morand *et al.* (1987), Fancett, (1988), Brewer, (1989), Perez-Ruzafa, (2002), Purcell, (2003), Flynn and Gibbons, (2007), Lilley *et al.* (2009) Rosa *et al.* (2013) and Lilley *et al.* (2014), each provide counts of the amount of macrozooplankton found within the stomachs of adult medusae (the application of this information within the GIS methodology is described below, in section 3.3.2). Macrozooplankton counts within the CPR database were therefore used as a prey proxy for the purposes of mapping jellyfish suitability distributions, based on the occurrence of one of their main prey items. It is acknowledged that this approach has limitations and potentially lead to underestimations in the suitability of locations across the Northeast Atlantic for jellyfish populations as only one prey item was assessed. However, as aspects of the diet of many macrozooplankton species overlaps with jellyfish medusae, consuming both phytoplankton and micro-zooplankton (Graham and Kroutil, 2001), an assumption was made that in areas of increased macrozooplankton, other prey items of jellyfish likely occur, resulting in the CPR macrozooplankton counts being used as a prey index.

Each CPR sample represented the number of macrozooplankton counted during samples taken in $3m^3$ of water during 18 km tows at an average depth of 7m (SAHFOS, 2016) within the same coordinates as the SST and PPT data (45^0N to 64^0N and 10^0E to 20^0W) from the year 2000 to 2012 (35,000 data points in total, evenly distributed across each month of each year). All tow data were stored in a spreadsheet that contained the date of collection, coordinates and the macrozooplankton counts at each sample. The data within the spreadsheet was organised and collated based on the years the samples were taken. The yearly data was then subdivided based on whether the sample was taken in summer, spring, autumn or winter, consistent with the SST and PPT data layers. The coordinates of each sample location within each season over the 12 years of data were then plotted in ArcMap 10.3 based on the GPS coordinates each count was taken (using the add data and display XY functions in ArcMap).

The aim was to then present the spatial distribution of the prey index in the same format as the SST and PPT data layers by converting the GPS points into raster grid matrices (1^{o}x1^{o} grid resolution across the coordinates 45^{o}N to 64^{o}N and 10^{o}E to 20^{o}W). To do this, estimations of the macrozooplankton counts across the mapping site were required as there are areas that the annual CPR tows do not sample as regularly (in other words, the point data could not simply be converted to raster data layers in ArcMap using the conversion tool due to data gaps across the spatial surface). Raster data layers that contained estimations of unknown macrozooplankton counts were therefore developed using interpolations, using the macrozooplankton counts at each GPS location as Z-values. The two commonly used interpolation methods that were potentially applicable were kriging and IDW (inverse distance weighted), as they use known Z-values (the CPR counts) and functional weightings based on the distance between known points to generate raster data layers that contain estimations of the unknowns across a spatial surface (Sui, 2004). Both methods depend on Tobler's first law of geography, as they estimate values based on measurements around them, assuming points that are closer together are more related (Sui, 2004). Kriging was deemed to be more appropriate because of the distributions and locations of the points within the macrozooplankton data sets. The CPR is towed by merchant ships that use the same specific shipping routes each year, resulting in some areas within the study areas that are comparatively under sampled. As certain areas had been sampled more, estimations of some unknowns would potentially be based on an increased number of points compared to other areas that were further away from the CPR towing routes, impacting accuracy. Potentially, underestimations and overestimations would occur in areas where fewer points contributed to the interpolation of each raster square. Such issues would have been possible had IDW interpolations been applied, because the methodology exclusively uses the Z-values and the distances between them to estimate unknown values (Li and Heap, 2011), which would have been influenced by the sampling effort of the CPR. Kriging on the other hand, corrects for biases within data sets because the method applies a semivariogram that calculates spatial autocorrelation between points with increasing distances from each other, defining the distance when no autocorrelation occurs (Li and Heap, 2011). The autocorrelation then determines weightings that should be applied to unknowns from each of the points depending on the distances between them, correcting weightings given to points at locations that are comparatively under sampled (Li and Heap, 2011). Kriging is similar to IDW interpolations in that the estimations of the unknowns are still influenced the most by the closest location sampled, but the weightings generated in the semivariogram allow the influence of the number of samples to be considered in the interpolation and the estimations of unknowns.

The semivariogram is plotted graphically and describes the autocorrelation between data points based on the distances between them, up until the distance where no autocorrelation occurs, generating a sample separation point used to weight points in the interpolation (Li and Heap, 2011). The method calculates the squared difference of the Z-values of each pair of points, displaying the average value between points as distance increases (Matheron, 1963). Each of the GPS points and their associated Z-values have unique distances between them and there are often more pairs than can be plotted. Pairs are therefore combined into lag bins and the semivariogram plots the average values within the lags on a y-axis and plots the distance between the lags across the x-axis. The semivariogram is made up by displaying the sill, which is the average variance between the points, the nugget effect, which is the measurement of error between the points (where the plotted curve crosses the y-axis), and the range, which is the distance where no autocorrelation occurs between points that informs the weightings used in a kriging interpolation. Specifically, when the distance between the points becomes greater than the range, they become spatially independent and have no influence on unknowns within the final interpolations (Li and Heap, 2011).

Initially, the semivariogram associated with the GPS points of the Z-values plotted in ArcMap was viewed using the geostatistical wizard (process repeated for each seasonal annual average set of data points). The data was then fit to an empirical semivariogram to act as the function to be applied to the kriging interpolation. There are several different semivariograms that can be applied to a kriging interpolation, depending on the spatial locations and values within the point data set. This includes functions or curves that can be plotted to describe semivariance such as spherical, circular, exponential, Gaussian and liner semivariograms (for review of each, consult Deutsch and Journel (1992) and Li and Heap (2011)). A spherical model was deemed appropriate for the interpolation of the CPR data because for each seasonal set of data points, the curve that was plotted, described a gradual decrease in autocorrelation between points up until the distances that the sill was reached. The curves then levelled off, highlighting the range where autocorrelation between the points was zero. Some points were above the model curve whereas others were below, but when the distances of the points below and above the curve were added together, similar values were revealed for each seasonal plot. The curves were initially steep, showing the points that had the most influence on their neighbours (points neighbouring each other by less than 4-5 miles depending on the season) that predictions would be based on. The range were no autocorrelation occurred was between 18 and 20 miles depending on the season.

Of the different types of kriging potentially applicable to the data set (ordinary, simple and universal), ordinary kriging was selected due to the use of a spherical semivariogram. Ordinary Kriging is the most widely used interpolation method and due to its flexibility, it can estimate unknowns based on spatial data that contains trends (in this case the sampling effort of the CPR tows leading to certain areas within the Northeast Atlantic containing more CPR data points than others) that can be displayed as raster layer (ESRI, 2017). The interpolations for each seasonal set of macrozooplankton counts were completed in ArcMap using the kriging spatial analyst tool. The input field was set to be the plots of the GPS coordinates of the CPR samples, the Z-values were set as the macrozooplankton counts, the kriging method was set to ordinary, the semivariogram was set to spherical and the output cell size was set to 1^{o}x1^{o} grid resolution (the resultant data layers from the kriging interpolation are displayed and discussed in Chapter 4).

3.3.2 Species Selection and Environmental Thresholds

Selection of potential jellyfish species for this study (species of the Northeast Atlantic that were selected are introduced in Chapter 2) was initially based on their present ranges in relation to the Northeast Atlantic (45^{0}N to 64^{0}N and 10^{0}E to 20^{0}W), as well as knowledge that exists on their physiological responses to ocean temperature, salinity and prey availability. Candidate species were identified through a search of species guides of native and invasive organisms to the Northeast Atlantic (guides consulted were the Hayward and Ryland (2008) hand book of marine fauna in Northwest Europe, the World Register of Marine species (WoRMS, 2017) and the Encyclopaedia of life (EoL, 2017)). Selection was then confirmed through consultation of studies that assessed the spatiotemporal ranges of the prospective list of species in the Northeast Atlantic (see Lynam *et al*. 2004; Houghton *et al.* 2006; Doyle *et a*l. 2007 and Pikesley *et al*. 2014). The final list of species was *A. aurita, P. noctiluca, C. lamarkii*, *C. capillata, R. pulmo, C. hysoscella* and *P. physalis*.

Each species has minimum and maximum temperature and salinity that they require to be able to survive in a body of water (Purcell *et al.* 2001; Collingridge *et al*. 2014) as well as a minimum prey level (Purcell *et al.* 2001; Hansson *et al*. 2005; Purcell *et al*. 2010). Within these ranges there are more specific levels of each environmental factor where reproduction can occur and when reproduction is not limited by the environment, allowing for high levels of medusae recruitment associated with blooming events (Collingridge *et al*. 2010). Correlations exist between a combination of suitable conditions within the environment and population growth, with growth associated with bloom levels only occurring when all aspects of the marine environment are not limiting reproduction between medusae (Collingridge *et al.* 2014). To gain an understanding of how suitable the Northeast Atlantic could be to different jellyfish species and if bloom increases are a possibility, thresholds were selected based on what is known about when survival and reproduction can occur, as well as the conditions when reproduction is not constrained by the environment. Below survival, survival, reproduction and bloom (non-limited reproduction) were therefore selected as the thresholds in response to the levels of each environmental parameter to assess different jellyfish populations that are possible across the Northeast Atlantic in the present day and in the future. These thresholds were influenced by rankings used by Collingridge *et al.* (2014), the only other attempt to give an indication of the potential distribution of a gelatinous organism within the Northeast Atlantic. Collingridge *et al.* (2014) modelled the suitability of the North Sea for the invasive ctenophore *Mnemiopsis leidyi* based on lab studies reporting survival and reproductive responses to temperature, salinity and prey availability. The categorisations used by Collingridge *et al.* (2014) were adopted for the species selected in this study due to the similarities between the responses of *M. leidyi* (survival and varying levels of reproduction in response to certain environments) and the responses of Northeast Atlantic jellyfish populations to specific temperatures, salinities and prey occurrence that have been reported (Purcell *et al*. 2001; Bamstedt *et al.* 2003; Purcell *et al.* 2010; Collingridge *et al*. 2014).

The thresholds in this study were based on the responses to the environment by the medusae stage of the life cycle, where initial reproduction between male and females occur (apart from the hermaphrodite, *C. hysoscella* where asexual reproduction is influenced). However, the importance of the benthic polyp stages within the life cycle of these species (except for the holoplanktonic *P. noctiluca* and the neustonic *P. physalis*) must be acknowledged. During the benthic polyp stage, budding and strobilation (asexual reproductive processes described in Chapter 2) are also influenced by the external environment in a similar way to how adult medusae respond to certain environmental conditions (Lucas, 2001). However, despite the importance of polyps within the life cycles of several of the study species, which includes increases in strobilation rates in response to certain temperatures, salinities and prey availabilities (Purcell *et al*. 1999; Ma and Purell, 2005; Prieto *et al*. 2010; Holst, 2012), there is a lack of species specific information on polyp ecology (including how they respond to the environment) and how they influence jellyfish population dynamics (Boero *et al*. 1996; Mills, 2001). The lack of studies can be attributed to the inconspicuousness of jellyfish polyps and the difficulty in identifying each species by their polyp (Pitt, 2000). The lack of species specific information on the conditions that influence the polyp stages of the life cycle meant that it was not possible to incorporate them into the assessment of locations where blooms could occur more regularly. It must be acknowledged, that the lack of polyp specific data is a limitation and future research should aim to address this knowledge gap.

In this study, initial indications of species-specific responses to the environment that could act as physiological thresholds were collected from the ocean biogeographical information system (OBIS) that provides species records and conditions of the ocean the species of interest occur in (all data available at http://www.iobis.org). The maximum and minimum temperature and salinity levels that each species had been reported to occur in (and therefore able to survive) in the Northeast Atlantic, presented in OBIS were set as the initial survival thresholds for each species. Any temperature or salinity below or above this was assumed to not be suitable for Northeast Atlantic jellyfish and was set as below survival for each species. The temperature and salinity levels where increasing numbers of each species occurred were then used to select the reproduction and bloom thresholds. Two levels of jellyfish occurrence above survival were available and thresholds were deduced from data (displayed in bar charts) presented by OBIS that displayed the temperatures and salinities that certain population sizes of each species occurred in. The first level presented were temperatures and salinities where increased numbers of medusae associated populations within their natural ranges occur. An assumption was made that reproduction was occurring in these populations and the corresponding temperature and salinity was set as the initial reproduction threshold for each species. The second level was the temperatures and salinities when highest numbers of jellyfish have been reported to occur (including bloomed populations) and was set as the bloom threshold for each species (the specific derivation of each threshold and the specific value for each species from OBIS is presented in Appendix A, Table A).

The initial OBIS thresholds were then compared with specific thresholds that laboratory studies determined differing survival and reproduction rates could occur for each species. A literature search was conducted (by typing the species of interest, the environmental parameter and the threshold into search engines (web of knowledge), e.g. "*Aurelia aurita* ocean temperature survival") to determine at what level of each of the three environmental factors that survival, reproduction and uninhibited reproduction (associated with blooming) is possible for each species, to determine the physiological thresholds of jellyfish species presence in relation to the OBIS thresholds. Specific temperatures and salinities that were reported to be where reproduction rates associated with survival, occurrence of natural populations and bloomed populations in each study were compared with the initial thresholds collected from the OBIS data sets. If there was disagreement, the OBIS threshold was adjusted to the threshold reported in the study that specifically tested survival and reproduction rates for a specific species. In some cases, species specific studies were not available (e.g. *C. lamarkii*), and the OBIS threshold were used as the final threshold. The full list of papers and the specific contribution they made to the final threshold compared to the OBIS data sets (whether they confirmed or changed the threshold) are displayed in Appendix A, Table B.

Due to a lack of species specific information in relation to the prey requirements to set thresholds for several species (discussed in section 3.3.1), an assumption had to be made that species of similar sizes and life cycles consume similar levels of planktonic prey. Medusae were therefore grouped by size, using the general assumption that species with larger medusae have different prey requirements to smaller medusae. The assumption was based on the difference in predation between different groups of medusae noted by Costello *et al.* (2008) where morphological features such as bell structure and size influences different swimming methods and therefore hunting techniques. Specifically, jet propulsion associated with smaller organisms and rowing propulsion associated with larger medusae (a more common characteristic in Scyphomedusae), influenced prey selection, feeding techniques and trophic roles within ecosystems. Typically, the larger rowing species can predate a greater amount and range of prey items, allowing them to reach larger sizes. Colin and Costello (2002) report specific differences between oblate and prolate medusae, where fluid mechanics and swimming ability influence the size, amount and type of prey captured. Prolates are generally smaller and swim by jet propulsion whereas oblates continually contract their medusae, as water to passes over them, enabling movement through the water via a rowing motion. These swimming methods influence prey selections as the larger and flatter medusae that swim via rowing, create vortices of water that bring prey into their feeding apparatus like a net (Costello and Colin, 2002), enabling them to catch large amounts of prey without the need to move through the water in an energetically expensive manner ($M_c$henry and Jed, 2003). The prolates that swim via jet propulsion do not combine swimming with predation, capturing prey during periods of drifting, where they use outstretched tentacles to capture prey items. They are therefore capable of colonising areas quickly due to their rapid movements but cannot capture prey as efficiently and do not grow to the sizes of the oblates ($M_c$henry and Jed, 2003). Differences have also been noted between Scyphomedusae of different sizes by Purcell (2003) when comparisons were made of the top down control that *Aurelia spp* and *Cyanea capillata* medusae exert on planktonic communities (in the Gulf of Alaska) providing evidence (through stomach content analysis) that larger medusae consumes higher levels of prey at faster rates, having a greater ecological influence per individual medusae.

Two key studies that assessed stomach contents (macrozooplankton counts consistent with the CPR data sets) and prey consumption associated with different population sizes of a species with large medusae (Fancett, 1988) and a species with a typically smaller medusae (Lilley *et al.* 2014) provided the most representative indications of the prey index thresholds in relation to populations of different types of jellyfish. The smaller and generally shorter-lived species were grouped together and contained *A. aurita*, *P. noctiluca*, *C. hysoscella* and *C. lamarkii*, with thresholds based on the findings of Lilley *et al.* (2014) where macrozooplankton counts within *P. noctiluca* medusae were made. The second group was larger and generally longer-lived species that comprised of *R. pulmo*, *C. capillata* and *P. physalis* and their prey index was based on a study by Fancett, (1988) on the stomach contents of *C. capillata* medusae from differing population sizes. Thresholds from the texts that had counted the stomach contents of the smaller jellyfish species and large jellyfish medusae were used as approximations of the sustenance requirements (and set as a prey index) for each species where survival and varying levels of reproduction can theoretically take place (see appendix A, Table B for the specific contributions of the two key texts to final threshold for the larger and smaller groups). However, some more specific stomach content reports exist that assessed a single physiological response that enabled some species-specific thresholds to be derived. Alterations to individual thresholds from the original groups for specific species were therefore made (see appendix A, Table B for the individual contributions of each study to the final thresholds form the original groups). The counts reported in these studies were consistent with the CPR counts and therefore used as a prey index that gave an indication as to how jellyfish populations could be spread across the Northeast Atlantic in relation to sustenance availability and how bloom risk could change in the future, accepting that it is likely that underestimation of bloom suitability could have occurred due to the data gaps that currently exist.

3.3.3 Methodological Steps of the Mapping

To develop a semi-quantitative maps / assessment tool, of locations that could sustain blooms, the three raster data layers representing SST, PPT and the prey index were reclassified (ArcMap: spatial analyst tool: reclassify) based on the physiological thresholds determined for each species. This methodology produced representations of their potential population dynamics of each species in the Northeast Atlantic in terms of each of the three environmental parameters. Each raster square representing the environmental conditions at a location within the three data layers was given a suitability ranking within the limits of the physiological thresholds (final thresholds are displayed in Chapter 4, section 4.2) of each jellyfish species. In other words, if the conditions in a raster square were below the survival threshold for a species, it was assigned a score of 0, if the conditions were above the survival threshold but below the reproduction threshold it was reclassified as 1, if conditions were above the survival threshold but below the bloom threshold it was reclassified as 2, and, if the conditions were above the bloom threshold, it was reclassified as 3 as long as survival could still occur (process visualised in Fig 3.1). This process was repeated for all the species for each of the three environmental parameters encompassing the four seasonal layers. For each species, the corresponding SST, PPT and plankton index reclassifications for each season were all overlaid and overall suitability score at each raster square was assigned using the minimum cell statistics tool (spatial analysts: cell statistics). The lowest suitability ranking from the corresponding raster squares within the overlay was displayed in final data layer due to the lower ranking of jellyfish suitability that was achieved. For example, two environmental parameters within a raster square could allow for blooms but blooms would not be possible if the third parameters only allowed for survival. Overlaying the reclassifications in this way aimed to avoid overestimation if a location could sustain a bloom.

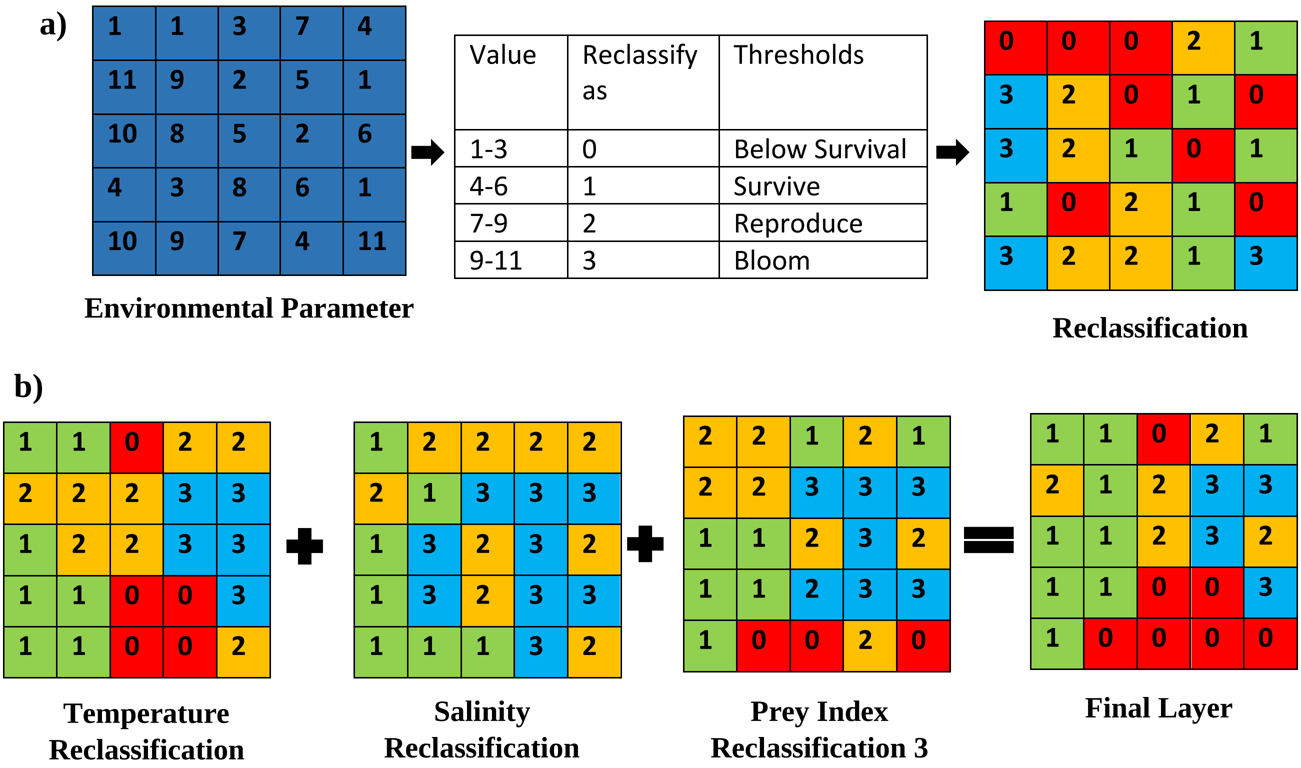


Figure 3.1 Visualisation of how the ArcGIS tools reclassify and overlay raster data layers. A) The raster data layer reclassification methodology that was repeated for each environmental parameter. The example shows how varying levels (1-11) of a hypothetical environmental parameter and how responses to that parameter of a jellyfish species was visualised using the reclassification based on the thresholds collected in the literature. B) The minimum cell statistics overlay of raster data. How reclassifications of temperature, salinity and prey index data layers were overlaid and displaying the minimum suitability that would occur. Red = below survival, green = survival, orange = reproduction is possible and blue = blooms are a possibility.

3.3.4 Future Jellyfish Blooms

As data sets that project future PPT and the prey index that can be incorporated into the GIS methodology do not exist along with future SST Projections to assess if jellyfish will bloom, a sensitivity analysis of the present-day data jellyfish suitability layers was carried out. The sensitivity analysis aimed to highlight how jellyfish suitability would change as a result of hypothetical increases and decreases in the three environmental factors (SST, PPT and prey index). To test sensitivity, two separate versions of the original environmental data layers were created, showing how suitability scores changed when SST, PPT and prey index layers were increased or decreased using the raster calculator. The resultant data layers were then reclassified based on the physiological thresholds of each of the jellyfish species. From the resultant layers, the percentage increase and decrease in suitability assignment of raster squares for each species from the original data reclassifications were plotted in a tornado graph (displayed in Chapter 4). The tornado graphs visualised subsequent changes to assignments of below survival, survival, reproduction and bloom for each species, highlighting how future changes to each environmental parameter could influence jellyfish populations in the future and reveal any increases in raster squares ranked as bloom.

3.3.5 Validation

Consideration was required as to whether there were any interactions between the three environmental data sets that could potentially influence jellyfish suitability. If specific locations were identified where the relationships between the environmental factors had the potential to alter jellyfish suitability, further considerations on the spatial location of blooms in the present day and the future could be made. Each corresponding seasonal raster layer representing the three environmental parameters was converted to point data (conversion tool: raster to point) representing the centre of each raster square. Data points were then exported into Excel spreadsheets and the conditions at each point from each of the three environmental data layers were plotted against each other in scatter graphs.

As the prey index data layers were created by estimating plankton levels using ordinary kriging interpolations of point data, and variability in yearly abundances was expected (Colebrook, 1978; SAHFOS, 2016), a cross validation of the data layers was carried out. The consideration of over or under estimations within the plankton count interpolations based on data availability as well as highlight how annual fluctuations could influence blooms. Cross validations were conducted by interpolating randomly selected sub samples from 30% of the original CPR data for each of the four seasons during each of the 12 years the data encompassed. Estimations of spatial locations of plankton levels from interpolations of subsamples were then compared with the original seasonal plankton abundance layers that used all the original CPR data. The annual interpolations of the seasonal sub samples and the original data sets were converted to point data displaying the average plankton abundances in each raster square. The plankton estimation points for each layer was then exported into a SPSS spreadsheet and the average estimation of plankton abundances for each year was calculated. Paired t-test quantified any significant difference between the plankton abundance estimations using 100% of the data and the randomly selected 30% subsamples (findings presented in Chapter 4, section 4.5).

Validation of the locations and times of year jellyfish may occur in the GIS output were conducting by comparing them with actual jellyfish distribution records. This was done by developing a representation of the conditions when a bloom was actually reported to have occurred in the Northeast Atlantic using the environmental raster data sets. The *P. noctiluca* blooming event that occurred throughout the Celtic Sea in 2007 (Doyle *et al.* 2008; Licandro *et al*. 2010) (discussed in Chapter 2) was selected as the existing empirical example. The SST, PPT and plankton counts for the summer and autumn of the year 2007 were displayed to represent the conditions when the bloom occurred. The 2007 environmental data layers were then reclassified based on the *P. noctiluca* physiological thresholds and the resultant layers were overlaid using the minimum cell statistics tool. This process was then repeated for the summer and autumn of the year 2000 when no blooms of *P. noctiluca* were reported at the start of the three environmental data sets. Comparisons of the frequencies and locations of any raster squares assigned as “bloom” were then made to assess how effectively the maps captured blooming events (see Chapter 4, section 4.8).

3.4 Impacts of Future Blooms

Following the GIS mapping phase of the work, geographical locations were identified based on the spatial and temporal distributions of jellyfish blooms indicated by the GIS maps; a particular focus was on locations with major fishery harbours and seaside towns where high levels of coastal tourism occur. Potential aquaculture locations were also considered (see section 3.6) although this strand of the research could not be accomplished, as explained below. A case study approach was adopted; this provides more depth in the understanding of the specific interactions with jellyfish in particular settings and locations. However, the value of the case study approach is contested in the social sciences. Some argue that case studies are very particular, serving mainly to elicit hypotheses, and that findings from case studies are not generalizable. Proponents of the approach argue that in-depth knowledge from a case study can be very valuable, especially if properly undertaken, whilst acknowledging that larger samples are essential for acquiring broader understanding (Flyvbjerg, 2011).

In this thesis, a case study approach was selected to examine how changes to ecosystem functions and services would impact groups using the marine environment in the context of the UK and the Northeast Atlantic, applying some of the conceptual work undertaken in the Mediterranean to the Northeast Atlantic. Understanding the effects in one location would give an initial indication if blooms, possibly more regular, would alter the benefits derived from marine and / or coastal ecosystem across the Northeast Atlantic and whether other locations should be studied. However, it must be acknowledged that the case study approach does limit the potential for replicability and benefit transfer of the findings (Bryman, 2015); the implications of this are discussed in the socioeconomic results chapters (Chapters 5 and 6) as well as the final discussion at the end of the thesis (Chapter 7).

Three case studies were originally selected, based on understandings of how coastal areas, and infrastructure, and marine industries are and may be affected by jellyfish blooms (see Chapter 2): a coastal location with high seasonal seaside tourism, a major fishery harbour and areas of finfish aquaculture, all in areas of increased suitability for blooms (by the highest number of species known to negatively impact these activities. Cases (Yin, 2009) were selected out of the locations that coincided with greater future bloom suitability in GIS. Selection was based on secondary data (data pertinent to each anthropogenic activity is discussed in section 3.5-3.7) indicating whether a location might include activities that may experience welfare impacts from jellyfish blooms (i.e. the most visited seaside tourism destinations providing a greater range of recreational activities or the largest fishery harbours with a bigger variety of vessels / fishing gear).

To collect these data, a survey approach was applied, to engage with people associated with fisheries, aquaculture and tourism. Surveys were deemed a suitable medium because they allowed for data collection directly from those who might experience alterations to the marine and / or coastal ecosystem and the services that they provide in the event of blooms (Bryman, 2015). The surveys aimed to generate an understanding of respondents' previous experiences of jellyfish blooms, if any, and how they envisaged changes to the way they interact with the marine and / or coastal ecosystem and their actions in responses to future blooms; these were used to generate quantified projections of potential consequences, in the forms of a standardised quantification of the value that is placed on the marine and / or coastal ecosystem under non-bloomed conditions; the data collected also enable an understanding of the impacts if blooms altered the way people benefit from marine and / or coastal ecosystem services. However, there are some limitations of this method that require acknowledgement. Although surveys can be structured to allow a combination of open ended and closed responses (Bryman, 2008), often closed responses are considered preferable as they retain consistency among responses. Although it can be argued that this increases the accuracy of the data collected, it presented an issue when considering future jellyfish populations in the Northeast Atlantic. This was because bloom responses in the area are poorly understood, and survey question had to be open ended to account for a variety of issue that could have been reported, potentially impacting the accuracy and depth of the information that could be gained about specific mechanism and responses to bloom future blooms and bloom increases. Administering the survey face to face also requires ample time and resources compared to email or phone surveys, which can affect the quantity of data collected. However, such an administration method was deemed appropriate and necessary for this research due to visual aspects of the survey (use of flash card, displayed in Appendix C and D) required to present respondents the same hypothetical bloom scenarios. The following sections discuss how the surveys were designed and administered as well as the analysis at each case study.

3.5 The Fishing Industry

The GPS coordinates of harbours containing commercial fishing fleets were extracted from the most recent (at the time of research) Marine Management Organisation (MMO) report into fisheries statistics (see Elliot *et al.* 2015). Harbour locations were plotted in GIS and overlaid onto the maps that dictated where large jellyfish populations could occur (Chapter 5 section 5.2). Potential case study sites were selected based on which GPS points coincided with the highest average raster square rankings of suitable areas for jellyfish. Several locations were highlighted by the overlay and final case studies were narrowed down by ranking them based on factors that made them more suitable for this study using MMO (2017) fleet data. Harbours were ranked based on the size of the fleet and fishermen numbers. Locations were selected based on the number of fishermen, range of fishing methods and fish biomass landed, with the purpose of selecting harbours with a greater variety of potential participants to the study. This resulted in the harbours of Brixham and Newlyn being selected as the case study locations (discussed further in Chapter 5, section 5.2).

3.5.1 Survey Design and Administration

Following case study selection, potential economic and welfare impacts associated with future blooms were investigated with fisherfolk. A semi-structured survey (Appendix C) was designed to elicit information and data to quantify any costs associated with future blooms based on previous experiences of jellyfish, similar in nature to the impacts blooms are known to cause in the present day based on existing studies (damaged nets, displacement effort, bycatch, injury from catch). Then, respondents were asked to envisage future interactions with jellyfish blooms using different types of fishing gear and consider how they would respond to such conditions. The survey was subdivided into four sections: (1) the fisherfolk's background, (2) costs of overheads that blooms could increase, (3) previous experience of jellyfish, and (4) responses to future bloom increases. The development of each these four sections drew upon a survey for fishermen about jellyfish blooms existing in the literature: Palmieri *et al.* (2014) interviewed fishermen in the Adriatic, who experience regular blooms on an annual basis, to understand how blooms interact with their operations and any associated economic and welfare costs (discussed in section 2.2.1).

The survey sections are outlined below, with an explanation of how some questions from Palmieri *et al*. (2014) were adapted for the purpose of this survey, specifically for data on impacts in the event of bloom increases (the survey is displayed in Appendix C):

1. Section A elicited information about the respondents and the fishing fleet that they belong to; adapted from the equivalent section in the Palmieri *et al.* (2014) survey.

2. Section B included questions about costs incurred in non-bloomed conditions that are similar in nature to issues blooms are known to cause. Questions were based on the findings of previous studies that have described how fishers interact with blooms, quantifying costs in locations where they are currently more common (Purcell *et al.* 2007; Palmieri *et al*. 2014). Open ended questions on present day costs were also included to enable elicitation of information that is potentially exclusive to fishing fleets in the Northeast Atlantic. Accessing the fishermen's knowledge provided insights for baseline costs associated with issues that blooms could trigger and how they would compare with any future costs associated with bloom increases (elicited in Section D).

3. Section C asked respondents about their previous experiences of jellyfish to gain qualitative insights as to whether jellyfish presence has been perceived to be increasing or if anomalous blooming events have occurred occasionally based on experience of those who fish in these waters.

4. Section D asked respondents to picture future hypothetical oceans where blooms of different species occur more regularly. The jellyfish were grouped based on similar morphological traits so that specific potential interactions could be discussed. The four species categories were the large stingers (*P. physalis* and *C. capillata*), the small stingers (*P. noctiluca*, *C. lamarkii* and *C. hysoscella*), the large non-stingers (*R. pul*mo) and the small non-stingers (*A. aurita*). Respondents were shown flash cards that informed them about the morphological features and bloom characteristics of the species that belonged to each of the groups (Appendix C, Section D) and a set of three questions were then asked about each group. The first question enquired whether respondents thought a group of species can impact their fishing activities if they bloomed. If yes, respondents were asked to describe how they envisaged blooms interacting with their fishing operations. The final question then enquired about actions they would take in response to such interactions and bloom presence in their fishing grounds.

Drafts of the survey were piloted with local fishermen based across East Anglia. The first pilot was on 30th November 2015 with a retired fisherman; a second re-draft was piloted on 2nd December 2015 with two fishermen with experience of working on commercial vessels who now targeted shellfish using pots and creels. These pilots helped to review technical aspects of the questions based on the respondents' expertise as well as clarifying questions that were unclear. The final surveys were then administered face to face with fishermen at Brixham and Newlyn harbours. Interviews were conducted between 25th January 2016 and 27th

February 2016 at the two study sites while fishermen were in the harbour area, often working on the boats while they were moored. Surveys were also completed with fishermen in pubs and cafes situated next to the harbour during their leisure time and no sea days. The fishermen who participated in the pilot studies also introduced me to potential respondents for the final surveys via social media (twitter). Social media (twitter) was therefore used to organise meetings with respondents and get into contact with other fishermen that previous interviewees in the final study suggested would participate. However, there were difficulties accessing fisherfolk. These difficulties included finding respondents who were available to complete the survey. This occurred because many of the respondents did not live in Brixham and Newlyn and were very quick to leave the harbour area once work was complete, meaning that being in the harbour at a time when these fisherfolk were available and able to participate in the study was a challenge. As surveying commenced in winter, there were occasions (often lasting a few days at a time) when the weather conditions forced there to be no sea days. During these periods, the harbour and surrounding area often contained no potential respondents, particularly as many of them did not live in the towns and had no reason to be there. An additional challenge was successfully getting fisherfolk to participate once approached. Survey rejections occurred regularly with several reasons given that included respondents being too busy, uninterested and had a mistrust of scientists. Due to these difficulties, further potential respondents were approached in the harbour. It is acknowledged that this could have led to biases in the type of respondents approached as the security cameras only covered the inner harbour but was necessary due to difficulties in accessing fisherfolk. Upon completion of the field work, the responses were analysed. Findings are presented in Chapter 5.

3.6 Finfish Aquaculture

Potential aquaculture case study sites were identified on an exploratory basis, based on how their GPS locations matched with potential bloom locations within the GIS maps produced. The locations of aquaculture pens were gained from records available from Marine Scotland (2014). Scottish finfish pens were focussed on due to the high levels of marine aquaculture present in the region and reported interactions with blooms (Doyle *et al*. 2008). A semi-quantitative survey similar to the one for fishermen was developed and consisted of the following four sections: (1) aquaculturist background; (2) costs of overheads during blooms; (3) previous jellyfish experience; and (4) costs arising from dealing with future jellyfish blooms. The survey was discussed informally with key actors within the industry who provided further insights on some of the technical aspects of the questions and suggested potential requirements of the industry in terms of jellyfish blooms, leading to improved re-drafts.

However, it became clear that practical considerations had to be considered, including administering the survey remotely (e.g. online) as visiting finfish pens was deemed not viable as they are vastly spread out. Furthermore, from conversations with key actors, important sensitivities within the sector emerged, including concerns and other commercial constraints, which significantly reduced the opportunity to carry out this part of the research, therefore bringing it to an end. For such a survey to be administered, good working relationships with the aquaculture industry need to be in place. For example, Kintner and Breirly, (2018) were able to recruit aquaculture participants for a three-year PhD study that identified blooming hydrozoan species that impact Scottish aquaculture. Weekly deployments of plankton tows were permitted within the waters of participating farms and samples identified hydrozoan species that would be expected to bloom and the seasons when bloom risk is greatest. Based on the seasonality of blooms of each species, risk associated with pathological conditions that hydrozoan presence can cause in farmed salmon (including medusae acting as vectors of disease) were stated. Economic impacts associated with mandatory culls of populations of infected salmon could then made. Bosch Belmar *et al.* (2017) were also able to quantify the economic costs of blooms on marine aquaculture sites across the Mediterranean through face to face and telephone surveys with impacted aquaculturists. Suggestions on future work with the aquaculture industry to identify potential risk in the event of Scyphozoan bloom increases in the Northeast Atlantic are therefore recommended in Chapter 7.

3.7 Coastal Tourism and Recreation

Identification of a location associated with coastal tourism as a case study for bloom impacts was undertaken in a similar manner to the selection of the fishery harbours. The locations of coastal towns and cities whose economy is reliant on tourism (criteria described below) were plotted and overlaid onto the jellyfish

GIS maps using their GPS coordinates. Given that seaside towns typically have infrastructures geared towards tourism and have a long history of coastal tourism, this is likely to continue into the future (Beatty *et al.* 2010). It was decided that the seaside town that was closest to the highest suitability for jellyfish (i.e. which coincided with the highest raster square rankings of the greatest number and variety of species in the GIS maps (see section 3.3)) would be selected as the case study area where the surveys would be conducted. However, due to the GIS map area containing many potential study sites case study selection was refined using also data on employment, economic output, location and trends of the seaside tourist industry in England and Wales as reported in Beatty *et al*. (2010). This is the only report that specifically assessed, at the time of writing, economic trends within individual locations and provides consistent indications of trends at specific locations as opposed to general regions (which is the more common approach for seaside tourism trend reports and visitor surveys). Beatty *et al*.'s (2010) estimation of trends is based on job figures in seaside towns and cities using official statistics (based on the Department for Communities and Local Government seaside economics reports) on the industry as a basis to estimate economic output by categorising employment trends and how they relate to the tourism industry. Principal seaside towns are defined by Beatty *et al.* (2010: 15) as "places with a population of at least 10,000 where seaside tourism is a significant component of the local economy." These areas act as hubs of coastal tourism, in the same way as the locations in the Mediterranean that have been reported being impacted by jellyfish blooms and were locations where large groups of coastal users may co-occur with future blooms. Therefore, the principal seaside town with the greatest visitor numbers and rates of tourism-based employment presented by Beatty *et al.* (2010) that tailored with the greatest jellyfish suability (as defined on the previous page) was chosen as the case study site; this was the Cornish town of St Ives. An extended description of the area, and further justification of why it was selected as the final case study, are reported in Chapter 6, section 6.2.

3.7.1 Survey Design and Administration

The cultural services (e.g. recreation) provided by coastal and marine ecosystems to seaside towns are different from the provisioning services (e.g. food for human consumption) provided by wild and farmed fish; the impacts of jellyfish blooms on these types of ecosystem services can be consider as different (Purcell *et al*. 2007; Öztürk, and İşinibilir, 2010; Ghermandi *et al.* 2015).

A survey was designed to investigate recreational activities and impacts from jellyfish on coastal tourism (Appendix D), and therefore followed a different structure to the one designed for the fisheries surveys. However, the main aims, understanding the responses of stakeholders to hypothetical future blooming events and associated impacts, were similar. The structure of the survey was based on three main sections, with a fourth section to be completed when respondents had concluded the three parts (see Appendix D for the full set of questions that were asked):

1. Section A focussed on respondents' visit, including the recreational activities they engaged in, questions on how far they had travelled to get

to the location, and how important various aspects of the coasts were to them. The aim was to generate an understanding of the range of different recreational users of the coasts that could experience bloom increases. This also enabled quantification later (using a travel cost method – see Section 3.7.2) of how much the location is valued based on respondent travel expenditure to access it; to estimate travel costs, survey questions included respondents' postcodes and method of transport used. A key question asked how respondents would (alternatively) recreate in the event of beach closures (at this stage blooms had not been mentioned). This was a relevant question as, later on in the survey, one scenario presented is based on the knowledge that blooms of certain stinging species are known to cause beach closures (Rosenthal, 2008; Mariottini and Pane, 2010; De Donno *et al.* 2014 Ghermandi *et al.* 2015) and understanding how respondents would recreate in the area if the beaches were no longer available would give an indication of the impacts if this were to occur.

2. Section B aimed to understand respondents' attitudes, experiences and knowledge of the jellyfish species mapped in GIS. This included asking respondents about jellyfish word associations (examples of words that were given included negative phrases such as sting and positive phrases such as beautiful), describing any previous interactions they had had with the jellyfish, but also asking respondents to identify species they were familiar with / were capable of stinging using flash cards. Gaining qualitative information about tourism and jellyfish allowed for consideration of what could influence future responses and management

of hypothetical future blooms as they contributed towards the cost scenarios which are displayed in Chapter 6, section 6.5.

Respondents' views on increased jellyfish biomass washed up on the seafront and occurring in the inshore waters were also investigated. To do this, respondents were introduced to a hypothetical situation where blooms were washed up on the beaches and persisted in the water (see Appendix D, section B; and Chapter 6, section 6.5.2). Initially, respondents were asked how concerned they were about future blooms using a 1-5 Likert scale that ranged from not concerned at all (1) to extremely concerned (5). Respondents were then asked how they would respond upon discovering a hypothetical bloom on the beach where they recreate. Like the fisheries survey, several responses were made available for interviewers to tick based on what actions respondents reported in response to hypothetical bloom increases, including "recreating as normal," "avoid the water but stay on the beach," "avoid the beach," "do alternative activity in the area," "travel to alternative locations – if yes, how far," as well as providing an 'other' open answer option. The final part of section B introduced respondents to a jellyfish management scheme (similar to the MED-Jelly RISK project: http://jellyrisk.eu) where, in the Mediterranean, temporary netting is used to create pools within the sea to separate beach recreationalists from jellyfish blooms. Respondents were then asked whether they thought that a similar scheme would be useful in the event of bloom increases where they recreate, and whether they would be willing to contribute financially to such a management scheme. The contingent valuation of the beaches of St Ives was projected based on the proportion of respondents that were willing to donate to such a scheme, the payment vehicle they would use to donate (e.g. collection buckets), how often they would make such a donation and how much they would donate each time (questions specifically asked for this informing in the survey, see Appendix D, section B). The per person contingent valuations were then scaled up based on the estimate of total beach users (gained through conversations with key actors) who would donate (based on the proportion of respondents who were willing to donate). These questions were designed to allow a comparison between the respondents' revealed value of accessing the recreational location (inferred with the travel cost analysis) to how much they said they would pay to protect the area from jellyfish blooms impacts (respondents' stated value).

3. Section C encompassed socio-economic questions including respondent expenditure on various aspects of their visit per person (e.g. accommodation, parking and on beach activities) per day, that could be influenced if jellyfish were to alter the respondents' visits. These data were collected to enable an understanding of the benefits related to the tourism industry, and how it could potentially be impacted by future blooms based on how the respondents reported that they would respond to blooms. Questions were also asked on their travel expenses for their trip to get to the case study site, so that inferred access values of the coastal ecosystem could be calculated using the travel cost method (see section 3.7.2). Other general socio-economic demographics, such as income, age

and education levels, were also collected to explore their influence on the responses provided in the previous sections of the survey, as well as the ecosystem access value (i.e. travel cost).

4. After the discussion with respondents was completed, interviewers filled in information that included their own name, the specific area within the location the survey took place, the interview duration and the environmental conditions at the time of the survey to enable to test if there was any influence on the results of the investigations.

Once a draft survey questionnaire was designed, a pilot study was conducted across Cromer beach (North Norfolk) on the 18th July 2016. This involved walking along the beach and approaching people recreating there in a similar manner to how data collection was planned for the final field work in St Ives (Cornwall). The aim was to pilot the survey on a range of respondents of different ages, genders as well as surveying respondents engaging in range of recreational activities to test questionnaire understanding and wording. Five interviews were completed, and alterations were made to the survey based on how the respondent reacted to, understood, and answered the questions.

During the survey fieldwork in St Ives, face-to-face surveys of randomly selected respondents were carried out from the 27th July to the 17th August 2016, during the school holidays, the height of the tourism season in the case study site. As high numbers of potential respondents were anticipated at the location, volunteers (MSc students) with previous experience of surveying were recruited from universities local to the survey site to assist with data collected during field work. Volunteers were trained to administer the survey:

all volunteers practised the survey administration together with me to ensure consistent data were collected. Their initial surveys in the field were also monitored to ensure data collection was consistent and debriefs held at the end of each day. The significance of the influence of interviewers' behaviour on survey results was also tested to ensure that there was no bias. Also, to help with initial introductions, all interviewers were also provided with a "jellyfish research" t-shirts so that potential respondents understood the purpose of interviewers approaching them.

3.7.2 Economic Methods for Analysis of Interactions

Initial analysis of the impacts of blooms was based on the relationship between traits associated with different respondents (such as reason for visit, gender age, income) and respondents' responses to bloom increases. Each test and related results are discussed throughout Chapter 6. The frequencies of responses (e.g. alterations to recreational activities) to hypothetical future blooming events provided an understanding of the prevalence of specific interference to recreational activities that would occur. The subsequent changes in expenditure patterns of visitors were used to project the costs to the coastal tourism industry by linking the expenditure that respondents reported on the various activities to their bloom responses. This allowed for assumptions to be made on how expenditure would change and to provide quantifiable projections of potential loss to the tourism industry**.** The average bloom cost impacts per person (based on survey data) could then be multiplied by the estimation of the total number of beach users to aggregate the total impacts across the whole of the case study site (expenditure change estimates are described in Chapter 6).

The impacts of blooms on the non-market values of the recreational experience in the case study site was also investigated to give a full picture of the impacts of blooms, as this study aimed to investigate both the social as well as economic issues. A specific travel cost model (a revealed preference technique - for a review of the stages and functions of travel cost, see Parsons, 2003) was used to estimate the welfare benefits that access to the beaches of St Ives provides. A single site travel cost model was used to estimate the access value of the coastal ecosystem per beach user based on their actual expenditure from their travel. The travel cost model was used because it employs a well-established economic valuation technique that can estimate welfare values comparable with market prices and it is based on the actual behaviour (travel, and related costs, to reach the touristic destination) of those recreationists who would be impacted by increasing blooms (Parsons, 2003). The model describes the demand function for the recreational site based on how travel cost influences the number of visits made to the site as follows:

$$r = f(tc_r, y, z) \qquad \text{[Equation 3.1]}$$

Where r is the number of trips to the site made by respondents over the season and tc_r is the trip cost.

The trip cost tc_r per site visit incorporated into Equation 3.1 was calculated using the return trip distance respondents had made to get to the case study location for their holiday based on their home postcodes that were asked during survey (results are in Chapter 6, section 6.6). Variables other than tc_r, including demographics and income, can also influence the number of recreational site visits and therefore the valuations of access (Parsons, 2003). In Equation 3.1, *y* is the income of the respondents and *z* represents the demographic variables of respondents. The demographic variables included into the model in Equation 3.1 were: gender, age, the number of people and number of children in the respondents' group.

The next stage of the travel cost method is to estimate the relationship between the parameters in the model (Parson, 2003). As the number of trips is count data, characterised by high instances of low numbers, a poisson distribution was assumed (based on the basic count data travel cost model (Parson, 2003)). The poisson regression was used to generate the relationship between the variables tc_r, *y* and *z* in the model and the number of site visits using the following function:

$$r = \beta tc_r + \beta y + \beta z \qquad \text{[Equation 3.2]}$$

Where β is the coefficients of each parameter (travel cost, income and demographics) in relation to the number of trips reported by respondents.

However, since over dispersion (unequal mean and variance, tested for using a Kolmogorov-Smirnov test) was found within the number of trips count data (Chapter 6, section 6.6), a poisson distribution was not assumed because the goodness of fit of the model was distorted. A negative binomial regression which assess the data using the same method but relaxes the constraint of over dispersion (Parsons, 2003), was therefore used instead to analyse the study data.

To calculate the access value, the β coefficient representing the relationship between average travel cost per person per day and the number of beach visits per day (βtc_r) per person was incorporated into the following function:

$$S_n = \frac{\bar{\lambda}n}{-\beta tcr} \quad \text{[Equation 3.3]}$$

Where S_n is the inferred access price (in this case the average amount spent on travel getting to St Ives) and $\bar{\lambda}n$ is the expected number of daily visits to the beach (number of beach visits were specifically reported by respondents).

The site access value per person was then multiplied by the estimated total number of people who visit the beaches per day during the summer season, provided by key actors, to get the aggregate value of St Ives' beaches. The responses to hypothetical beaches closures and blooms on open beaches were used to estimate percentage changes on individual welfare using the travel costs method results (discussed in section 3.7.1).

The estimated use value / welfare losses due to jellyfish blooms were then compared to the willingness to donate (the contingent valuation – see section 3.7.1, section B) towards a hypothetical management scheme to provide visitors with the same recreational experience despite a bloom event (their stated value). Results are reported Chapter 6. Recommendations on the management scheme proposed (a management scheme similar to the Med-Jelly nets - discussed in section 3.7.1) funded by donations from beach visitors are also discussed in Chapter 7.

3.8 Research Ethics

Before the fieldwork commenced, ethics approval was gained from the UEA General Research Ethics Committee for the data collection (for the fishermen and tourism surveys), as is required at UEA. Documentation was submitted that considered potential ethical issues related to the research and informed consent. Key considerations included ensuring confidentiality, respondent anonymity, any concerns about jellyfish and respondents feeling obliged or forced to participate. All completed surveys were kept securely in locked cupboards within a secure location. Data were stored on a password protected laptop issued by UEA that was kept in a securely locked office. Before surveys began, an introduction was offered to properly explain the research to all potential participants. It was made clear that all information provided would not be shared with third parties, only anonymised data would be collected, that participation was entirely voluntary and that participants could terminate the survey at any point and withdraw from the research. I also provided my contact details on a business card for respondents if they had any further concerns or additional questions after completion of the survey. Directly after both surveys (with fishermen and tourists), I offered to provide information about the species that occur in the Northeast Atlantic and jellyfish in general. The vast majority of the tourism respondents welcomed this information as they were had little knowledge on jellyfish (explored further in Chapter 6, section 6.4) and were interested in learning about the species. Generally, interviewers were received positively, particularly families with young children who enjoyed some of the facts about jellyfish and the images on the flash cards. Responses to the research by the fishermen was also generally positive but very few asked for more information due to more widespread familiarity they already had of most of the species featured in the survey. No ethical concerns were raised by respondents during fieldwork; the most common refusal to engage with the survey was from those who indicated they were time limited or uninterested.

3.9 Safety Training

As the fisheries surveys were conducted in and around working harbours that were closed to the public, where heavy machinery was used to lift and transport large objects in wet and slippery conditions, security clearance was gained from harbour security at the start of fieldwork. Clearance was granted on the condition that research was not to be conducted in certain areas deemed unsafe by the security guards, appropriate footwear was worn at all times whilst in the harbour and all work must stop upon hearing warning sounds emitted by machinery transporting large objects (usually fork lift trucks transporting crates containing catch). The final condition was that all surveys had to be completed in full view of the harbour CCTV cameras.

As MSc students volunteered to undertake the surveys at the coastal town, safety considerations were seriously considered for the fieldwork period. Due to the close proximity of the field locations to urban areas with rapid access to the emergency services (including life guards on duty at the field site) and good cell phone signal, it was deemed that I required the minimum out door first aid training after consultation with the School’s health and safety co-ordinator. I therefore completed a level 1 outdoor first aid course (8 hours) at the Hollowford Centre, Derbyshire (S33 8WB) on the 21st July2016 prior to the start of the field work. During surveys, care was also taken to make sure that interviewers had sufficient clothing and gear to conduct the research in all weather conditions.

3.10 Conclusion

This chapter has provided insights into the methodologies for the application of an ecosystem services approach to this study in order to value the potential socio-economic impacts of future changes and potential increases in jellyfish blooms across the Northeast Atlantic could cause. Innovatively, using the GIS methods and processes described in this chapter, environmental conditions that contribute towards jellyfish suitability was mapped based on the physiological thresholds currently available and a representation of the future conditions affecting jellyfish suitability. The maps indicate changes in jellyfish populations, what the populations could be like in the future and identify specific locations within the Northeast Atlantic where future blooms could occur. In such areas, the impacts on coastal visitors and fishing communities may be affected by how blooms alter coastal and marine activities. The results from the GIS work are presented and discussed in Chapter 4. The results of socio-economic investigations are reported in Chapter 5 (impacts of future bloom increase on commercial fishing) and Chapter 6 (impacts of future bloom increases on coastal tourism).

CHAPTER 4

MAPPING SUITABILITY OF THE NORHTEAST ATLANTIC FOR JELLYFISH BLOOMS

4.1 Introduction

In this chapter, this first research question (what does existing knowledge of changes in the marine environment reveal about potential future jellyfish blooms across the North East Atlantic, based on their physiological thresholds / responses to the marine environment?) is addressed, to determine and describe the spatial extent of jellyfish and potential blooms. Output gained during the stages of the GIS mapping in ArcMap (methods discussed throughout Chapter 3) and the final visualisations of how suitable Northeast Atlantic waters are to a range of jellyfish species in the present day are displayed (sections 4.2, 4.3, 4.6 and 4.7). The maps are based on the environmental drivers of jellyfish population changes and blooms described throughout Chapter 2. The output validation (sections 4.4, 4.5 and 4.8) is then used to assess whether using ocean sea surface temperature, salinity and the CPR plankton counts effectively allows areas suited to larger jellyfish populations, as well as suggest how addressing knowledge gaps can further develop the maps and their applications (section 4.10). This then enabled consideration of whether future changes to the environmental parameters would alter bloom occurrence (section 4.9). In later chapters, case studies within such areas were then analysed to conclude as to whether there would be any impacts on the coastal anthropogenic communities if blooms were to materialise more frequently. The implications of the outcomes were also used to contribute to the discussion as to whether the perceived increases in jellyfish populations over the past decade could conceivably have occurred and how the methodology could contribute to the general understanding of bloom formation.

4.2 Study Species

The list of species with life history and physiological characteristics based on the initial literature review are displayed in Table 4.1. Selection of a species was based on known distributions in relation to Northeast Atlantic waters, a known ability to impact coastal industries, and, the existence of data that could be used to determine physiological thresholds (see appendix A for the contributions of a variety to the final threshold) to the environmental parameters (temperature, salinity and prey index). Greater suitability occurred at higher temperatures for each type of jellyfish apart from for the two *Cyanea* species which were more likely to reproduce and bloom as temperatures decreased as they were reported to be more suited to boreal conditions (Brewer, 1989; Purcell, 2012). Due to limited data availability there was a high level of consistency between the physiological thresholds (in terms of temperature and salinity) for each species. Further research is required to confirm if the similarities in suitable temperatures and salinities displayed in Table 4.1 are accurate or if there if more variation occurs between species (discussed in Chapter 7). Due to the lack of species specific data on prey requirement, two sets of prey requirements thresholds were formed separating each species based on similar morphological traits and life histories (see chapter 3, section 3.3.2). Smaller shorter-lived species were shown to require less prey than the larger longer-lived species to achieve certain reproduction rates associated with greater suitability, with the limited species- specific data providing some variation around the thresholds used.

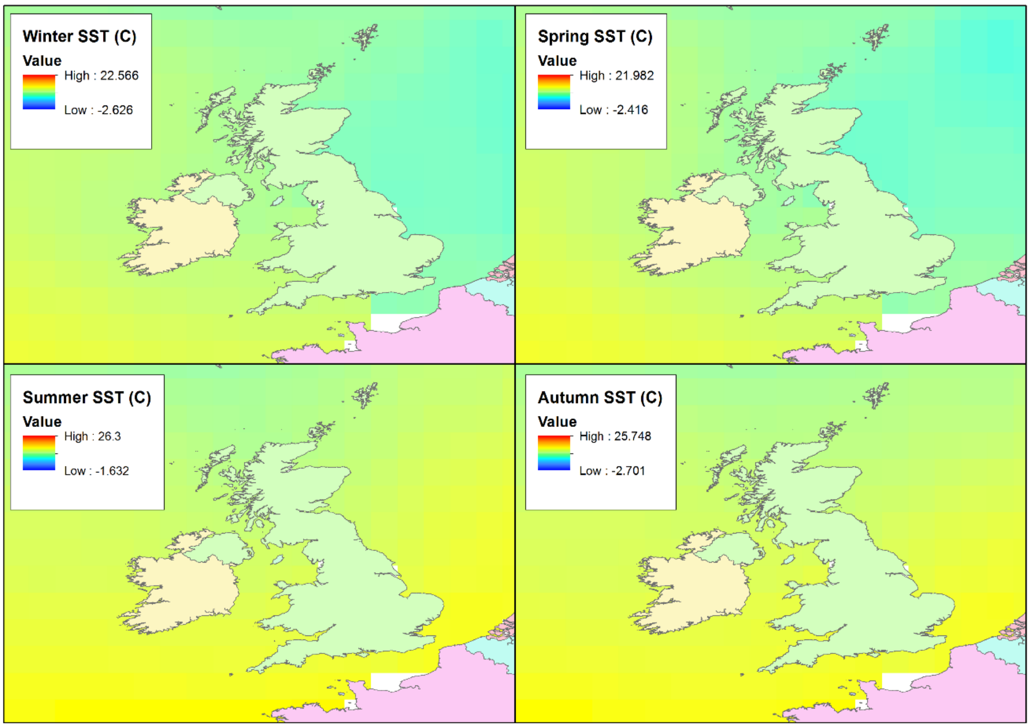
Table 4.1 Species selected for spatial modelling and their physiological thresholds to the environmental factors where survival, reproduction and blooms were possible

Environmental Condition Thresholds				References
Species	**SST (^{0}C)**	**PPT**	**Prey Index**	
Aurelia aurita	Survival: 5 Reproduce: 13 Bloom: 15	Survival: 17 Reproduce: 30 Bloom: 35	Survival: 5 Reproduce: 40 Bloom: 60	Morand *et al.* (1987) Lucas, (2001), Purcell, (2007), Holst and Jarms, (2010), Purcell *et al.* (2012), Pascual *et al.* (2014), OBIS, (2017)
Pelagia noctiluca	Survival: 5 Reproduce: 12 Bloom: 15	Survival: 30 Reproduce: 31 Bloom: 35	Survival: 5 Reproduce: 40 Bloom: 60	Morand *et al.* (1987), Doyle *et al.* (2008), Rosa *et al.* (2013), Lilley *et al.* (2014), OBIS, (2017)
Cyanea capillata	Survival: 16 Reproduce: 15 Bloom: 10	Survival: 25 Reproduce: 32 Bloom: 35	Survival: 30 Reproduce: 60 Bloom: 100	Fancett, (1988), Purcell, (2003), Holst and Jarms (2010), Holst, (2012) OBIS, (2017)
Rhizostoma pulmo	Survival: 14 Reproduce: 15 Bloom: 20	Survival: 30 Reproduce: 36 Bloom: 36	Survival: 40 Reproduce: 60 Bloom: 100	Perez-Ruzafa *et al.* (2002), Lilley *et al.* (2009), Fuentes *et al.* (2011), Purcell *et al.* (2012), OBIS, (2017)
Chrysaora hysoscella	Survival: 13 Reproduce: 15 Bloom: 16	Survival: 20 Reproduce: 32 Bloom: 35	Survival: 30 Reproduce: 40 Bloom: 60	Sparks *et al.* (2001), Flynn and Gibbons, (2003) Holst and Jarms, (2010), Purcell *et al.* (2012), Holst, (2012)
Cyanea lamarkii	Survival: 16 Reproduce: 15 Bloom: 10	Survival: 25 Reproduce: 32 Bloom: 35	Survival: 15 Reproduce: 40 Bloom: 60	Brewer, (1989), Holst and Jarms, (2010), Purcell *et al.* (2012), Holst, (2012) OBIS, (2017)
Physalia physalis	Survival: 2 Reproduce: 15 Bloom: 20	Survival: 30 Reproduce: 31 Bloom: 35	Survival: 30 Reproduce: 60 Bloom: 100	Purcell, (1984), Purcell, (2003), OBIS, (2017)

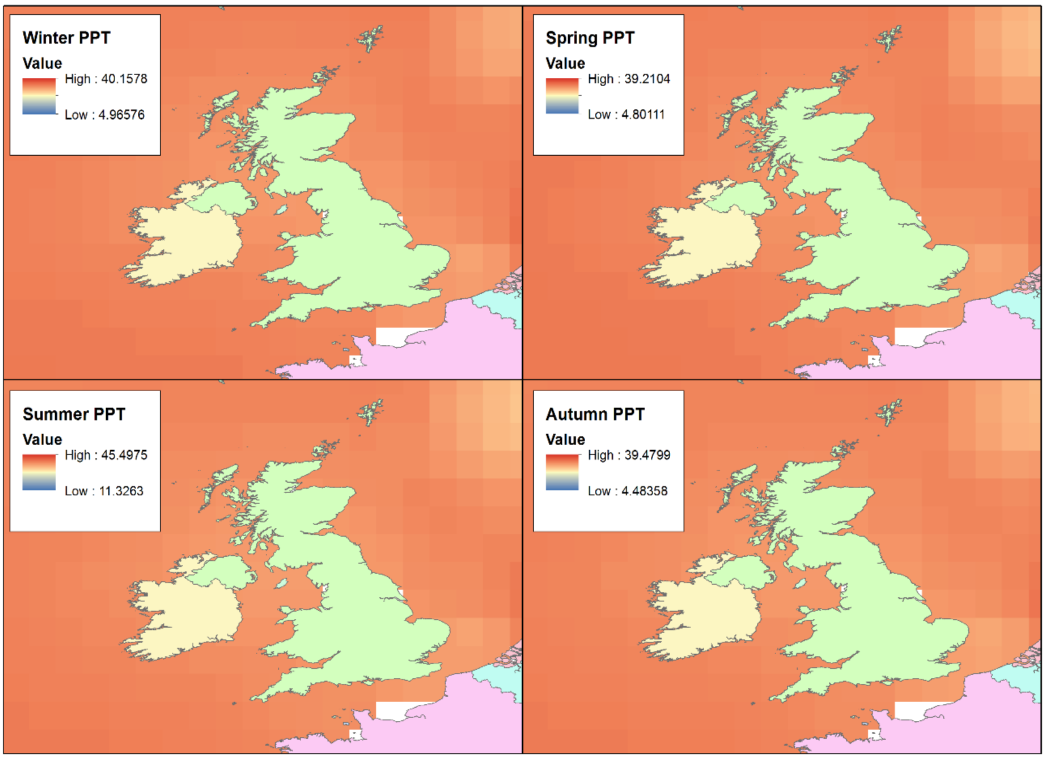
4.3 Environmental Data Layers

The maps representing the environmental data layers (Fig 4.1a-c) are displayed across the coordinates 45N to 65N and 10E to 20W, with cell of 1^0 X 1^0 grid resolution which form the basis of the spatial model. They fulfilled the purpose of generating data representing the average environmental conditions and act as a prey index (see Chapter 3, section 3.3.1 for explanation of the interpolation used to generate the maps) that jellyfish would be expected to experience over the course of an average year. Each seasonal raster data layer was also suitable for reclassification based on physiological threshold ranges of different levels of suitability for each of the different jellyfish species.

A



B



C

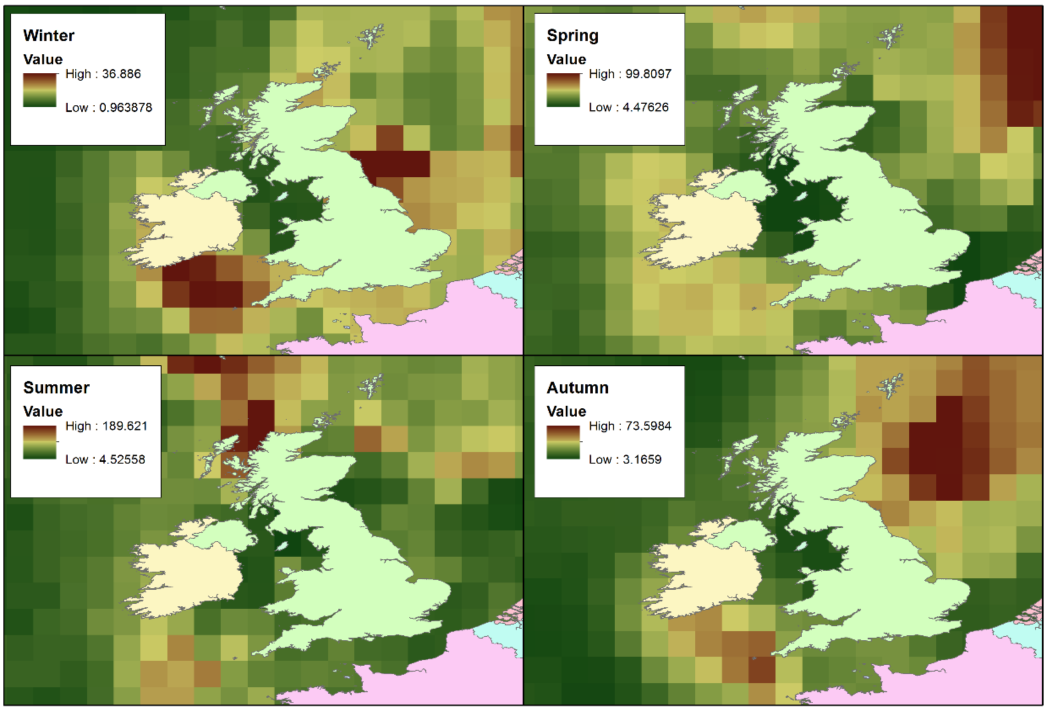


Fig 4.1 The raster data layers representing the average seasonal environmental conditions and prey abundances jellyfish would experience. A) the average seasonal sea surface temperatures (^{0}C). B) the average seasonal salinities (PPT). C) The average seasonal projections of prey index based on the interpolations of the continuous plankton recorder (CPR) count data.

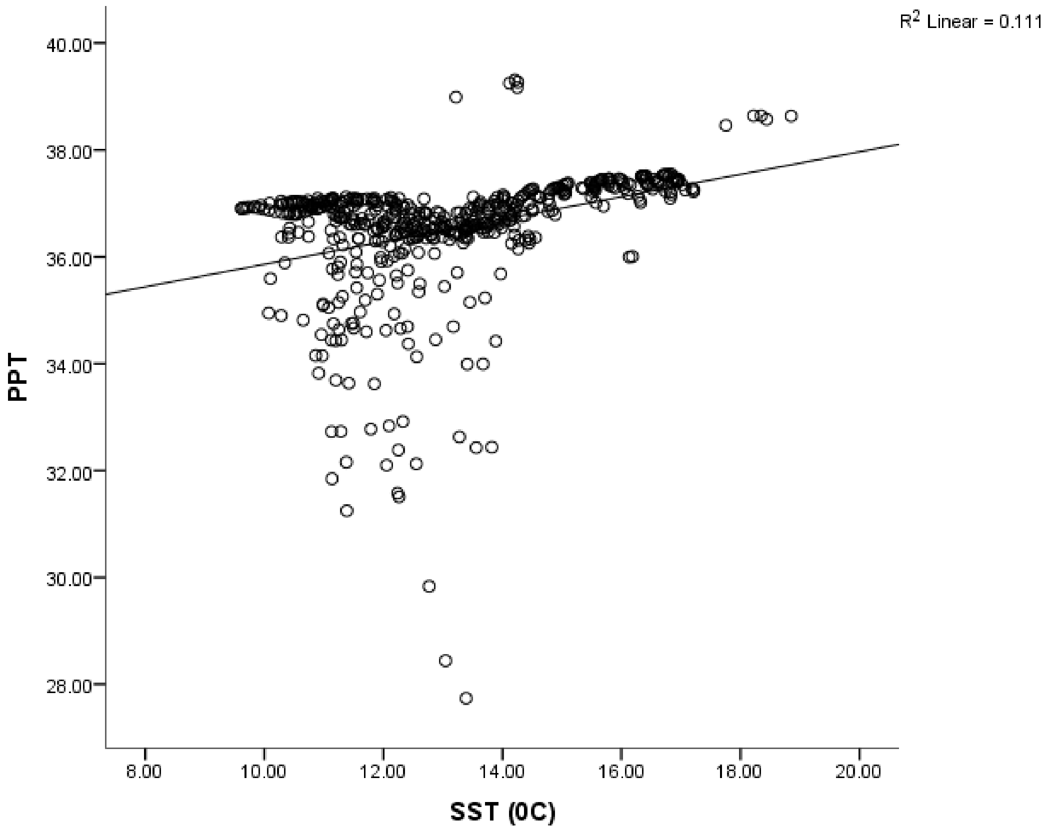
The annual variability between years that occurred during the seasonal average calculations was relatively low for the SST layers (Fig. 4.1a) (average standard deviation for winter = 0.29, spring = 0.4, summer = 0.42, autumn =0.62) and PPT layers (Fig. 4.1b) (average standard deviation for winter = 0.06, spring = 0.1, summer = 0.17, autumn = 0.11). Jellyfish suitability in relation to SST and PPT was therefore assumed to have remained relatively consistent during the time period that the averages encompass (2000-15). However, there was greater seasonal and geographical variation in plankton levels within the average prey index data layers (Fig.4.1c) (average standard deviation for winter = 23.04, spring = 55.94, summer = 79.22, autumn = 71.75). It was therefore assumed that the greater variability in prey levels, characterised by localised areas of intense abundance at different times of the year, was more likely to influence a jellyfish species ability to bloom, particularly if the other environmental factors were consistently suitable. The locations of intense plankton abundance were therefore the areas where potential case studies of conflict with stakeholders were more likely to be identified. Generally, summer conditions initially appeared to provide the most suitable data layers for jellyfish blooms if they were to occur, as prey index and temperatures were higher, increasing the chances of suitable physiological thresholds for the majority of the species in Table 4.1.

4.4 Interactions between Environmental Factors

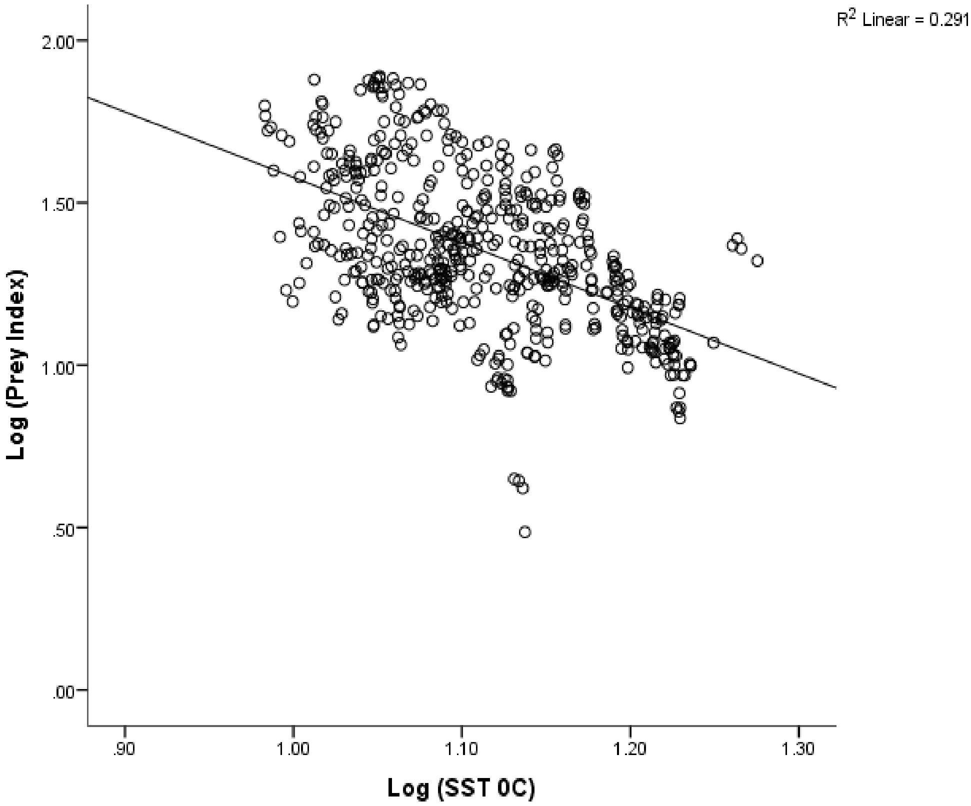
Trends observed in the plots (Fig 4.2a-c) comparing the influence between the data in the GIS layers for each of the three environmental factors showed weak correlations were present between them. As SST increased, PPT gradually increased. This trend is known to occur in the oceans as PPT increases with decreasing ocean densities and increasing evaporation associated with warmer waters (Curry *et al.* 2003). As SST increased, the prey index decreased which agrees with the generalised trend that colder, more northerly waters in the Northeast Atlantic are considered to be more productive (Johnsen *et al.* 2003). Therefore, as PPT increased, the prey index decreased. However, the weak correlations between PPT and SST and between PPT and the prey index described by the low R^2 values of 0.111 and 0.033 respectively, indicates that at the resolution and scale the data was presented, the influence would have no subsequent impact on jellyfish suitability. The change in PPT over the course of the temperature range (Fig 4.2a) and macrozooplankton count range (Fig 4.2c) would not influence bloom risk as the ranges between the physiological thresholds consistently remained above the bloom threshold for each species. Based on the data and the thresholds it can therefore be stated that for the majority of the Northeast Atlantic, salinities are suitable for blooms of each medusae.

However, despite the correlation being relatively weak ($R^2 = 0.291$), the decrease in the prey index as temperature increased (Fig 4.2b) was likely to influence jellyfish suitability as the changes in both temperature and prey went beyond the difference between thresholds of different suitability displayed in Table 4.1 (section 4.2) for each of the 7 species. Increasing jellyfish suitability is therefore more likely to occur for species that can tolerate lower temperatures within the mapping site, enabling them to take advantage of the increased prey levels. It must be acknowledged however, that a log transformation was applied to the data plotted in Fig 4.2b because it initially appeared that the data was skewed. The skewing of the data likely occurred due to plankton blooms picked up within the CPR data that increased the scale of the y-axis, causing the more typical data points to skew. The relationship between SST and the prey index was therefore less obvious, so the log transformation showed a comparison between the geometric mean between the points at a more consistent scale for the majority of the data. The transformation highlighted more of a relationship between the SST and prey index with higher plankton counts occurring at colder temperatures, but the relationship remained relatively weak.

A



B



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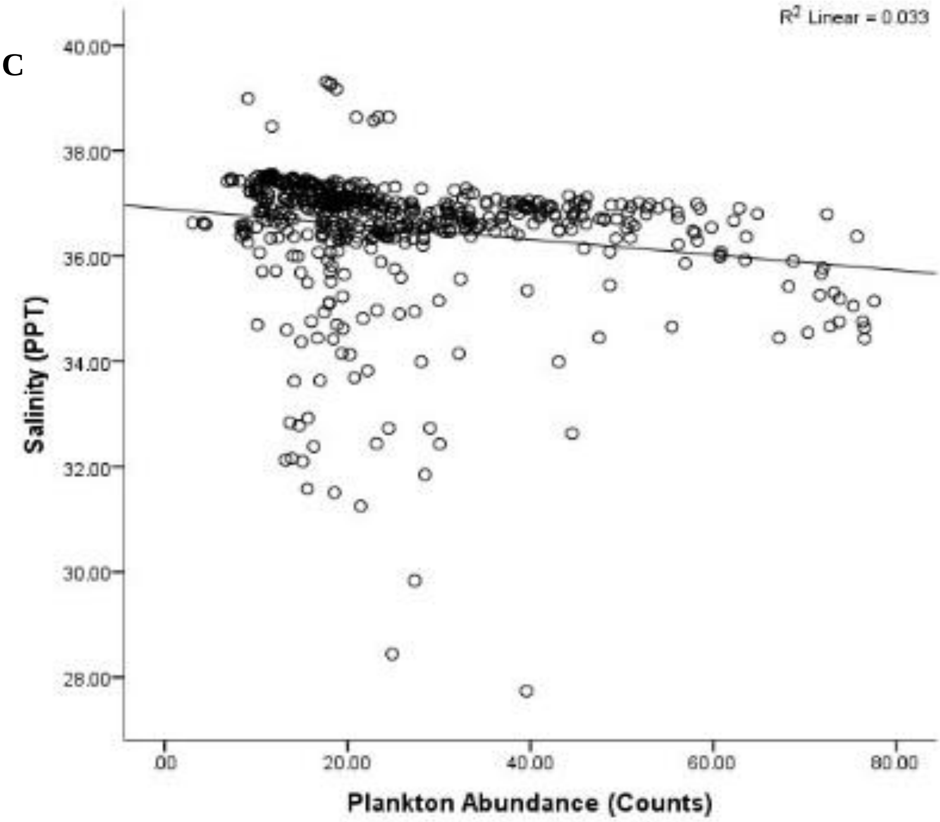
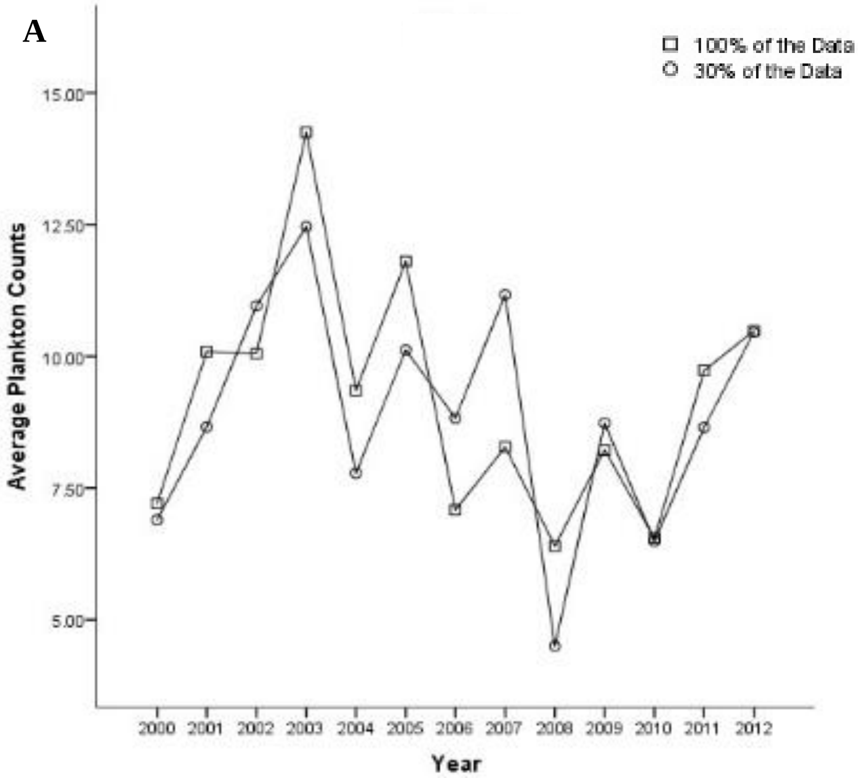


Fig 4.2 Scatter plots representing correlations between the environmental parameters. A) Correlation between SST and PPT. B) Correlation between SST and prey index. CF) Correlation between PPT and prey index.

It must be acknowledged that several outlying points occurred within Fig 4.2a and 4.2c, due to areas of significantly lower salinity captured within the environmental data sets. Such points represented locations within the mapping sites where sharp salinity decreases occur, which included eastern areas within the North Sea that experience outflows of freshwater. Such freshwater input is known to come from the Baltic Sea, a location of low salinity due to it being relatively shallow and having high inputs of freshwater from inland ecosystems such as lakes (Hordoir *et al*. 2013). Such locations occurred towards the borders of the GIS mapping site covered by the NetCDF data layers. These locations were not focussed on during the socioeconomic assessment of increasing bloom impacts, as they occurred away from locations of increased socioeconomic activity that could potentially be impacted by blooms, including offshore waters that the Baltic Sea flows into. However, it must be acknowledged, that there were additional factors influencing the salinity in the plots between the three environmental factors that will have influenced the relationships discussed above. For example, in Fig 4.2a, the locations that experience outflows of freshwater generally occur in areas with lower temperatures, which were the more northerly latitudes and more easterly longitudes within the GIS maps. The result was points within the plots that represented salinities effected by freshwater outflows that coincidentally occurred within the cooler temperatures. The outliers will therefore have influenced the trend lines in the plots acting as leverage points that exaggerated the suggestion that colder temperatures are more associated with lower salinities. Although this generally was case (despite the minimal relationship seen), the trend would have been less pronounced (characterised by an even lower R^2 value) without the influence of the outliers within the salinity data set. Taking into consideration of the leverage effect the outliers had, further confirmation is provided that there was little influence between salinity and the other environmental factors that could potentially influence bloom risk at the resolution the data layers were presented in relation to the physiological tolerances.

4.5 Plankton Abundance Cross Validation

The final investigation into the environmental data before it was reclassified, was a cross validation of the prey index data layers (Fig 4.3a-d) to test whether the fluctuations seen in the initial data layers were a symptom of the kriging interpolation methodology instead of naturally occurring variation detected in the CPR samples. The lack of significant difference between the estimations of prey from the interpolations of original data set and the 30% sub-sample in winter ($t = 0.704$, $df = 12$, $p = 0.495$), spring ($t = -0.474$, $df = 12$, $p = 0.644$), summer ($t = 0.996$, $df = 12$, $p = 0.399$) and autumn ($t = -1.573$, $df = 12$, $p = 0.142$) indicated that the methodology consistently estimated plankton levels based on the data available. The 30% subsample of the data used for validation showed the same annual fluctuations in plankton abundance. The differences observed were minimal and would have been unlikely to impact on the number of raster squares achieving certain suitability assignments once the large amount of data in the layers had been averaged out over the 12 years, across the whole map.


A
100% of the Data
30% of the Data
15.00
12.50
10.00
7.50
5.00
Average Plankton Counts
2000
2001
2002
2003
2004
2005
2006
2007
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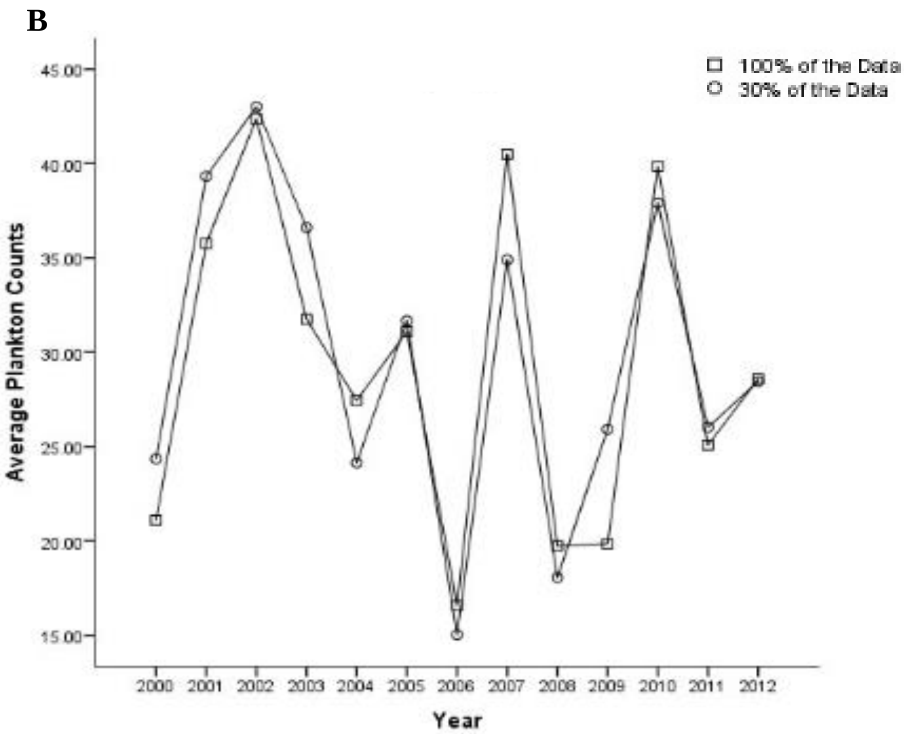
2009
2010
2011
2012
Year


B
100% of the Data
30% of the Data
45.00
40.00
35.00
30.00
25.00
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Average Plankton Counts
2000
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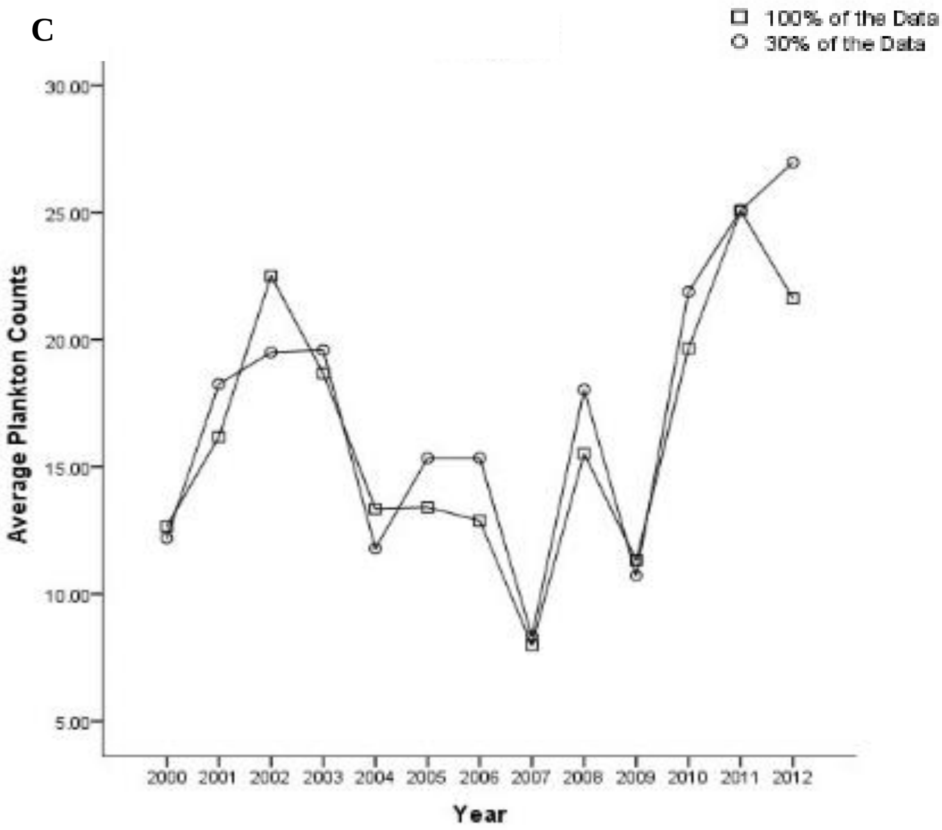


D

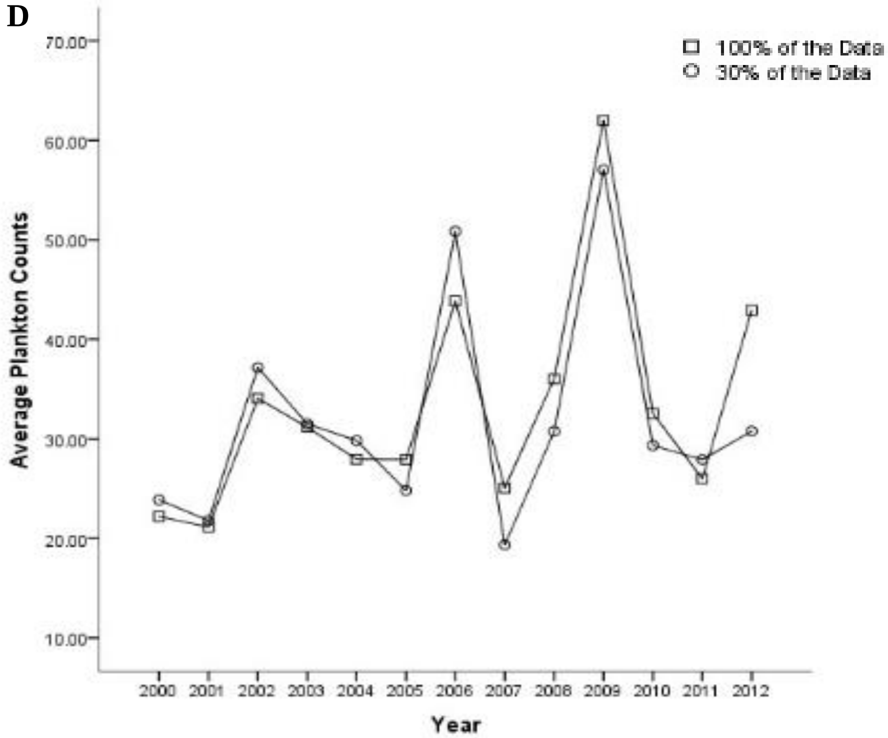


Fig 4.3 Cross validation of seasonal plankton abundance layers comparing interpolations using 100% of the CPR data and the 30% subsample. A) Annual winter plankton abundance cross validation. B) Annual spring plankton abundance cross validation. C) Annual summer plankton abundance cross validation. D) Annual autumn plankton abundance cross validation

However, some areas (such as northern sections of the Celtic Sea) within the mapped range were comparatively under sampled, with spaces occurring between CPR tows. Scattering of the plankton abundance samples therefore occurred, which led to areas within the data layers having fewer points contributing to the estimation of plankton abundance that the cross validation could not quantify. It must therefore be considered that the spikes in plankton abundance described in the environmental data layers (Fig 4.1c) could have been a symptom of certain areas being sampling more, and plankton levels are actually more consistent than the data layers suggest. However, fluctuations in plankton abundance are recorded in the Northeast Atlantic (Colebrook, 1978) supporting the observations of plankton abundance in Figures 4.1 and 4.3. Jellyfish are also known to consume other organisms (Purcell, 1984; Graham and Kroutil, 2001; Tilves *et al.* 2016) than just macrozooplankton that were used as a prey index in the maps, indicating that underestimation of prey may occur. However, as this study aimed to provide a risk scoring system that screened areas in the Northeast Atlantic as potential locations for blooms, as opposed to a fully quantitative model, this should not be a major concern.

4.6 Reclassifications

The reclassifications (reclassification method discussed in Chapter 3, section 3.3.3) of the environmental data layers show the time of year each species achieved highest average raster scores to each of the three parameters (the full set of reclassifications are displayed in Appendix B). For each of the environmental factors studied, summer was generally the most suitable, except the boreal species which achieved the highest suitability rankings in spring. The reclassifications of the SST layers into jellyfish suitability based on physiological data displayed in Table 4.1 resulted in horizontal zones of suitability across the maps with highest suitability situated to the south. The higher rankings of suitability for native and more common species spread further north than ones thought to be less common. The opposite occurred for the boreal species with highest suitability occurring to the north with *C. capillata* showing highest suitably to temperatures in the North Sea. PPT was not a physiological barrier as highest suitability ranking occurred over the majority of the maps. Reclassifications of the prey index layers mirrored the pattern in the data layer, with waters to the southwest, north and northwest showing greatest suitability. The environmental suitability for larger (such as *R. pulmo*) and smaller species (such as (*A. aurita*) of jellyfish both showed the same overall distribution, a higher number of higher raster squares ranked highly in terms of potential bloom occurrence.

4.7 Suitability Maps

Once the corresponding reclassification (reclassification method discussed in Chapter 3, section 3.3.3) layers had been overlaid, the final suitability maps (Fig 4.4a-d) were displayed. Like the reclassifications, highest suitability of the Northeast Atlantic for jellyfish occurred throughout summer, achieving the highest average raster square rankings for 5 of the 7 species (Table 4.2). The smaller and typically more common Scyphomedusae such as *A. aurita* made up the majority of the species showing greatest suitability to the summer conditions, but also showed suitability to the spring and autumn, with some ability to overwinter. Summer was also the peak season for highest suitability of the larger and generally less common species such as *R. pulmo,* despite them achieving consistently lower rankings than the smaller species. The two species where conditions were most suitable for reproduction or blooms that was outside of summer were the species associated with colder boreal environments (*C. capillata* and *C. lamarkii*), with highest raster square ranking occurring as a result of the conditions found in spring (Table 4.2). The maps also suggested they could persist for the majority of the year, particularly *C. lamarkii*. Species with populations described to be expanding northwards that are also known to be infrequent visitors to the mapping area such as *P. physalis* was most suited to summer conditions. *P. physalis* was one of the few species that achieved no bloom assignment, but large areas where reproduction was possible occurred within the suitability maps. Geographically, highest jellyfish suitability occurred within northern regions of the North Sea and south western areas including the Celtic Sea. This was the case for several of the smaller jellyfish as well as the colder water species. Less common species associated with warmer waters (such as *P. physalis*) showed either an ability to survive or be capable of reproduction mainly to the south west.

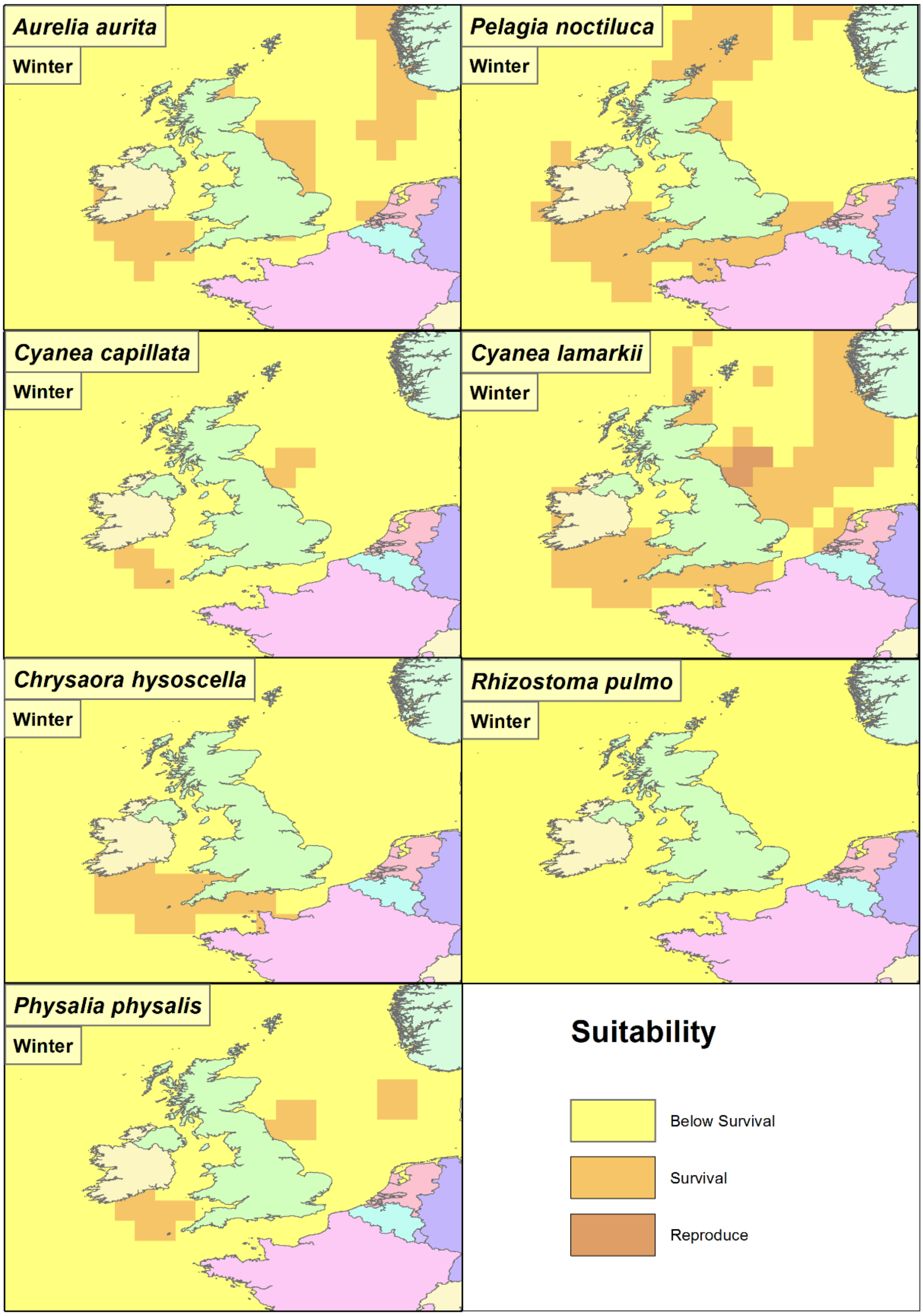
Table 4.2 The number of each raster squares within the mapping sites that was assigned a certain suitability ranking for each species over each season.

Species	Season	Suitability ranking	Number of Raster Squares
A.aurita	Winter	Below survival	586
		Survival	59
		Reproduction	1
		Bloom	0
	Spring	Below survival	238
		Survival	384
		Reproduction	4
		Bloom	1
	Summer	Below survival	3
		Survival	477
		Reproduction	120
		Bloom	8
	Autumn	Below survival	440
		Survival	158
		Reproduction	10
		Bloom	0
P. noctiluca	Winter	Below survival	477
		Survival	169
		Reproduction	0
		Bloom	0
	Spring	Below survival	164
		Survival	457
		Reproduction	4
		Bloom	2
	Summer	Below survival	88
		Survival	149
		Reproduction	363
		Bloom	8
	Autumn	Below survival	384
		Survival	204
		Reproduction	20
		Bloom	0
C. capillata	Winter	Below survival	637
		Survival	9
		Reproduction	0
		Bloom	0
	Spring	Below survival	380
		Survival	214
		Reproduction	33
		Bloom	0
	Summer	Below survival	374
		Survival	195
		Reproduction	39
		Bloom	0
	Autumn	Below survival	514
		Survival	87
		Reproduction	7
		Bloom	0
C. lamarkii	Winter	Below survival	476
		Survival	166
		Reproduction	4
		Bloom	0
	Spring	Below survival	122
		Survival	437
		Reproduction	67
		Bloom	1

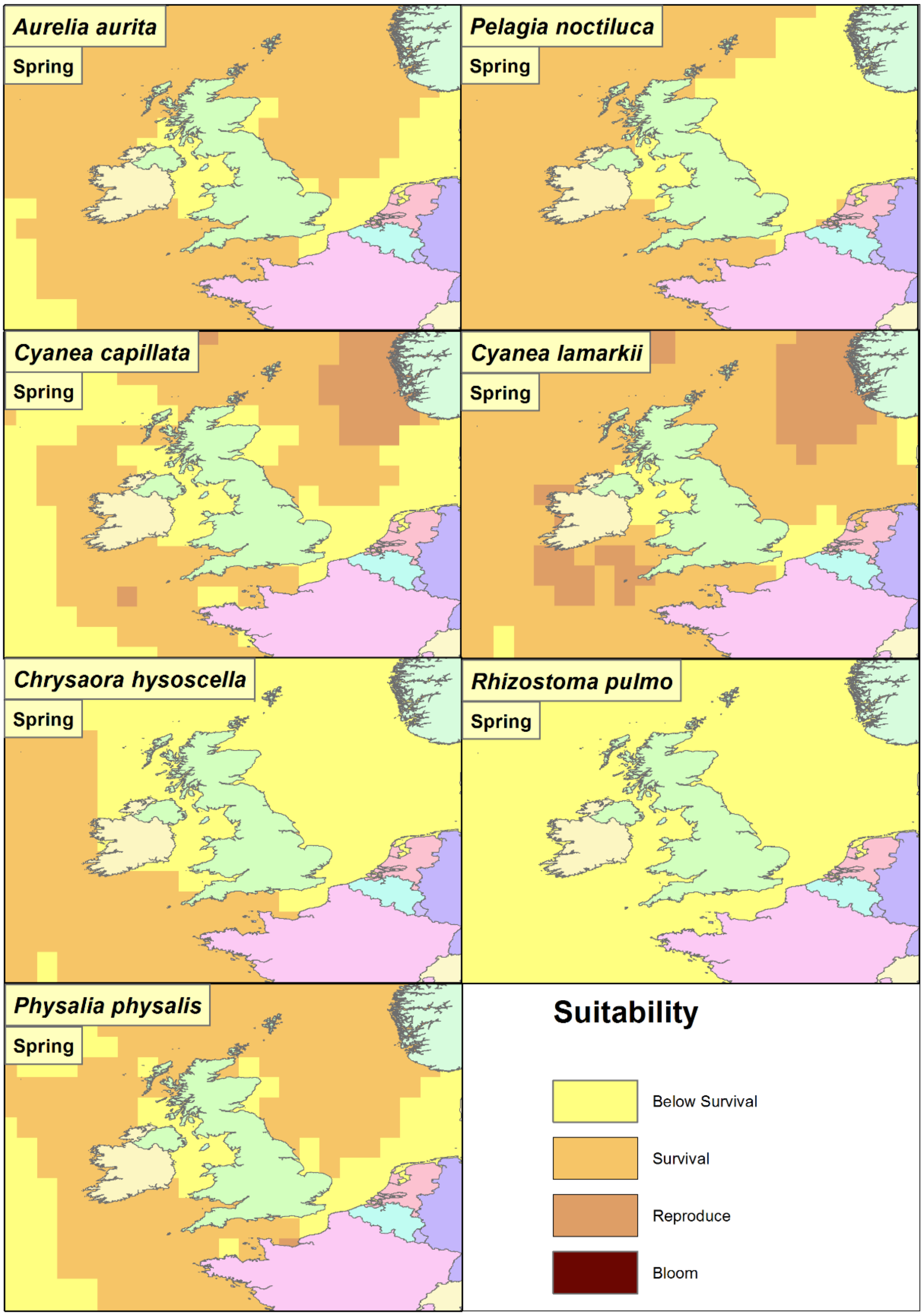
Table 4.2 continued

	Summer	Below survival	157
		Survival	333
		Reproduction	115
		Bloom	3
	Autumn	Below survival	407
		Survival	190
		Reproduction	11
		Bloom	0
C. hysoscella	Winter	Below survival	550
		Survival	96
		Reproduction	0
		Bloom	0
	Spring	Below survival	344
		Survival	281
		Reproduction	1
		Bloom	1
	Summer	Below survival	5
		Survival	540
		Reproduction	58
		Bloom	5
	Autumn	Below survival	403
		Survival	205
		Reproduction	0
		Bloom	0
R. pulmo	Winter	Below survival	646
		Survival	0
		Reproduction	0
		Bloom	0
	Spring	Below survival	621
		Survival	4
		Reproduction	2
		Bloom	0
	Summer	Below survival	545
		Survival	55
		Reproduction	8
		Bloom	0
	Autumn	Below survival	600
		Survival	8
		Reproduction	0
		Bloom	0
P. physalis	Winter	Below survival	626
		Survival	20
		Reproduction	0
		Bloom	0
	Spring	Below survival	312
		Survival	305
		Reproduction	10
		Bloom	0
	Summer	Below survival	350
		Survival	250
		Reproduction	8
		Bloom	0
	Autumn	Below survival	486
		Survival	119
		Reproduction	3
		Bloom	0

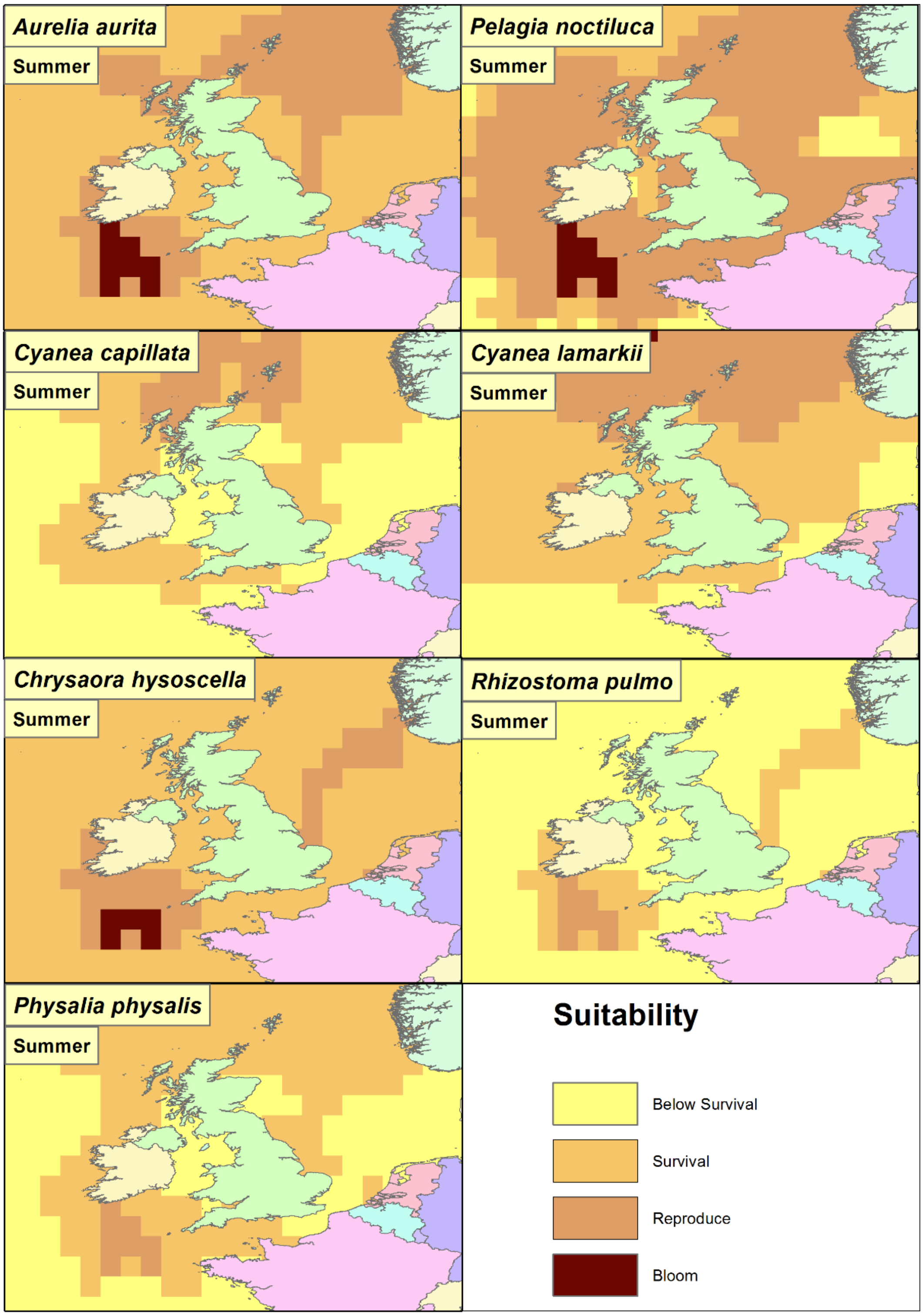
A) Winter


Aurelia aurita
Winter
Pelagia noctiluca
Winter
Cyanea capillata
Winter
Cyanea lamarkii
Winter
Chrysaora hysoscella
Winter
Rhizostoma pulmo
Winter
Physalia physalis
Winter
Suitability
Below Survival
Survival
Reproduce

B) Spring


Aurelia aurita
Spring
Pelagia noctiluca
Spring
Cyanea capillata
Spring
Cyanea lamarkii
Spring
Chrysaora hysoscella
Spring
Rhizostoma pulmo
Spring
Physalia physalis
Spring
Suitability
Below Survival
Survival
Reproduce
Bloom

C) Summer


Aurelia aurita
Summer
Pelagia noctiluca
Summer
Cyanea capillata
Summer
Cyanea lamarkii
Summer
Chrysaora hysoscella
Summer
Rhizostoma pulmo
Summer
Physalia physalis
Summer
Suitability
Below Survival
Survival
Reproduce
Bloom

D) Autumn

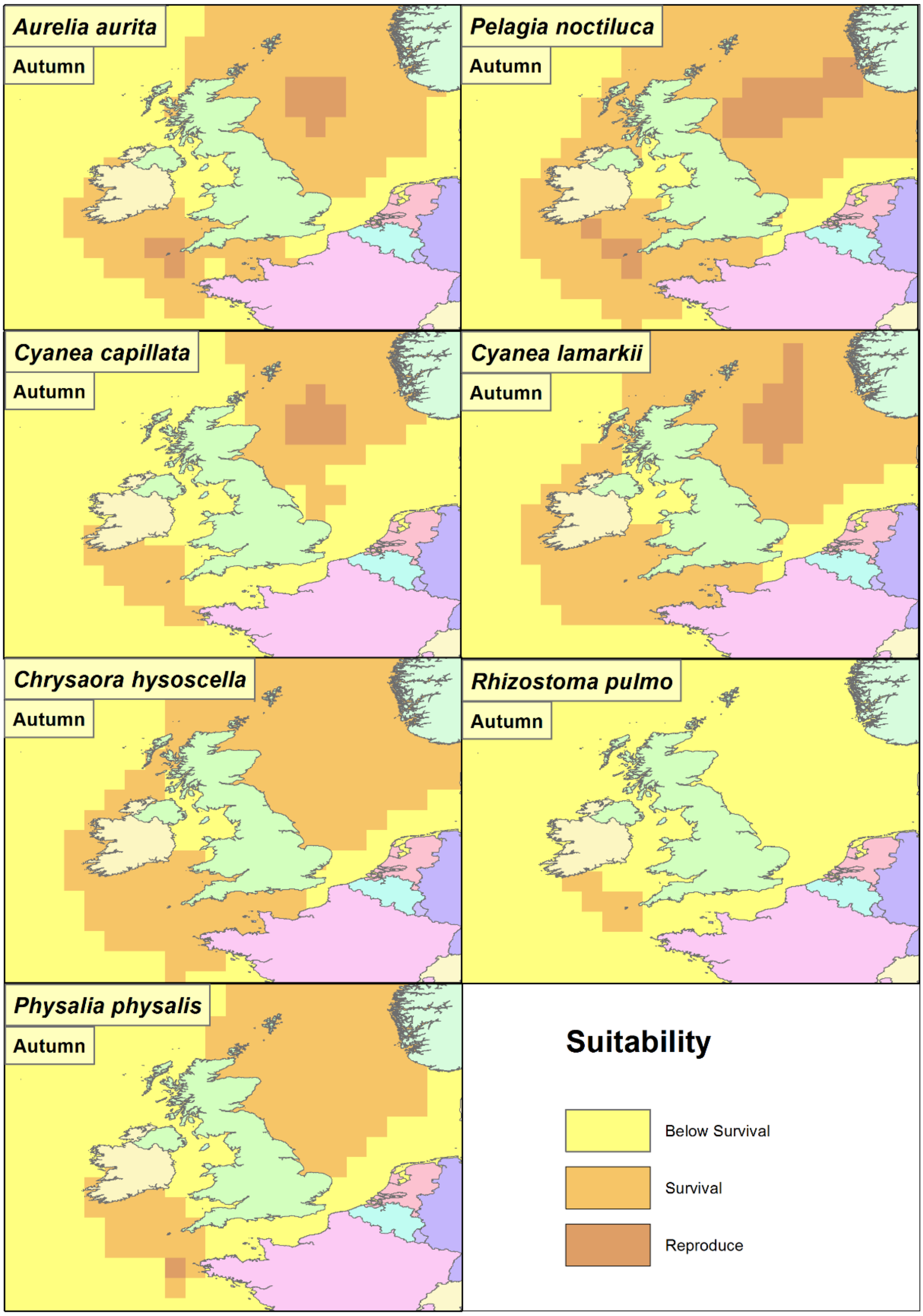


Fig 4.4 Visualisations of the average suitability of the mapping site for each species over the 4 seasons. A) final suitability during winter. B) final suitability during spring. C) final suitability during summer. D) final suitability during autumn.

As suggested when comparing the relationships between the environmental data layers, higher raster square ranking occurred for species that could tolerate colder temperatures (i.e. <14^0C), enabling them to take advantage of the increased prey. This occurred for several of the small Scyphozoa and the boreal species to the north with the typically warmer water species showing greatest suitability to the southwest. The overlap between areas of increased plankton abundance and higher jellyfish suitability, highlighted the fluctuating prey abundances between spatial locations as a significant limiting factor of potential bloom risk within the zones of tolerable temperatures and salinities.

4.8 Comparison between Map Output and Previous Blooms

Before the implications of locations for current and future jellyfish suitability were considered, the output was tested by comparing the results to the occurrence of knowing blooming events. The results of the physiological reclassification and overlay of data representing the year 2007 when *P. noctiluca* was recorded to have bloomed extensively across the Celtic Sea (Doyle *et al.* 2008) was compared to rankings of equivalent data layers representing the year 2000 when no blooms were reported (Figure 4.7). The reclassifications of the data layers representing the environmental conditions during the year 2000, described large areas where reproduction was possible but a negligible amount of raster squares (1%) were assigned as able to support bloomed populations, in agreement with the notion that no abnormal occurrence was reported during this time. The opposite occurred when the 2007 data layer was treated, as high bloom risk was assigned over large areas (25% of raster squares, all of which fell just to the south of Ireland) that coincides with reports of the *P. noctiluca* blooms (Boero *et al.* 2008; Doyle *et al.* 2008; Licandro *et al.* 2010) and when the CPR tows sampled increased gelatinous tissue which was hypothesised to be as a result of the bloom (Licandro *et al.* 2010). This indicates that the methodology was capable of distinguishing between the conditions where blooms have historically occurred with areas of below survival being ranked adjacently to areas where high suitability occurred, with those for which blooms have not been recorded.

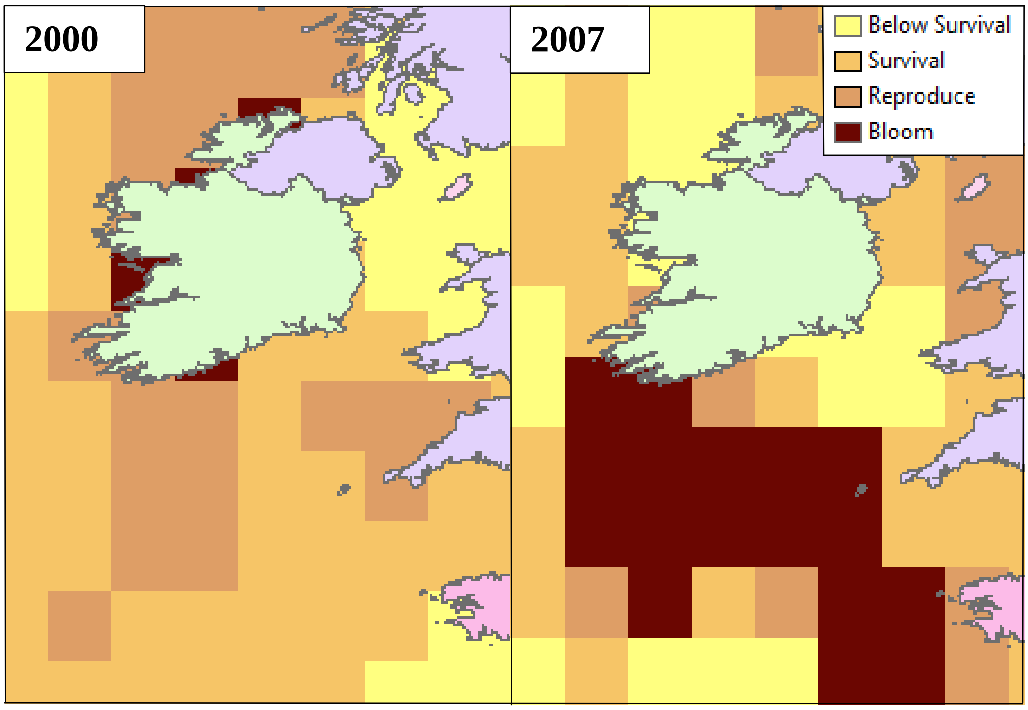


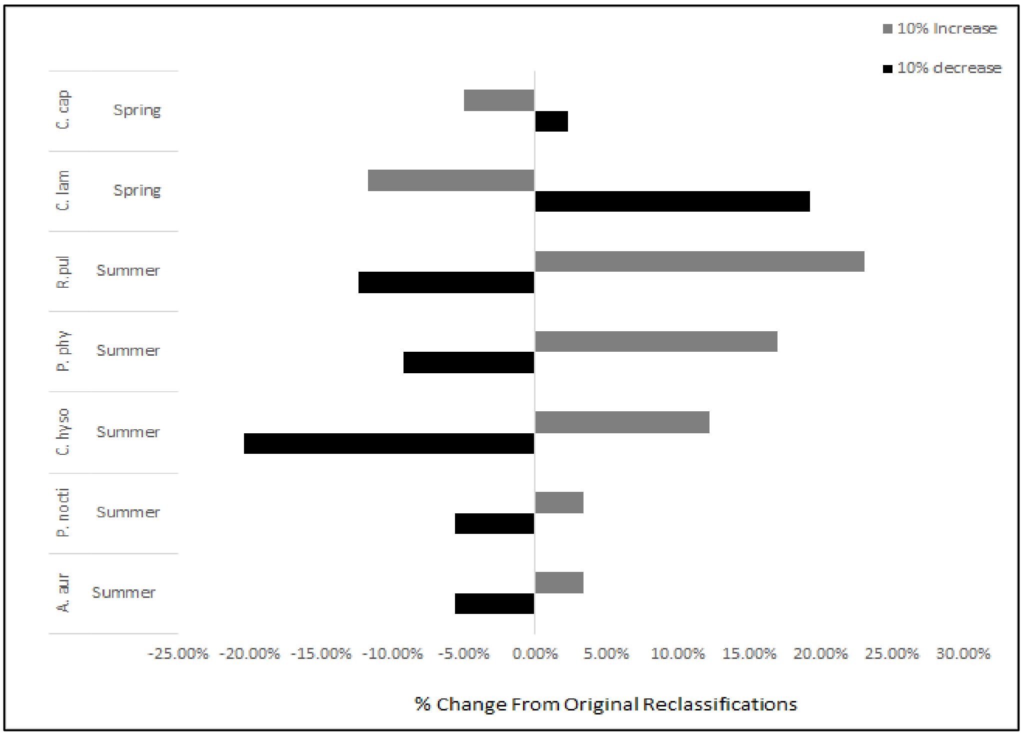
Fig 4.6 Suitability maps of *P. noctiluca* in the year 2000 and 2007 across the Celtic Sea.

However, despite the maps picking up on bloom risk during a time period when an event occurred, some areas within the Celtic Sea were assigned survival and in some cases below survival. Increased gelatinous material was detected in the CPR samples across the whole area throughout 2007, suggesting that the map picked up on the most optimal conditions for the bloom to form, but didn't recognise how they were dispersed. This trend occurred for both the 2000 and 2007 data, with areas of below survival being ranked adjacently to areas where high suitability occurred, which can be considered unrealistic due to the lack of physical barriers in the water.

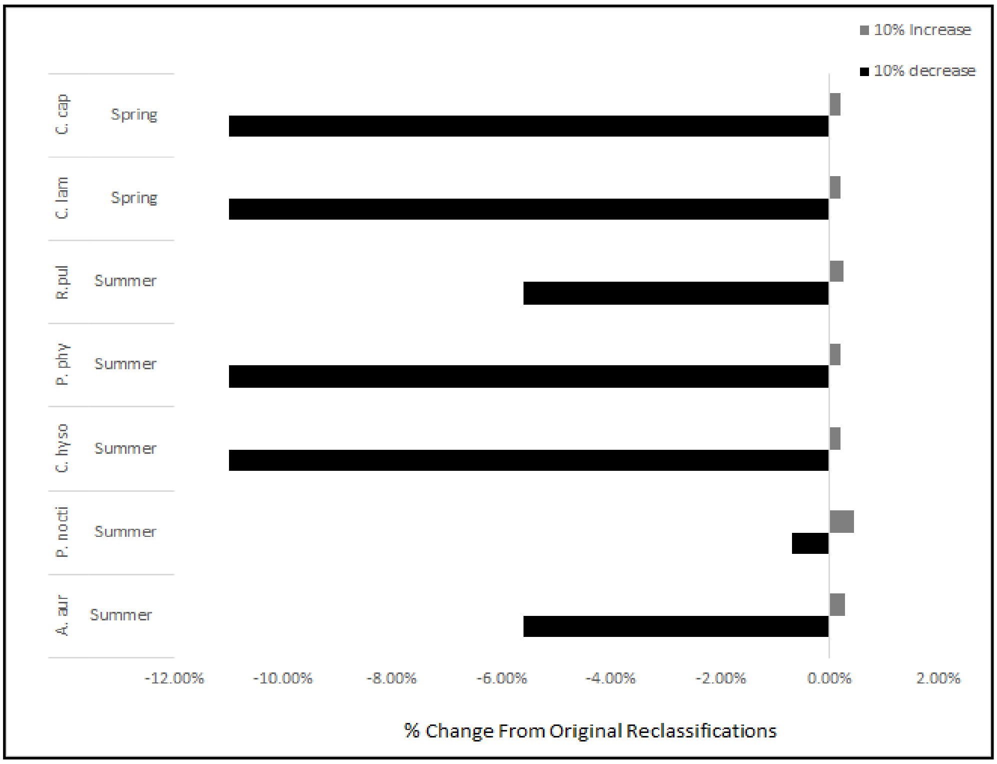
4.9 Future Risk

The sensitivity analysis (methods discussed in Chapter 3, section 3.3.5) of the season when the greatest amount of raster squares were assigned as suitable for blooms for each species (in the case of *R. pulmo*, *P physalis*, *C. capillata* and *C. lamarkii*, no bloom rankings were achieved so raster squares with a reproduction ranking are displayed) (Fig 4.8a-c) resulted in changes in overall jellyfish suitability rankings. These alterations suggested which species were more likely to increase or decrease in number due to changes in the environmental factors and the time of year this was more likely to occur. The 10% temperature increase (Fig 4.7a) resulted in proportionally greater suitability increases to the summer conditions for the larger and generally less common Scyphomedusae, *R. pulmo* and the hydrozoan, *P. physalis* (saw an 23% and 17% increases highest raster square ranking respectively) that currently show relatively low suitability to the present-day conditions compared to the smaller, more common species (*A. aurita* and *C. hysoscella*). This indicates that increasing summer temperatures could allow for northern expansions of larger populations of these species into Northeast Atlantic waters where the prey levels and salinity can currently sustain them. Such increases in populations of larger species would likely have an impact, even if they don’t bloom due to their conspicuousness and in some cases, their ability to sting. Increased risk associated with the smaller more common species (*A. aurita* and *C hysoscella*) also occurred, but the risk increase was proportionally lower than the increase seen for larger species as higher suitability to the present-day temperatures already occurred. This included increase of bloom assignment of 5% in the most common species, *A. aurita*, up to 15% increase in *C hysoscella* risk. A general increase in reproduction assignments also occurred. However, the species associated with boreal conditions (*Cyanea* spp) showed less suitability (reproduction rankings decreased by 13% for C. *lamarkii* and 7% for *C. capillata*) to the increased temperature indicating that population contractions away from their current range would occur in the event of temperature increases. Conversely, the temperature decreases resulted in lower suitability for the temperate and warmer water species (ranging from 5% decrease for *A. aurita* and *P. noctiluca* to 20% decrease in *C. hysoscella*).

A) SST



B) PPT



C) Prey Index

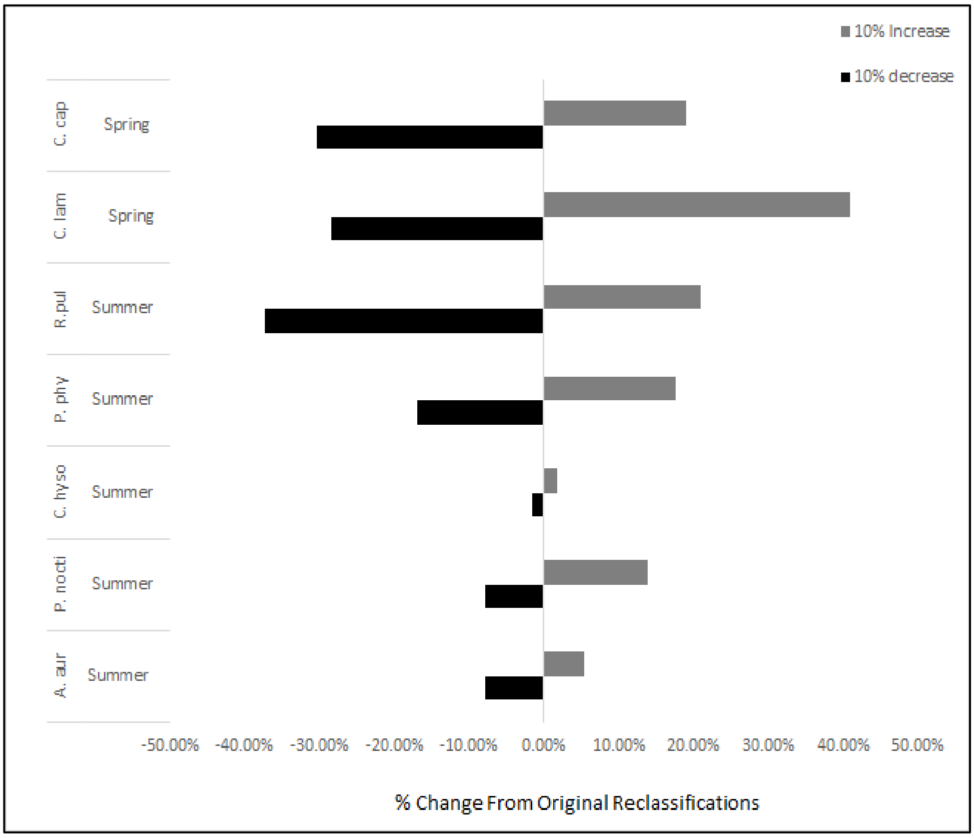


Fig 4.7 Raster square assignment frequency difference from the original reclassification layers after the + and – 10% sensitives treatments. A) SST. B) PPT. C) prey index.

The sensitivities applied to the PPT layers and subsequent reclassifications resulted in a different pattern. The low increases (<1%) in highest raster square assignment jellyfish as a result of the +10% sensitivity added to the result from the reclassification (Fig 4.1) that the salinities in Northeast Atlantic waters already cross the thresholds of highest suitability in the present day for all of the species. The decreases in salinity resulted in decreases between 5% and 10% in the highest suitability assignments during the most suitable time of year for each species, highlighting that the thresholds were sensitive to the impacts of salinity change and only significant decreases would impact populations. The percentage changes in risk assignment in relation to prey abundances (Fig 4.8c) were greater than what was achieved during the sensitivity analysis of the other two environmental factors. The groups of jellyfish that contain both large and small medusae both had increases and decreases in their highest raster square rankings as a result of applying the sensitives to the prey index layers with the suitability for the larger medusae showing greater changes (e.g. *C. capillata* increased by 40% whereas *A. aurita* increased by 8%). This indicates the potential importance of fluctuating prey levels in bloom forming species as well as the conspicuous ones and how future alterations could influence their populations, particularly if they occur in the zones of increased summer temperature, with populations of the larger species more likely to increase and decrease in response to prey abundance fluctuations.

4.10 Conclusions

The mapping process achieved the aim of revealing locations within the Northeast Atlantic that were more likely to experience noticeable jellyfish populations by applying existing knowledge of their physiological tolerances to a representation of the marine environment. This was achieved over a wide-ranging area using species specific physiological thresholds (where possible) and freely available environmental data layers of consistent resolutions. Physiological tolerance to each of the potential bloom limiting factors were combined to visualise their overall influence on jellyfish populations within a geographic region perceived to be experiencing an increase in blooming events. Mapping was completed for 7 species based on present day conditions, generating an understanding of how key environmental factors contribute towards greater jellyfish suitability. It also highlighted the locations more susceptible to larger populations and therefore blooming events if environmental parameters were to change in favour of jellyfish. More specifically, the times of year when the populations of each species were likely to be at their greatest was represented, allowing for more specific considerations of the coastal industries at risk from the impacts of hypothetical future blooms. Generally, the locations of higher suitability in the maps coincided with the coastlines where each of the species have been found washed up or occurring in waters in greatest numbers (Avian, 1986; Doyle *et al*. 2007; Pikesley *et al.* 2014; OBIS, 2017) as well as the location of incidents involving a species and anthropogenic activity reported in the scientific literature (Purcell *et al.* 2007) and the media (e.g. Godson, 2015).

It can be concluded that the patchy distributions seen in the plankton data layers, characterised by areas of intense abundance, were the key drivers of the distribution of highest jellyfish rankings achieved in the maps. The distributions of high plankton abundance were mirrored by spatial locations of greatest jellyfish suitability in the species-specific reclassifications and therefore the final risk maps. The responses to seasonal and localised plankton fluctuations within the risk maps can be offered as an explanation to the sudden appearances and disappearances of large numbers of medusae that have been associated with blooms (Mills, 2001; Graham *et al.* 2003; Palmieri *et al.* 2015). Several of the species (e.g. *A aurita*) are also known to show plasticity to the environmental factors (e.g. ocean temperature) within the model (Nawroth *et al.* 2012; Chisholm, 2013), suggesting that such spikes in prey abundance are a leading cause of instances where historical blooms have been able to develop within Northeast Atlantic waters. However, prey abundance was not the only limiting factor, as the ocean temperatures created horizontal layers of varying suitability across the map that the fluctuations of increased prey abundance necessary for increased jellyfish populations occurred in. Spikes in prey abundance within the larger and less changeable zones of suitable SST and PPT provided optimal conditions for reproduction and bloom assignment of raster squares in certain areas that included the southwest of the maps, particularly the Celtic Sea. However, large areas were not suitable for larger populations of several of the species in northern areas of the North Sea where the waters were too cold for reproduction and in some cases survival, despite the highest prey abundances occurring there. In contrast, the boreal species and species generally accepted to be native year-round such as *A. aurita* were able to take advantage of the increased plankton abundance due to their ability to occur in colder temperatures. However, ocean temperature must not be a considered a barrier to jellyfish suitability as sudden increases have also been hypothesised to trigger increases in reproduction associated with blooming events in lab conditions (Mills, 2001; Purcell *et al.* 2012; Holst, 2012; Pascual *et al.* 2014). Annual increases in temperature have also be described to aid jellyfish populations as it allows them to reproduce and spawn earlier in the year leading to even greater populations at peak times (Purcell, 2012). The maps generated in this study can therefore be used to understand how the conditions at a certain time can influence the risk of species in a proceeding season. For example, large areas of higher environmental suitability were assigned to the summer conditions, potentially resulting in large numbers of medusae persisting into the autumn despite the lower suitability rankings, as medusae have been shown to be able to tolerate less suitable conditions more than ephyrae and the larval forms within the jellyfish life cycle (Lilley *et al.* 2014; Collingridge *et al.* 2014). The mapping methodology also contributed towards an understanding as to whether frequencies of jellyfish populations could have increased in recent years. During the period when the apparent increase in reports of blooms occurred, increasing concern has been linked to factors which can trigger prey abundance spikes such as coastal eutrophication (Richardson *et al.* 2009) leading to organic matter feeds up the food web (Nixon, 1995; Bennet *et al.* 2001) that jellyfish exploit (Richardson et al. 2009; Purcell, 2012), as well as the temperature of the North East Atlantic experiencing increased warming in recent decades (Philippart *et al.* 2011). The sensitivity analysis suggested that increases in these two factors make Northeast Atlantic waters more suitable to the majority of the species in this study, agreeing with the notion that increased jellyfish populations in the Northeast Atlantic could have occurred and could continue to increase, with localised blooming events forming due to small scale prey and temperature fluctuations. Whether there has been a general increase in populations or just an increase in anomalous blooming cannot be concluded, but the sensitivity analysis suggests that both could have be possible. However, if the oceans were to continue to warm and planktonic abundance spikes were to become more intense in the future, Northeast Atlantic waters could potentially offer a consistently suitable environment for larger populations of currently common and uncommon species that could develop into blooms more regularly.

4.10.1 Limitations and Future Map Development

The main limitation of this model is that it is based on organisms that are historically understudied with data lacking on their physiological responses to aspects of the marine environment. Based on the best information available, the model acts as an initial screening exercise tool to identify locations that could potentially experience larger jellyfish populations based on three environmental parameters. Despite having to rely on data that could be more accurate it successfully ranked a location as suitable for a bloom of a specific species, during a time when a bloom was actually reported, whilst suggesting times when no reports of blooms exist, that the environment was not suitable for a bloom. As jellyfish are opportunistic organisms, capable of responding rapidly to favourable conditions by blooming (Purcell, 2005), accurately predicting more specific times and locations of blooms using the model remains a challenge. As the field of jellyfish bloom research develops, applying improved information and additional data (if they were ever to become available), could provide more specific notice as to when blooms of a certain species are more likely to occur in a specific location, due to the successes of the methodology that have been reported in this chapter. Additional environmental factors have been shown to influence jellyfish populations for which physiological response thresholds currently do not exist. These include ocean pH and oxygenation (Richardson and Gibbons, 2008; Richardson *et al.* 2009). Responses of jellyfish species to factors such as stressful oxygen levels and lower pH has been hypothesised to allow gelatinous species to outcompete fauna with higher oxygen demands and more calcareous structures, as well as provide predator free sanctuaries for jellyfish (Richardson *et al.* 2009) that contribute towards increased medusae recruitment associated with blooms. Developing reclassifications of data layers that visualise the impact on jellyfish populations once they become available would provide further understanding of the conditions that enable blooms and where they will occur.

The distribution of areas where data were missing within the GIS model were highlighted within the environmental data layers, their reclassifications and the suitability maps, leading to some uncertainty associated with the final outcomes. This included examples such as the below survival rankings of species such as *R. pulmo* in parts of the Celtic Sea where they are known to occur (Hayward and Ryland, 2008) and the locations of low suitability of *P. noctiluca* within locations where it bloomed in the year 2007. Several explanations can be offered as to why this occurred. The first, was the areas that are not sampled during the CPR surveys potentially impacted the raster square rankings of the prey abundance estimations. Areas in the interpolations of low prey abundance which were potentially underestimations due to the conditions the sample was taken or under sampling contributed towards the below survival raster square assignment in locations where certain species occur. The data used to create the prey index layers was also based on macrozooplankton despite the knowledge that jellyfish also prey on other items such as fish eggs and microplankton (Purcell, 1984; Tilves *et al.* 2016). Other data layers that represents abundance of other prey items currently do not exist or data were not available that could be interpolated into raster layers. Information on the amount of prey required that contributed towards individual jellyfish physiological thresholds was scarce, resulting in some assumptions to be made based on key studies that gave a general assumption of prey requirements of species with similar morphologies and life histories. Generally improving information on the thresholds of each species and the development of additional data sets representing other prey items across more of the mapping site would contribute towards addressing any underestimation that may have occurred. Additional physical features of the marine environment also require consideration to improve jellyfish risk assignment. For example, ocean currents are known to disperse jellyfish populations (Hays *et al.* 2005; Richardson, 2008), so visualising the impacts on distribution in future iterations of the model could explain the differences between the suitability maps and the locations of actual occurrence as well as occasions when high suitability occurred alongside low suitability. Applying the general directions of the ocean currents and areas more likely to experience subsequent settlements of marine organism could potentially explain discrepancies, describing how blooms are transported from where they develop to locations where the medusae are also able to survive.

If future iterations of the maps or uses of the methodology were to be developed, they should seek to address some of the knowledge and data gaps that have been identified to assess if any improvements can be made when assigning bloom risk to a location based on environmental suitability. Chapter 7 (section 7.2), discusses some suggestions on the data requirements to further test the suitability of the Northeast Atlantic for blooms based on a variety of additional data that are required. Ideally, coastal industries would require a version of the maps that could assign bloom risk of each type of species at shorter notice, in the form of a forecast to enable preparations that could mitigate the impacts of blooms that are investigated in Chapter 5 and 6. An additional component to achieving this would be to develop data layers that predict future prey abundance and salinity changes consistent with the future ocean temperature layers that exist that can be reclassified based on jellyfish physiology scores so that more specific future risk can be visualised. However, it is highly debatable as to whether short term forecasts and further future projections of certain environmental parameters can be achieved, therefore Chapters 5 and 6 display the application of the maps generated in this study for the purposes of projecting the impacts that bloom could have on both the fishing and tourism industries in the Northeast Atlantic in relation to an ecosystem services approach.

4.10.2 Further Work

The suitability maps combined with the information generated in the sensitivity analysis in this chapter suggested areas and times of year that greatest jellyfish occurrence was possible and has provided an overview of where interactions with coastal industries would occur. The large areas of increased suitability of the two *Cyanea* species as well as high suitability for *A. aurita* and *P. noctiluca* to the north of the maps coincided with the high levels of finfish aquaculture that occurs across Scotland. These four species are known to cause mortality of finfish, with previous blooming events of *P. noctiluca* interfering with Irish aquaculture in 2007 (Doyle *et al.* 2008; Licandro *et al.* 2010) and *C. capillata* impacting Scottish aquaculture in 1996 (Purcell *et al.* 2007), costing the industry millions in lost revenue. Based on the risk identified by the sensitivity analysis, future spikes of prey in these areas would increase the suitability for the boreal species. Increases in temperature would increase suitability for both *A. aurita* and *P. noctiluca* as well as northern expansions other species such as *P. physalis* or *C. hysoscella* that have the morphological characteristics to cause detrimental impacts on aquaculture. The minimal impact increasing temperature had on the prey index would also be unlikely to cancel out the temperature induced increases in jellyfish suitability of the warmer water species, because the change was less than the difference between the physiological thresholds presented in Table 4.1. Despite spring and summer (and therefore autumn if medusae persists) generally being the time where increased suitability was recorded, increased bloom occurrence at any time of the year would have impacts due to the long durations finfish are reared with only a single blooming event required to result in significant losses (Purcell *et al.* 2007).

The increased suitability assignment of raster squares to the south west of the maps for the rest of the species coincided with locations associated with increased coastal tourism and the locations of harbours where significant fisheries are based. This included the coasts of Cornwall where there are several coastal towns dependent on tourism (Beatty *et al.* 2010) as well harbours that act as a base for some large-scale fisheries (IFCA, 2017). Both of these industries have been impacted by annual jellyfish blooming occurrence in other geographic locations in the past (Palmieri *et al*. 2014; Ghermandi *et al.* 2015).

No studies have attempted quantifications like these for Northeast Atlantic waters referring to specific cases studies (that the author is aware of), so understanding how any impacts of blooms are required so that management can be considered. The species that showed increased suitability to the south west all showed increased risk when temperature and prey abundance increased indicating that future conflict could increase if factors that cause ocean temperatures to rise or if prey increases were to occur in the area. Summer showed greatest suitability to the species that were situated to the south west, including stingers (e.g. *C. hysoscella*) known to be capable of negatively impacting coastal tourism and the activities of fishermen (Palmieri *et al.* 2014; Ghermandi *et al.* 2015). As summer is the peak time for coastal tourism, interactions with jellyfish are more likely. Like aquaculture, fisheries operate all year, but the seasonality of blooms could still have specific impacts based on the seasonality of target fish species and how the specific gear required interacts with blooms. Currently, it can only be hypothesized that there would be socioeconomic impacts of increasing blooms. An understanding of how industries would interact with jellyfish within the areas of greater suitability is therefore required to enable quantification of the impacts if jellyfish were to bloom more frequently. These are explored in subsequent Chapters 5 and 6.

CHAPTER 5

JELLYFISH BLOOM IMPACTS ON FISHERIES

5.1 Introduction

This chapter explores potential socio-economic impacts from possible future jellyfish bloom increases on those working within the fishing industry, thus addressing the second research question set out in Chapter 1 (what would be the magnitude of the socio-economic impacts related to the tourism and fishing industry in the event of increased jellyfish blooms occurrence in the Northeast Atlantic?). It is based on results from a survey of fisherfolks in Newlyn and Brixham that elicited how they envisage their activities would be altered using their responses to hypothetical bloom increases. Impact quantifications were then developed by focusing on costs to fisherfolks in the present day and how they would compare with any impact the increasing bloom frequencies would have. Survey responses were combined with secondary economic data to generate scenarios of how fisherfolk activities would change to enable valuations of impacts of future bloom increases. Impact projections were then compared with the range of impacts blooms are known to cause in other geographic locations. Initially, section 5.2 explains the selection of the study sites, and how they compare with the spatial distribution maps of locations where high jellyfish numbers could occur. Section 5.3 discusses the characteristics of the fisherfolks that participated in the surveys, deriving insights on their present-day operations for comparison with how they would operate in bloomed waters. Section 5.4 then reports the previous experiences and responses of study participants to jellyfish blooms in their fishing grounds. Section 5.5 displays the responses of fisherfolks in terms of possible behaviour and operations changes once they had been introduced to hypothetical scenarios where increasing blooms occur within their Northeast Atlantic fishing grounds. The responses to the increased bloom of different species groups and relevant secondary data were then used to quantify any subsequent costs (sections 5.6); section 5.7 highlights potential welfare and social impacts. Section 5.8 discusses how the impact valuations from this study compare to the impacts in other geographic locations and how these could contribute towards fisherfolk's decision-making that minimises impacts whilst fishing during blooming events.

5.2 Study Locations

For the purposes of this study, locations within the Northeast Atlantic that could be affected by jellyfish blooms and are frequented by fisherfolk, were the focus of the research. Based on the results reported in Chapter 4, the south-western waters off the UK were selected as:

(a) they encompassed more marine areas where large jellyfish populations could conceivably occur for a greater number of jellyfish species (Fig 5.1),

(b) they included areas of the sea where species that are more sensitive to environmental change (e.g. *R. pulmo* and *P. physalis*, see Chapter 4) as well species known to impact fisheries (*P. noctiluca* and *A. aurita*, see Chapter 2) were potentially capable of blooming according to the GIS maps generated with the methodology developed in Chapter 3 (Fig 5.1).

(c) Fisherfolks in the south-west use mobile gears (e.g. trawls) such as those used in other harbours; around 80% of both demersal and pelagic landings reported in UK harbours, including the south-west, are made with mobile gear (MMO, 2017a), thus providing a potential means of comparison with studies of bloom impacts in other locations (e.g. Palmieri *et al.* 2014) where similar gears are used.

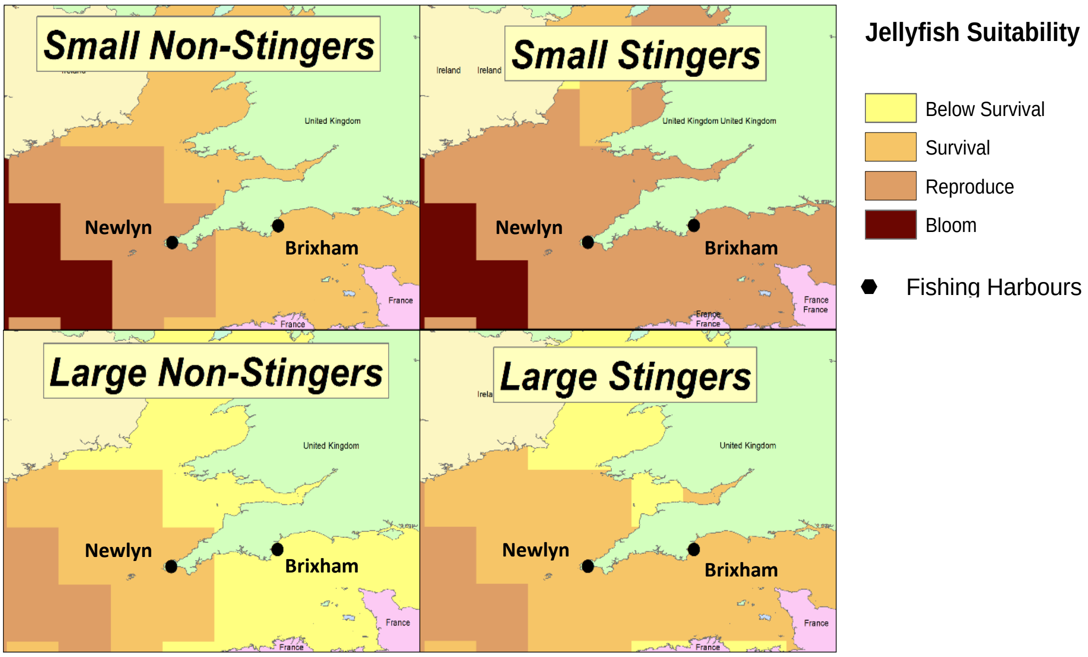


Fig 5.1 Expected distribution of summer suitability of the waters off southwestern coats of the UK to species belonging to the small non-stinger (represented by *Aurelia aurita*), small stinger (represented by *Pelagia noctiluca*), large non-stinger (represented by *Rhizostoma pulmo*) and large stinger (represented by *Cyanea capillata*) groups in relation to Brixham and Newlyn fishery harbours.

The fishing harbours that were selected as case studies within these waters were Brixham (-3.5054096 ° W, 50.3977178° N) and Newlyn (-5.553 ° W, 50.101 ° N), see Figure 5.1. Brixham and Newlyn are located within close proximity to each other with vessels operating within similar stretches of water (based on AIS tracking provided by Marine Traffic, 2017). The majority of vessels in both of these harbours are <10 meters in length, using nets to target mainly pelagic fish species, but there are a number of large commercial vessels >10m, that fish for either mainly pelagic or mainly demersal species (MMO, 2017a). There are also some large vessels >10m that target shellfish (particularly in Brixham (MMO, 2017a). There is a variety of different mobile gears on these vessels that target pelagic and demersal fish (MMO 2017a) which were considered in this study (e.g. trawls). Brixham and Newlyn harbours have 250 and 600 registered vessels respectively, with 553 fishermen based in Brixham and 684 based in Newlyn (around 75% are classed as full time) as of 2015 (MMO, 2017b). The most recent monthly report (June 2017 at the time of writing) (MMO, 2017a) states that the largest landings in England are at Brixham, but the catch brought into Newlyn harbour have the highest value. Possibly, at Brixham greater quantities were caught due to the few large vessels catching large amounts of shellfish (MMO, 2017a), and in the last few years the harbour underwent regeneration that modernised operations (Torbay Harbour Master, 2015). The value of the Newlyn catch was likely greater as more pelagic species were landed by the greater number of vessels (MMO, 2017a). Pelagic fish species are the only group that have undergone price rises in the past year contributing to the increased value of the catch: pelagic fish prices increased by 6%, where demersal species and shellfish prices declined by 15% and 19% respectively (MMO, 2017a).

5.3 Survey Respondents

A total of 67 fishermen were approached during field work (methods discussed in Chapter 3, section 3.5.1). Due to the fact that most fishermen who lived outside of Brixham and Newlyn spent little time in the harbours and the towns, 33 surveys were successfully completed (21 in Brixham, 12 in Newlyn), achieving a response rate of 49% of those that were approached. Recent reports indicate there are 553 and 684 fishermen based in Brixham and Newlyn respectively (MMO, 2017a). The characteristics of the fishermen that participated in the survey are displayed in Table 5.1.

Table 5.1 Characteristics of respondents in Brixham and Newlyn harbours

Characteristic		**Frequency (% per harbour)**	
		Brixham	Newlyn
Gender	Male	100%	100%
	Female	0%	0%
Years fishing	0 – 5	10	8
	6 – 10	14	17
	11 – 15	19	33
	16 – 20	33	25
	21 – 25	5	0
	26 – 30	14	17
	31 – 35	5	0
Fishermen Status	Vessel Owners	48	42
	Vessel Employee	52	58
Vessel Length	Over 10m	47	58
	Under 10m	53	42

Table 5.1 continued

Fishing Type	Demersal Trawler Pelagic Trawler Small Scale Fishery Pots and Creels Gill Net	43 19 29 10 0	33 25 33 0.0 8
Average Distance they Fish from Coasts (miles)	0 – 10 11 – 20 21 – 30 31 – 40 41 – 50 51 – 60 61 – 70 71 – 80 81 – 90 91 – 100+	14 24 0 5 33 5 0 0 0 10	50 20 0 0 20 0 0 0 0 10
Previous Interactions with Jellyfish	Yes No	71 29	64 36
Perceived Increases of Jellyfish in the last 10 years	Yes No	57 43	83 17

On average, respondents had 17 years of fishing experience (lower bound was 14.5 years, upper bound was 20 years) and all were male. Most of the fishermen who were interviewed were either trawlers (based on vessels that target either pelagic or demersal fish species, >10m in length) or based on vessels <10m in length using pelagic netting gear. No surveys occurred with those who worked on the large shellfish targeting vessels, as many shellfish species were not in season when field work occurred (Direct Seafood, 2017). However, no evidence exists that blooms can impact the operations of shellfish vessels. As a result, all of the different fishermen surveyed used mobile gears, similar to the gears known to be impacted by blooms in other geographic locations. A range of fishermen who work on different boat sizes were also surveyed, with more surveys achieved with respondents based on vessels <10 meters in length (however this was only a small difference – five respondents) and the vast majority of these fishermen fished close to shore (40 miles from the shore or less). Of respondents surveyed, 45% were the vessel owners or skippers, which was potentially significant as they would make decisions about how they would fish in bloomed waters. Of respondents, 67.5% had specific interaction with jellyfish with 70.2% fishermen in Brixham, and 83.3% in Newlyn, feeling that jellyfish are on the increase. Even though there were differences in catch quantities and values between the harbours, fishing operations were broadly similar. Other similarities were represented by the characteristics of the respondents in this study, such as the number of fishing years (average 16.5 in Newlyn, 17.9 in Brixham), the similar proportion of vessel owners to vessel employees (41.7% owner in Newlyn, 47.6% owners in Brixham), the similar boat sizes (average vessel length in Newlyn was 15m and in Brixham 16.7m), and the similar fishing distances from the coasts (Newlyn average distance from the coasts was 28.5 miles with Brixham fishermen reporting 37 miles) that was reported.

Due to these similarities the data collected were combined so that a more meaningful analysis of the impacts of bloom could be carried out (influence of harbour was tested in section 5.5 to test if harbour had influence on bloom responses). It is difficult to assess how typical the respondents were of the harbours of Brixham and Newlyn, or of the British fishing fleet, as freely available demographic data on those who work in the fishing industry is scarce. However, some similarities were reported in previous studies that included demographic information as part of their analysis such as a study of fatigue within the industry (Allen *et al.* 2010). Several similarities between respondents in their data sample and the ones interviewed as part of this study were found, including that the vast majority of fisherfolk were male, that they typically had

15-20 years total experience, that more fisherfolk worked on smaller boats <10m, and that a proportionally high amount of vessel skippers participate in the research. Other aspects of the respondents in this survey appeared typical of the southwestern fishing fleet when compared with the general fleet statistics collected by the MMO (2017). For example, the proportions of fisherfolk who work on each of the vessel types and the species they target were similar to what the respondents in this study reported (e.g. higher numbers of smaller vessels employed a greater number of people than the fewer larger vessels that had bigger crews). Although there are some suggestions that the sample is typical of the southwestern and UK fleets, it is too small (n= 33) to conclude that it is representative (as there are 12,000 + fishermen across the UK (Allen *et al*. 2010)) and can only provide an initial indication as to whether future bloom increases will have any impact on the industry across the Northeast Atlantic. The findings were also limited by the types of fishermen available during the field work, which was influenced by the seasonality of the species they were targeting. Fishermen deployed in other methods of fishing (e.g. shellfish targeting vessels) could not be surveyed.

5.4 Experience of Blooms in the Northeast Atlantic

Previous experiences of jellyfish in the respondents' fishing grounds (questions displayed in section C of Appendix C) were also analysed and discussed, as this might inform their views on future blooms. Of respondents, 70% of fishermen had experience of jellyfish, ranging from stings (36%), bycatch (9%), net clogging (12%) to just generally seeing them in the ocean (12%). The remaining (31%) respondents reported no direct experience. When asked which species they recognised as occurring in their fishing grounds, respondents most commonly identified *R. pulmo*, *A. aurita* and *C. hysoscella*, which matches with the spatial distribution for these species that was described in the GIS maps. However, very few fishermen reported that they had seen *P. noctiluca* which the GIS maps indicated the southwestern waters to be suitable for and was also a species highlighted by Licandro *et al*. (2010) as one occurring more often in the area based on CPR samples. Two thirds of respondents had witnessed episodes of high numbers of jellyfish in the sea, most commonly stating that these occur in the summer (48% of respondents) and last for around 2 weeks (36% of respondents). The latter is in line with what is reported for jellyfish occurrence in the Northeast Atlantic (specifically the UK coastline) in Palmieri *et al.* (2015: 228) who state, based on public records and anecdotal evidence, that "mass strandings occur mostly between May and August, coinciding with warmer weather and last for a period of around 2 weeks across the UK, mainly in the south west," as well the analysis of species distributions across the UK by Pikesley *et al.* (2014) based on public sightings data. However, nearly as many respondents were not in agreement, with 44% suggesting that there was no set time of the year when larger populations occur, and events can be both longer and shorter than two weeks, suggesting overall that the spatial distributions and duration of increased populations in the Northeast Atlantic are quite unpredictable, which potentially contributed to the discrepancies between the GIS models, scientific literature and the experiences fishermen had of *P. noctiluca*.

Table 5.2 indicates that most fishermen surveyed have had some experience of blooms already (in some cases experienced repeated blooming events) and that debate appears to exist in the fishing community as to whether blooms are increasing in Northeast Atlantic as well as in the scientific literature.

Table 5.2 Changes in jellyfish populations reported by fisherfolk in Brixham and Newlyn

Previous Bloom Experience	Frequency of Responses (%)
Blooms occur at least once a year	78
Blooms occur several times a year	39
Blooms frequencies increased in the last decade.	49
Bloom frequencies have not increased in the last decade	30
Do not know if blooms have increased in the last decades	21

The next section of the thesis explores the operational changes fishermen would make in the event of increasing blooms and the impacts that they envisage will occur in relation to a number of different species within their fishing grounds to act as a basis for projections of any socio-economic impacts that would occur. The influence of the respondent characteristics such as the harbour they were based in, the number of years they have been fishing and the type of fishing they engage in (section 5.3) as well as their previous experiences of jellyfish (section 5.4) on the future bloom response were tested to give an indication of any specific impacts (if any) that would be experienced.

5.5 Responses to Hypothetical Future Bloom Increases

Section D of the survey questionnaire (Appendix C) asked respondents to consider hypothetical scenarios where jellyfish belonging to each of the four groups (large non-stingers, large stingers, small non-stingers and small stingers – see Chapter 3, section 3.5.1 for grouping methodology) bloom more frequently in their fishing grounds. Respondents were introduced to the characteristics of the four groups using flash cards (see Appendix C, section D), and the following excerpt was used to introduce respondents to this section of the survey:

"Evidence suggests that the jellyfish populations we discussed in section C could increase, characterised by more instances of blooming events. If this was to occur, there would be potential for increased interactions with the fisheries here. In this section, I would like to ask you to draw upon your expertise as a fisherman to imagine hypothetical future oceans where blooms are more common, to answer questions on how you think they would interact with your fishing operations (if at all) and how you would fish in bloomed waters."

Section D started by asking questions about each jellyfish group: whether bloom increases of species within each group would cause them issues (yes or no); the specific issues they envisaged; and actions they would take in response to the issues while fishing in bloomed waters (both open questions). Initially, general consensus of the bloom impacts that could occur in the Northeast Atlantic was developed and displayed in Figure 5.2, which reports all the impacts that were envisaged by respondents who saw increasing jellyfish (from any of the four groups) blooms as capable of impacting their activities.

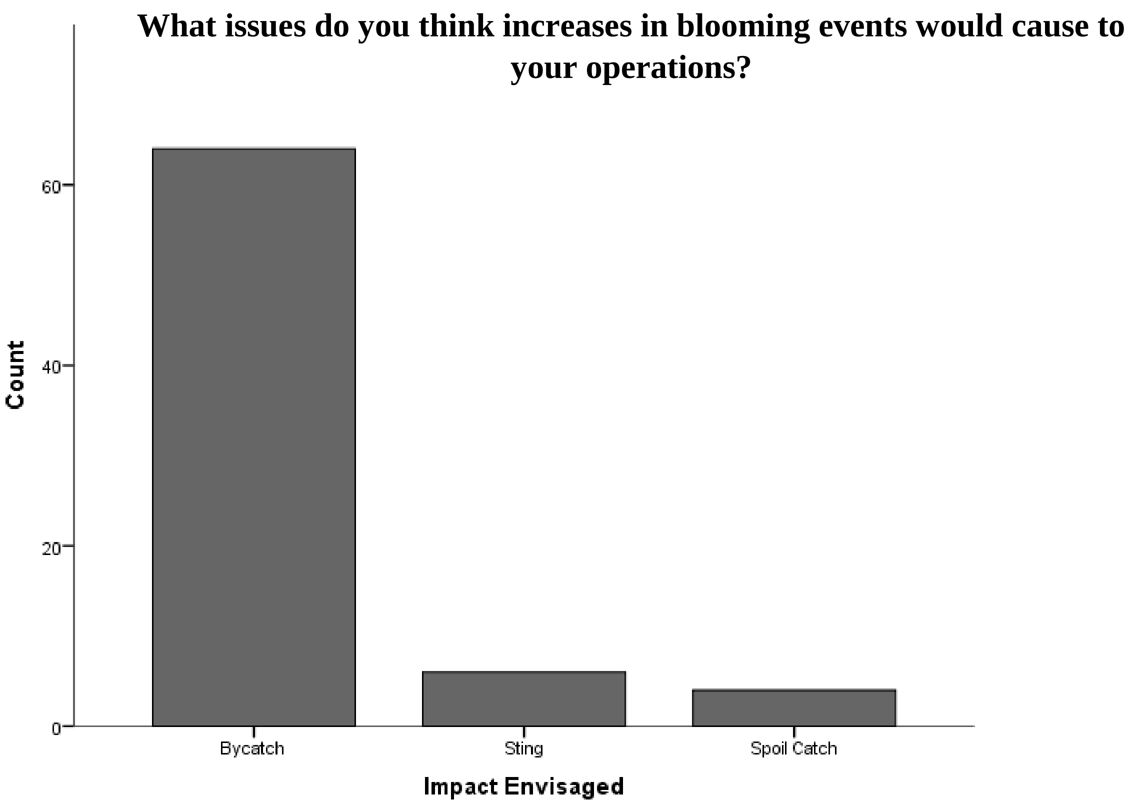


Fig 5.2 The impacts of jellyfish bloom increases envisaged by all respondents

Only three impacts were envisaged by respondents in response to all of the jellyfish species, with the vast majority stating that bycatch of jellyfish would be their primary concern. Of the respondents who reported bycatch, several suggested excess time sorting of catch would occur, but there would be no other implications. However, four of these respondents suggested that bloom bycatch could spoil their haul of target catch. Stinging was the only other impact (however, this was directly linked to accidentally hauling jellyfish aboard) but was only reported on six occasions.

In order to define the future relationship between fishermen and increased bloom biomass in their fishing grounds, I now investigated which types of fishermen (based on their characteristics) would incur the impacts reported in Figure 5.5, and which group of jellyfish species would cause those issues. As well as the responses given to them, the relationships between different types of fishermen and increased blooms were assessed using significance testing of the survey data set. This included testing the influence of respondent characteristics (either categorical (e.g. vessel type) or continuous data (e.g. years fishing)) on the varying responses given to hypothetical bloom increases of each of the four species groups (all categorical data e.g. “yes” or “no” to future impacts associated with a species group). Each statistical test was between independent data columns associated with respondent characteristics and their future bloom responses. Due to the lack of variation in the different impacts envisaged (Fig 5.2), the few bloom responses available to fishermen (see below, Table 5.3) and the small sample size (discussed in section 5.3), significance testing could not occur on the influences of impacts and responses envisaged. Assessment of the future impacts of bloom increases and responses were based on frequency of which they were reported.

The harbour the fishermen were based had no effect on responses related to:

- the number of jellyfish groups that respondents envisaged to cause future issues (L.R Chi Square = 1.364, DF = 3, p = 0.714).
- the impacts that blooms increases would have, as they did not differ between harbours because fishermen from both exclusively reported that they envisaged impacts from bycatch of increased bloom biomass (including stinging).
- the difference in the frequencies of the type of responses to blooms of the different species groups. Respondents from both harbours reported they

would travel to alternate fishing sites, accept bloom interactions and using additional safety gear in responses to hypothetical bloom increases of the large non-stinger, large stingers and the small stingers in equal amounts with very few responses being reported in response to the small non-stingers at both harbours.

The different characteristics of all fishermen surveyed, however, had varying influences on future issues envisaged with hypothetical increases in future blooming events:

- the amount of years a respondent had been fishing had no significant influence on the number of jellyfish groups perceived as capable of impacting their operations in the event of bloom increases (Pearson Correlation = 0.120, N = 33, p = 0.504),
- vessel owners / skippers significantly envisaged impacts with more groups of jellyfish species if they were to bloom (Mann-Whitney U = 64.00, N = 33, p = <0.05), which is of relevance because they are in charge of the boat, plan fishing voyages, and make decisions in order to achieve the best catch (National Careers Service, 2017), meaning that, regardless of the causes, the more concerned respondents would be making decisions about fishing in bloomed waters.

Different types of fishermen (based on the three vessel types, described in section 5.3) envisaged similar future issues associated with increased blooms of the individual species groups and suggested similar responses to them, but certain fishermen envisaged these issues more often. In responses to hypothetical bloom increases of large non-stinging jellyfish, pelagic trawlers (on vessels <10m and > 10m) significantly reported that they envisaged (by indicating "yes" to future issues) greater instances of impacts associated with this group more than the demersal trawlers (L.R Chi square = 6.357, DF = 2, p = <0.05). The fishermen who mainly target pelagic fish mostly reported that blooms of large non-stingers would make catching target fish species more difficult due to them getting caught up in nets during trawls, decreasing catch per trawl and increasing sorting times of catch and the number of trawls they would have to do. The most common response of these respondents on the vessels >10m was to do addition trawls, but the fishermen based on the vessels <10m a higher number of respondents reported that they would move to new fishing grounds before bycatch could occur. The few demersal trawlers who envisaged impacts, suggested that they would remain in their fishing grounds and would do more trawls until quotas were achieved.

A similar pattern was observed with the responses to the large stinger group with all pelagic fishermen (on vessels <10m and > 10m) envisaging significantly more future issues than the demersal fishermen (L.R Chi square = 8.624, DF = 2, p = <0.05). Again, bycatch of blooms was the most commonly reported concern by fishermen who indicated they would expect interactions. These respondents reported they would either relocate to other fishing grounds before fishing gear is deployed in bloomed waters or accept interactions with blooms and increase the number of trawls to achieve quotas. The pelagic vessels >10m and demersal trawlers reported they would do additional trawls more often and fishermen based on vessels <10m reported they would find alternate fishing sites more often. Of the pelagic trawlers >10m respondents, 20% also reported that they would increase the amount of protective clothing if they were to haul large numbers of the large stingers, as well as doing additional trawls. All those who reported the increase in the use of safety gear already had what was necessary to protect them and kept it on board at all times.

Once introduced to the small stinging group, pelagic vessels (both <10m and >10m) were significantly more likely to envisage future issues (L.R Chi square = 8.624, DF = 2, p = <0.05) than fishermen based on large demersal trawling vessels. Again, bycatch was reported as the issues that would cause displacement effort (moving to alternate fishing sites or travelling further due to increased trawls necessary to achieve quotas). However, additional sorting time and increased use of protective clothing was indicated by respondents who expected issues associated with this group.

The only group of species where there was no significant difference in issues envisaged between the different types of fishermen was the small non-stingers (Chi square = 3.314, DF = 2, p = 0.191) due to the small number of fishermen from each group who envisaged issues. Of the few respondents who envisaged future issues with this group (mostly pelagic fishers on vessels <10m), spending more time sorting each haul if they were to catch large numbers of the small non-stinger group was reported. A summary of the most frequent issues related to jellyfish blooms that respondents envisaged and most frequent responses by vessel type, is presented in Table 5.3.

Table 5.3 Most common responses of fishermen based on different vessels to each jellyfish group

Vessel	Survey Responses	Large Non-Stinger	Large Stinger	Small Stinger	Small Non-Stinger
Demersal Fishing (Vessels >10m)	% Envisaged Impacts of Future Bloom	39%	39%	23%	39%
	Most Common Impact Envisaged	Bycatch	Bycatch	Bycatch	Bycatch
	Most Common Measures	Additional Trawls	Additional trawls	Additional Sorting	Additional Sorting
Pelagic Fishing (Vessels >10m)	% Envisaged Impacts of Future Bloom	86%	86%	43%	86%
	Most Common Impact Envisaged	Bycatch	Bycatch	Bycatch	Bycatch
	Most Common Measures	Additional Trawls	Additional trawls	Additional Sorting	Additional Sorting
Small Scale Pelagic Fishing (Vessels <10m)	% Envisaged Impacts of Future Bloom	80%	90%	60%	90%
	Most Common Impact Envisaged	Bycatch	Bycatch	Bycatch	Bycatch
	Most Common Mitigation Measure	Travel to Alternate site	Travel to Alternate site	Additional Sorting	Additional Sorting

The large non-stingers, particularly *R. pulmo* (an organism that 91% of respondents had experience of and could identify), were mentioned by the greatest number of respondents as capable of impacting their ability to land fish for human consumption, causing fishermen to either travel to alternate fishing sites (displacement), or engage in more trawls and spend more time sorting catch if blooms were to happen more regularly in the future. All impacts envisaged by the fishermen (see Table 5.3) were considered as resulting in additional overheads as a consequence of bycatch; no decreases in number or duration of fishing trips (e.g. returning to port) or overall reduced catch were envisaged. Few decreases in overall benefit derived from the marine ecosystems (i.e. fish for food consumption) were reported as fishermen believed they were capable of catching their quotas in bloomed waters and did not expect fishing gear damage to increase as a result of interactions with increased jellyfish biomass. Some groups of species were seen as capable of causing more impacts than others, and different morphological features elicited greater concern than others. For example, large non-stingers were reported by the respondents as a potential future issue more than the small stingers (67% compared to 61% overall) indicating that size of medusae is a more salient concern to fishermen in the Northeast Atlantic than the ability to sting because of the bycatch issues and the fact that fisherfolk already have the relevant safety gear to protect themselves from stings. The results of the study suggest that the investigated impacts from potential future jellyfish bloom increases were less varied than those reported in the literature. For example, Palmieri *et al*. (2014) projected socio-economic impacts related to fishing gear damage, wide spread reports of stinging, reduction in catches in the Adriatic Sea, which were not envisaged by study respondents based in the Northeast Atlantic. This was initially surprising, given that there were more factors which would have seemed to suggest that impacts could be much wider ranging, due for instance to the greater variety of jellyfish species that could potentially bloom more regularly in those fishing grounds, and the diversity of vessels (catching fish at differing depths). Therefore, these findings seem to suggest that increased impacts incurred by fishermen in the Northeast Atlantic may not be as common as they are in the Mediterranean where a greater variety of issues are attributed to blooms that currently occur there. However, the findings of this study are based on current perceptions that may differ substantially in the future if blooms were to increase in the Northeast Atlantic.

The next section will focus on the costs that the different vessel types (introduced in section 5.3) could possibly incur as a result of the issues that have been described in this section. Vessel type is important, not only because of the different amounts of concern fishermen based on each vessel type reported, but also because vessels have different operating costs (SeaFish 2013; SeaFish 2017), which could result in different impacts even if based on similar responses (i.e. moving to alternate sites or engaging in increased trawls to achieve catch in bloomed water) to bloom increases.

5.5.1 Current Fishing Overheads

Before costs associated with future bloom increases and the related operational responses were assessed, operational costs that occur in the present day were investigated, based on data elicited in section B of the survey (displayed in Appendix C) so that these could be compared with any future blooms costs. Respondents provided general costs for 'standard' interferences incurring whilst operating during normal (i.e. non-bloomed) conditions. They were asked to list the 'standard' interferences, the related issues (i.e. net clogging, gear damage, bycatch issues and injury to crew members) and the magnitude of the related overheads that they currently experience, which blooms could potentially exasperate. Any overlap in issues that blooms are known to cause in the literature and what was envisaged in response to bloom increases in the Northeast Atlantic (section 5.5) with the present-day costs were used to give an initial estimate of the costs bloom increases could cause. Although not reported as a potential impact of bloom increases in the Northeast Atlantic, bloom biomass has been reported to damage mobile gears where they are more common (Palmieri *et al.* 2014). Gear damage reported by respondents caused by objects in the water was the most reported by a majority of respondents as a present-day issue (67%), with “general flotsam” being the main cause of damage to gear. Although the average cost of damage was reported to be on average of £1,424 (£1332 - £4,180) to replace the damaged gear, 42% of respondents reported that objects in the water did not result in any immediate monetary costs because they were still able to use the gear even if not fully operational. Of all respondents, 55% reported that the area containing the objects capable of causing gear damage was about 0-5km^2. Of all respondents 21% reported that they avoid fishing in areas with objects in the water, travelling 7.5 miles[3] on average to new fishing grounds (lower bound 4 miles, 10.8 miles upper bound). Trawlers and fishermen based on larger boats (>10m) more regularly reported that they continue fishing in an area compared to the pelagic fishermen on smaller boats (<10m). However, those fishermen on the larger vessels who reported they would avoid an area were willing to travel further than those on the smaller boats to find unaffected fishing grounds, giving an indication of the expectations of bloom impacts (discussed in section 5.5) are different and gear damage is caused. Bycatch of any non-target species was another impact reported with costs to present day operations. Bycatch increased the amount of time it forced fishermen to be out at sea (reported by 39% of respondents), usually as consequence of additional sorting time once the catch

[3] Miles travelled across the ocean was reported by respondents and are therefore used throughout this chapter

had been hauled aboard; this was most often reported by respondents based on boats <10 meters in length. On average the additional time was reported to be 2.7 additional hours (1.5 - 7 hours). Other impacts reported are injuries coming from stings and minor contact with sea life that they had caught, requiring no or minor treatment, which had no overall impact on fishing activities. These present-day overheads therefore give an indication of the scale of the type of impacts that increasing blooms could cause: these are based on bloom impacts that are reported in the literature and the impacts that fishermen in the Northeast Atlantic envisage could happen with increasing blooms. The following section reports projections of the costs that could occur based on the operational responses to hypothetical bloom increases and the impacts and related present days costs reported in this section.

5.6 Potential Future Bloom Costs

The most commonly envisaged impact of hypothetical future bloom increases indicated by respondents was displacement effort, which implies fishermen travelling further across the ocean to be able to achieve quotas in bloomed waters (i.e. travelling to alternate fishing sites and extra distance travelled during extra trawls) in case of hypothetical jellyfish bloom increases. Subsequent additional fuel usage is used to quantify costs of these changes to operations as a result of displacement effort as vessels would have to travel further consuming more fuel. Two potential future cost scenarios were considered in detail, which developed as a result of the actions in response to blooms reported by respondents in section 5.5.

The first scenario (section 5.6.1) considers the fuel expenditure that would occur based on the pelagic trawlers >10m and pelagic netters <10m travelling to alternate fishing sites, quantifying additional fuel based on how far fisherfolk were willing to travel to find unaffected fishing sites. The second scenario (section 5.6.2) is based on additional trawls in the event of blooms clogging nets, forcing fisherman to do additional trawls to achieve quotas with quantifiable projections of associated additional fuel expenditure based on the extra distance travelled during the additional trawls. Potential changes to fuel usage and cost are of importance because they make up a significant overhead for demersal trawlers >10m, pelagic trawlers >10m and the smaller netter vessels <10m (they report fuel costs of 18%, 12%, 10% of their income respectively (SeaFish, 2017)); they are known to fluctuate, meaning that the operational responses to blooms could result in fluctuating costs depending on when bloom increases occur. Currently fuel costs are relatively low as over the past couple of prices have declined (Breene, 2017). The SeaFish economic survey of the years 2011, 2012 and 2013 (published in 2013, closer to the time when surveys were done), indicates that fuel cost as a percentage of profit for the demersal trawlers >10m, pelagic trawlers >10m and the vessels <10m was around 37%, 25% and 17% respectively. If blooms were to occur during times when fuel prices are higher, any economic impacts of increased fuel usage due to blooms could increase further.

To quantify the costs of future jellyfish blooms that would occur during the two scenarios, fuel usage and time out at sea in non-bloomed waters are required so that hypothetical future changes in distance travelled during fishing trips can be accounted for to quantify any additional costs of operating within bloomed waters. Based on the descriptions of present day operating costs reported by the fishermen, an estimation of the non-bloom fuel cost can be generated. Respondents reported that typical fuel expenditure is made up of travelling to trawl sites, moving across the ocean whilst doing the trawls and returning to the harbour. Fuel expenditure is therefore projected using the following equation:

$$C = ((D_c + (D_{tr} * tr))*c_f) \qquad \text{[Equation 5.1]}$$

Where:

C is the total present-day fuel cost to be calculated.

D_c is the return distance in miles that fishermen travel between the harbour and the location where trawling gear is deployed (the distance to the catch). This is calculated for each vessel type by taking an average of the distances respondents reported to fish from the shores. The average distance from harbour to trawl site estimated is then doubled to give an indication of the return trip distances, resulting in figures of 60 miles for demersal trawlers >10m, 50 miles for pelagic trawlers >10m and 16 miles for fishing vessels <10m.

D_{tr} is the distance covered by a vessel trawling with the fishing gear deployed. Data for trawl related fuel costs were not collected during the surveys, as it was only recognised as relevant after the surveys had taken place. Therefore, personal communication with Cefas experts (spotters, with experience of working on each vessel type) provided indications of the duration and speed of trawls in knots (demersal trawlers 2 hours at 2.5 knots p/h, Pelagic Trawlers for 4 hours at 3 knots p/h). Knots were converted to miles for consistency with the survey data. Duration was then multiplied by speed to give the estimation of trawl distances in miles. Trawl distances for demersal and pelagic trawlers were 5.76 miles and 17.25 miles respectively. In terms of the vessels <10m, there is a lack of knowledge on the trawl distances, so an estimation was required, which was based on personal communication with respondents. On average fishermen based on the smaller vessels travel 8 miles from the shore to fishing sites. Based on this, 8 miles was set as the upper bound of trawl distance with the average and lower bounds set to be 4 miles and 1 mile respectively to act as estimations.

tr is the number of trawls per fishing trip within a day. There is no standard number of trawls that fishermen do per trip, so the number of trawls was calculated up until the number of trawls possible within a day (based on the trawl durations and the time it took for a return trip to the trawl sites). A fishing trip with one trawl was set as the lower bound for all vessel types. The maximum trawls possible within a day set as the upper bound was 4 additional trawls for the demersal vessels >10m (5 in total), 2 additional trawls for the pelagic vessels >10m (3 in total) and 3 additional trawls (4 in total) for the <10m vessels.

$\mathbf{c_f}$ is the fuel cost per mile and was calculated by dividing the total fuel cost per day for each vessel type (SeaFish, 2013 - economic annual reviews of the UK fishing fleets) by the distance in miles that each vessel type travels per day (reported by respondents in section 5.5). The 2013 SeaFish report is referred to in this section despite the more recent publication of the 2017 report (July 2017) because the time in which the 2013 SeaFish study was conducted is more representative of the conditions that the respondents in this study were experiencing in terms of decisions they would make which was potentially influenced by fuel cost. This is because the field work and analysis pre-dated the decrease in global fuel prices (Breene, 2017) and fuel expenditure for each vessel type within the SeaFish reports were proportionally different, indicating that fuel costs do influence how a different vessels types respond to costs and the responses reported in section 5.5 were only relevant to the time the field work commenced.

Table 5.4 displays the figures discussed above in relation to distance travelled and fuel costs as well as the resultant minimum and maximum ranges of total fuel use (C) that were estimated for each vessel type during non-bloomed conditions.

Table 5.4 the present-day total fuel cost estimation (C) for each vessel type based on the return distances to trawl sites (D_c), trawl distances (D_{tr}), minimum and maximum trawl numbers per day (tr) and fuel cost per mile (c_f) for each vessel type.

	D_c (in miles)	**D_{tr} (in miles)**	**Tr (number of trawls possible within a day)**	**c_f (in £)**	**C (in £)**	
					Min	Max
Demersal Trawlers over 10m	60	5.76	Between 1 and 5	£15	£986	£1332
Pelagic Trawlers over 10m	50	17.25	Between 1 and 3	£17	£1143	£1530
Pelagic Trawlers under 10m	16	12.55	Between 1 and 4	£13	£364	£861

It must be acknowledged that there are several factors that result in different levels of fuel consumption that these estimations do not capture such as the influence of quotas, catch rates (Schau *et al.* 2009), vessel gear and species targeted (Thrane, 2004). It is also acknowledged that these projections contain assumptions (e.g. the number of trawls per day and the distance the small vessels deploy mobile gear for) and estimations based on the best secondary data available (e.g. the trawl distances) and have been built up from a small data sample (33 fishermen). A comparison between the figures displayed in Table 5.4 to other fuel costs estimations in the literature such as the SeaFish report (2013) was carried out. The SeaFish report states that the average daily fuel cost for the demersal trawlers >10m was £1241, which within the upper ranges of this study (£986 - £1332). The SeaFish (2013) average fuel cost estimation of the pelagic trawlers >10m was £1432, which was also within the upper ranges in this study (£1143 and £1530). Since the SeaFish averages are higher than the averages in this study but within the upper ranges in, it is likely that underestimation of the costs occurred for the reasons suggested above. However, the average daily cost of the vessel <10m, reported by SeaFish (2013) was £251 which was considerably lower than the ranges stated in this study (£364 - £861), which likely came from overestimations in the trawl distance assumptions. But, the total fuel usage (C) projections in this study (Table 5.4) were based on operational activities that could be impacted by blooms and the best data available at the time of the study, so they are used in the next section as basis for consistent comparison of proportional fuel use changes that could occur under bloomed conditions based on the bloom responses reported in section 5.5.

5.6.1 Fuel cost estimation in Scenario 1: moving to different fishing

The first scenario is based on fishermen relocating to alternate fishing grounds, before fishing gear is deployed, in response to bloom presence. Travelling to alternate sites was the most common response of the fishermen based on vessels <10m to all four species groups and was the second most reported response by the pelagic vessels >10m to the large non-stingers, large stingers and small stingers (section 5.5). No demersal fishermen reported that they would respond in this way because of the lower depth in the water column that they trawl and were therefore not included in this scenario. The scenario is described by:

$$C_{f1} = C + (D_E * c_f) \qquad \textbf{[}\text{Equation 5.2]}$$

Where:

C_{f1} is the total future fuel cost in scenario 1.

C is the same total fuel costs and c_f is the same fuel cost per mile (assumed to be unaffected day blooms) from the non-bloom fuel expenditure estimations (each calculated and displayed in section 5.6).

D_E is the extra distance fishermen were willing to travel to unaffected new fishing sites. The maximum distances respondents were willing to travel to find alternate fishing sites unaffected by blooms were averaged out for each type of vessel (data collected by asking respondents who would travel to alternate sites, the maximum distance they would travel in QD3 of the survey, see Appendix C, section D). The maximum average distances for pelagic vessels >10m were 54 miles (27 miles reported, with an assumed 27-mile return trip) and for the <10m vessels was 16 miles (8 miles reported, with 8-mile return trip). A minimum distance to avoid blooms is also factored into calculations because trawl sites are often large and moving within fishing grounds could result in the avoidance of blooms. A minimum of 1 mile was used to give an indication of the added cost per mile so that a range of costs at an incremental scale can be provided for skippers to make decisions in response to future blooms in terms of fuel use. The projected future per day fuel usage as a consequence of fishermen moving to alternate fishing grounds to avoid blooms is displayed in Table 5.5.

Table 5.5 The future fuel cost increase estimation (C_{f1}) in the event of blooms causing fishermen to move to new fishing sites comapred to the present day fuel cost (C) based on the minimum and maximum additional distances in miles fishermen were willing to travel to new sites (D_E) multiplied by the the cost of fuel per mile (c_f)

	C		**D_E**		**C_f**	**C_{f1}**	
	Min	Max	Min	Max		Min	Max
Pelagic Trawlers over 10m	£1,143	£1,332	2	54	£17	£1,177	£2,250
Pelagic Trawlers under 10m	£364	£861	2	16	£13	£390	£1,069

For the pelagic trawlers >10m, fuel expenditure increases (C_{f1}) between 3% and 68% were estimated, depending on how far vessels would move to new locations from the present-day total fuel expenditure estimation (C) in section 5.6. For every additional return mile of displacement due to bloom presence, fuel expenditure would increase by 3%. This went up to 68% based on maximum distance respondents indicated they would be willing to travel to find unaffected fishing sites (27 additional miles going to the new site and 27 miles returning). For every additional return mile, vessels <10m in length would be displaced to find new fishing sites unaffected by jellyfish with a fuel expenditure increased by

7% compared to the present-day total costs (C). This increases to 24% from total present-day fuel costs (C) based on the average maximum distance fisherfolk were willing to travel to find new fishing sites (8 miles going to the new site, and 8 miles returning, first stated in section 5.6).

When considering the cost of fuel as a percentage of total vessel profits the impact of blooms on fishermen moving sites becomes clearer. According to SeaFish (2013), large pelagic vessels >10m report that fuel costs are equal to 25% of their profits. If this relationship is retained, in this hypothetical scenario the 3% increase in fuel per additional return mile of travel translates as an increase of fuel cost as a percentage of income by 0.75%. In the event of the pelagic fishing vessels >10m travelling the maximum distance, fuel cost as a percentage of profits would rise to 42% (due to C_{f1} being 68% greater than C (tale 5.4)). For the vessels <10m, SeaFish (2013) reported that fuel cost as a percentage of profit before blooms was 17%; which would increase by 7% (based on the C_{f1} min increase from C) per additional return mile travelled. Based on the maximum distance these fishermen would travel, the fuel costs as a percentage of profit would increase by 24% (C_{f1} max increase from C), which would result in future fuel costs as a percentage of profit under bloomed conditions to increase to 21% from the current 17% as estimated in SeaFish.

5.6.2 Fuel Cost Estimation in Scenario 2: adding trawls

The second scenario, which is based on fishermen survey responses, focuses on the increased amounts of trawls required due to bloom bycatch clogging nets resulting in less catch of target species per trawl. This scenario is likely to be common because respondents on the pelagic vessels >10m reported they would do more trawls if they were to catch jellyfish accidentally most frequently. Doing more trawls was the second most common response of fishermen on the vessels <10m to each of the three species groups (large stingers, large non-stingers and small stingers). Although no impacts were reported by the majority of fishermen on the demersal trawlers, some indicated additional trawls could be a potential consequence of future blooms by large stingers and large non-stingers and were included in this fuel costing scenario. The projections of additional fuel costs due to additional trawls for Scenario 2 is described by:

$$C_{f2} = C + ((c_f * D_{tr}) * T_e) \qquad \text{[Equation 5.3]}$$

Where:

$\mathbf{C_{f2}}$ is the estimation of the future costs based on scenario 2.

C is the present-day total fuel cost, c_f is the fuel costs per mile, D_{tr} is the distance travelled per trawl that were all first estimated and displayed in section 5.6 where the present-day fuel usage before blooms was estimated.

$\mathbf{T_E}$ is the extra number of trawls required because of bloom presence. It is not known specifically how much catch per trawl would decrease by, because of bloom bycatch clogging nets and how many additional trawls would be undertaken but understanding the cost of each extra trawl provides an indication of additional costs associated with blooms.

The resultant fuel expenditure changes for each vessel are displayed in Table 5.6. Cost per trawl is calculated by multiplying c_f (the fuel cost per mile, first displayed in the present-day fuel cost estimation in section 5.6) by the distance per trawl (D_{tr}, also first estimated and displayed in section 5.6). The cost per trawl is then multiplied by each extra trawl (T_E). Table 5.6 displays the min and max cost of a fishing expedition with an additional trawl (C_{f2}) by adding the cost of an additional trawl to the minimum and maximum present-day total fuel costs (C) (first estimated and displayed in section 5.6).

Table 5.6 The future expected fuel costs (C_{f2}) with a bloom induced additional trawls (T_E) compared to the present day fuel cost (C) based on the distance of trawls (D_{tr}) in miles multiplied by the costs of fuel per mile (c_f), added to the pre-bloom fuel expenditure (C).

	C		c_f	D_{tr}			C_{f2} **(1 additional trawl (**T_E**))**					
	Min	Max					**Min**			**Max**		
Demersal Trawlers over 10m	£986	£1,332	£15	5.76			£1072			£1418		
Pelagic Trawlers over 10m	£1143	£1530	£17	17.25			£1436			£1823		
Pelagic Trawlers under 10m	£364	£861	£13	1	4	8	£377	£416	£468	£874	£913	£965

If demersal trawlers were to do extra trawls in the event of blooms, each additional trawl would increase fuel expenditure between 6% and 8% compared to the total present-day fuel costs (C), whereas each additional trawl made by the pelagic trawlers >10 metres would increase fuel usage between 16% and 21% from the total present-day fuel costs (C). Depending on how far the smaller vessels (under 10 metres in length) travel with gear deployed (D_{tr}, assumed to be either, 1, 4 or 8 miles (see section 5.6)), each additional trawl could result in an increase in fuel costs between 3%, 13% and 23% when comparing the minimum present-day fuel costs (C_{min}) with the minimum future cost (C_{f2min}). However, the upper ranges of increased cost of each trawl could range from 2% or 6% and 11% when comparing maximum present-day fuel costs (C_{max}) with the maximum future cost (C_{f2max}). Despite the response of having to do more trawls due to the blooms clogging nets and the associated increase in fuel costs, a decrease in catch was not envisaged by respondents. However, it is not known if enough trawls could be made to achieve quotas in bloomed waters with the additional time out at sea required to land quotas and whether fisherman would change fishing operations as opposed to accepting bycatch and additional trawls (not reported during surveys). It is also not known if the added expense of additional trawls would go beyond the income fisherman make from their catch.

5.7 Costs of additional time out at sea

The effects of added time out at sea whilst relocating to alternate fishing grounds, doing additional trawls and subsequent additional sorting of catch, ought to be considered as an impact to the fishermen in addition to the impacts of the added overheads due to the potential impacts on their subjective well-being. For example, each additional trawl for the pelagic trawlers >10m would add around 4.5 hours out at sea and the demersal trawlers >10m would experience an additional 2 hours of work out at sea (reported in section 5.6, based on experience of Cefas spotters). If the added time trawling is combined with the amount of time sorting bycatch, an additional 2.7 hours (average amount of additional sorting time bycatch of non-target species currently causes respondents (estimated in section 5.5.1)) can be added to each trawl (T_E), resulting in roughly 7.2 hours and 4.7 hours extra time the pelagic and demersal trawlers >10m would spend out at sea respectively. These could be significantly extended if one considers that multiple additional trawls would expose fishermen and their vessels to difficult conditions associated with the Northeast Atlantic, as well as bycatch of dangerous marine life (including the stinging species of jellyfish), providing some indication that blooms could impact fisherfolk well-being. Overall, the responses to blooms were similar to their responses to the issues they currently experience in non-bloomed conditions, such as bycatch (presented in section 5.5.1). Measures to avoid impacts were primarily made to retain the economic benefit of staying out at sea and continuing catching with little consideration of the subjective well-being effects this could have on the crew.

Open questions were asked about blooms that could have included financial or subjective wellbeing issues, but only economic impacts were reported. Whether this was because they only envisaged economic impacts is not known. For example, when asked how far they would travel to avoid blooms a common answer was ‘as far as it is necessary.’ During informal chats with the respondents, the fishermen would often mention that they accept that fishing is a difficult profession, characterised by a number of environmental impacts, and would suggest that blooms would just be another issue leading to similar responses to the issues they already experience in section 5.5.1. As already discussed, this potentially led to an underestimation in the variety of impacts that blooms could have. Another example is that the species respondents had experience of in the Northeast Atlantic (mainly *R. pulmo, A. aurita* and *C. hysoscella*) do not possess potent stings, which may influence respondent expectations of future blooms and therefore their future responses to them. If increases in stinging species were to materialise (such as *P.noctiluca* as this GIS maps suggest) the expectations of the impacts of blooms could be different to what will actually occur (e.g. health impacts associated with stinging that are rarely reported in the Northeast Atlantic, but are common in the Mediterranean (Cegolon *et al*, 2013; Palmieri *et al*, 2014). This is further investigated in the conclusion of the thesis (Chapter 7).

5.8 Conclusion

This chapter has quantified current and future hypothetical economic impacts on the fishing industry that could occur as a consequence of jellyfish blooms in the Northeast Atlantic. The future cost projections are based on the expertise of skippers and crew members who fish in locations within the Northeast Atlantic where future blooming events could occur. Through a survey-based questionnaire, an understanding of the actions that different types of fishermen would take to reduce the impacts of each of the different groups of jellyfish presented in the survey that could potentially occur in their fishing grounds was gained. This information formed the basis for the quantification of the economic cost projections that future bloom increases could cause.

The main findings of this chapter are:

Increases in blooms of larger medusae pose a greater risk to fishing operations in Northeast Atlantic waters than the other groups presented in the survey, because the bloom impacts envisaged by fisherfolk were more likely to be accentuated by the presence of the larger species. Bycatch was the most commonly reported impact that would occur because of blooms, and bycatch of larger species was suggested as the most likely cause of net clogging. Fisherfolk who use mobile gears to target pelagic fish species were more likely to envisage issues associated with bloom increases, but generally the responses between fisherfolk based on different vessels to each type of jellyfish were broadly similar as bycatch was the primary concern for many of the respondents.

The two main actions that fishermen indicated they would enact in response to future bloom increases were:

(a) moving to alternate fishing grounds to avoid blooms; or

(b) carry on trawling, accepting bycatch and clogged nets, but doing additional trawls to compensate for any decreased catch per trawl.

Both actions are consistent with some of the responses reported in the literature where blooms are currently more common such as the Mediterranean (Palmieri *et al.* 2014). Increased fuel costs are the most obvious impact from these two options due to the extra distance they would have travel, but also the increased time out at sea during fishing trips. When comparing the costs associated with the two main responses and subsequent fuel consumption increases, the economic impact of each response varies. Variation in costs depends on a number of circumstances, including how many additional trawls would be required in bloomed waters, and the maximum distances between affected and unaffected fishing sites. The projections of costs of these two actions could potentially enable fishermen to make decisions about operating in bloomed waters that could maximise catch and reduce bloom overheads. For example, for the fishermen based on the pelagic trawlers <10m, the additional fuel cost of doing two additional trawls in bloomed waters is less than the added fuel cost of the maximum distance they were willing to travel to avoid blooms. However, the extra trawls would potentially increase the exposure of crew to injury (depending on the species blooming) and to difficult weather conditions compared to moving to unaffected sites.

Participants to this study mentioned fewer types of impacts from jellyfish blooms compared to those reported by fishermen operating in waters where blooms are currently more common (e.g. the Mediterranean, Gulf of Mexico and Japan). For example, because of blooms, Palmieri *et al*. (2014) reported costs associated with: damaged gear; additional sorting; being forced to return to port; changing fishing grounds; stings; reduction in catch; and gear clogging. This study only able to make projections on the costs of additional fuel consumption due to the only elements mentioned by the respondents: displacement effort caused by moving to alternate fishing sites; and additional trawls due to net clogging as a consequence of bloom bycatch. These differences are potentially due to the differences between the vessels that fish within the Northeast Atlantic and the Adriatic, or to the limited familiarity of fishermen with jellyfish blooms in the Northeast Atlantic than in the Mediterranean. Some suggestion of subjective well-being impact was also indirectly inferred (section 5.7). However, differently from Palmieri *et al*. (2014) that were able to quantify subjective well-being impacts on fishermen such as additional man hours repairing gear due to bloom damage by engaging with fisherfolk who experience elevated blooms every year, this was not possible in this study due to the limited familiarity with jellyfish blooms in the Northeast Atlantic. Chapter 7 therefore discusses some recommendations on further research of future jellyfish populations in the Northeast Atlantic and subsequent socioeconomic impacts. The following chapter (Chapter 6) further contributes to the second research by presenting the results of the potential impacts of future bloom increases on coastal tourism within the Northeast Atlantic for comparison with the impacts on the fisheries presented in this chapter.

CHAPTER 6

JELLYFISH BLOOM IMPACTS ON COASTAL TOURISM

6.1 Introduction

This chapter assesses the potential socioeconomic impacts of increasing blooming events on coastal tourism, addressing the second research question of this study (what would be the magnitude of the socio-economic impacts related to the tourism and fishing industry in the event of increased jellyfish blooms occurrence in the Northeast Atlantic?). The research focuses specifically on a coastal location reliant on beach tourism, where beach visitors and users were surveyed about the current and future use of the coast and the sea, and their spending, to generate projections of any changes in recreational value of the beaches (based on valuations of the coastal ecosystem) because of bloom presence. This chapter also considers whether mitigation schemes in response to future blooming events may be required to maintain the value of the coastal ecosystem for summer visitors and if schemes used in other countries could be viable to protect recreation at beaches that are yet to experience large scale impacts associated with blooms. In this chapter, section 6.2 introduces St Ives, the seaside town associated with coastal tourism selected as a case study. An analysis of survey responses and findings, including respondents' demographics (section 6.3), their general attitudes, previous experiences and knowledge of jellyfish (section 6.4) and how they recreate, quantifying their expenditure patterns during recreational trips (section 6.5) is then presented. The losses that would occur as a result of altered expenditure patterns are then explored (section 6.5); the welfare implications of blooms to beach and sea users are assessed in relation to different bloom scenarios based on their willingness to pay (WTP) to access the coasts (section 6.6), and related to demographics, previous experiences, knowledge and perceptions of respondents. Quantification of impacts are based on how seaside users reported that they would react to blooms on the beaches, leading to changes their expenditure while in St Ives and to changes in welfare due to loss of recreation opportunities on the beaches. Based on these findings, jellyfish bloom mitigation schemes are discussed (section 6.7), leading onto the conclusion of the chapter (section 6.8).

6.2 Study Location

The Cornish coasts were identified as a suitable area of study for considering the potential future impacts of increasing blooms on tourism, due to the high concentration of seaside towns with an economy reliant on tourism (defined by Beatty *et al*. (2010), discussed in Chapter 3) and the large areas potentially suitable for blooms in south western waters of the Celtic Sea during summer for the greatest variety of jellyfish species belonging to each of the large non-stinging, large stinging, small non-stinging and small stinging species groups. Figure 6.1 highlights the varying distributions of areas that can sustain members belonging to each of the groups of jellyfish in relation to the Cornish coasts.

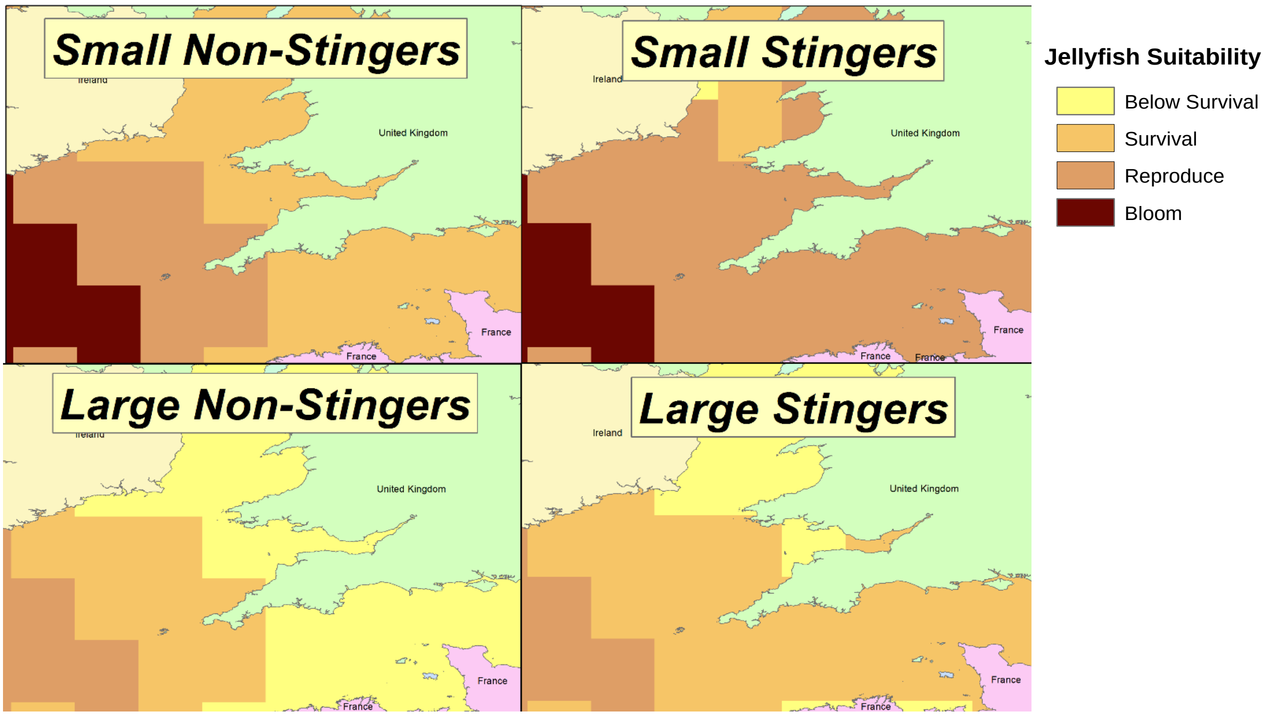


Fig 6.1 Average present-day jellyfish area suitability of the most common species belonging to the small non-stinger (represented by *Aurelia aurita*), small stinger (represented by *Pelagia noctiluca*), large non-stinger (represented by *Rhizostoma pulmo*) and large stinger (represented by *Cyanea capillata*) groups in relation to the Cornish coasts.

St Ives (50.2084° N, 5.4909° W) (Fig 6.2) was chosen as the case study along the Cornish coast because:

(a) it occurs within the closet proximity to the areas of increased jellyfish area suitability in the GIS maps compared to the other Cornish principal seaside towns and therefore more likely to experience blooms if they were to increase.

(b) Beatty *et al.* (2010) classed 77% of jobs within the central town as directly or indirectly reliant on coastal tourism for income (amongst the highest in Cornwall) with the area offering a variety of activities that includes both beach and water recreation (including surfing and bathing as well as general recreation on the beaches such as sports, relaxation, family activities and walking); in other locations, these activities have been known to be affected by blooms, either when they wash up along the shore or persist within inshore waters (Rosenthal 2008; Mariottini and Pane 2010; De Donno *et al.* 2014; Ghermandi *et al.* 2015).

(c) along the seafront, St Ives has four main beaches (Fig 6.2) where a range of recreational activities occur that were accessible for the study, particularly as visitors are based on the beach for large portions of the day.

Fig 6.2 Aerial view of St Ives and the beaches where field work was planned. Source: ESRI - ArcGIS online

6.3 Survey Data Collection

Over three weeks in the summer of 2016, 182 people across the four beaches of St Ives were surveyed. Surveys (final survey displayed in Appendix D) took 13 minutes to administer on average, achieving a 70% response rate. The majority (93%) of the interviews occurred on the two larger beaches (Porthmintser and Porthmeor) in hot and sunny weather conditions with 91% of respondents enthusiastic (subjectively classed by interviewers). Table 6.1 summarises survey respondent key demographic characteristics, which included a range of different recreational users of the marine environment who engaged in an array of activities. For example, the age range of respondents was between 18 and 75+ years old and activities ranged from beach recreation to visiting galleries in the town. Respondents also had a range of different education levels and household incomes, but most stated that they were in fulltime employment (however, a high proportion of no data was recorded in relation to employment status, see table 6.1). The gender of respondents was evenly split between males and females and most respondents had travelled relatively long distances to get to St Ives, in groups of at least four people which contained children. Of the 182 respondents, 73% reported to be in St Ives for a holiday lasting for 7 days or longer; 22% on shorter breaks; 5% identified themselves as local to the area. Of all these respondents, the majority specifically described their visit as a beach holiday (83%), with 71% of these reporting that they spend most of each day on the beach if conditions allowed for it (average of 5 hours spent on the beach per day, but the modal amount of time was 8+ hours). 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. Of all respondents, 95% reported that the day the survey was done was a typical beach day for them and 94% of interviews occurred at times when people were visibly recreating in the sea.

A high number of surfers appeared within the data set and this may have occurred because Porthmeor beach (location of high survey effort) is a famous surfing location in the UK, associated with ideal conditions for the activity. A surf school is also located on Porthmeor beach that provides recreational users of the marine environment with the equipment they require to engage in surfing as well as surf lessons. A proportionally high number of surfers likely occurred in the data set due to the high number of surfers drawn to the area. Of the surfers (12% of the total number of respondents), 66% stated that surfing was their only recreational activity that they engaged in during their visit to St Ives (the remaining 34% engaged in water and some land recreation). It must be acknowledged that such respondent characteristics (e.g. the activity they engage in) would likely have had an influence on their responses to jellyfish blooms and other aspects of the data (e.g. expenditure patters), compared to general beach visitors who engage in a greater variety of activities (on average, 4 activities were engaged in by these respondents). For example, bloom responses of surfers would likely be focussed on interactions with jellyfish in the water. However, it is likely that interactions with jellyfish blooms washed up on shore would be more common because land recreation in St Ives is generally more common. Also, these respondents spend more time in the water and are more likely to have previous experiences of jellyfish that may influence survey responses to hypothetical bloom increases.

Information on all types of recreational visitors to St Ives was collected during the survey because the aim of the study was to give an overview of all the potential impacts associated with bloom increases. However, due to the nature of the surfing as an activity (i.e. it occurs in water where interactions with blooms are more likely), and the fact that most surfers only primarily engage in this water-based recreation, an assumption was made that they would likely experience more effects, given the greater contact they may have with jellyfish. In many cases, surfers are also the only type of recreational user where most of the coastal recreation they engage in would encounter blooms (apart from when on the beach) and their responses may differ from the general survey population. The impacts to surfers was therefore investigated separately to give an idea of their influence on the whole data set and to assess whether they would incur greater impacts.

Table 6.1 Demographic characteristics of respondents in St Ives

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
	No Data	49[4]

[4] The data collected by one of the four surveyors (72 of the completed surveys) contained no information on the employment status (data pertinent to question C8 of the survey). Also, 17 out of the 110 respondents asked the question, refused to provide the information, resulting in almost half of the employment status data set (49%) containing no information.

Table 6.1 continued

Characteristic		Frequency (%)
Number of Children	0	30
	1	19
	2	35
	3	10
	4	3
	5	1
	6	0
	7	1
	8	1
Distance Travelled to get to St Ives (miles)	0 – 50	7
	51 – 100	2
	101 – 150	1
	151 – 200	9
	201 – 250	9
	251 – 300	22
	301 – 350	23
	351 – 400	19
	401 – 450	4
	451 – 500	3
	500+	1
Purpose of Visit	Visit Family	8
	Beach Holiday	83
	Cultural Holiday	2
	Activity Holiday	4
	Passing Through the Area	3
	Work	0
Beach of Interview	Porthmintser	36
	Porthmeor	57
	Porthgwidden	3
	Harbour Beach	4
House Hold 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

Table 6.1 continued

Characteristic		Frequency (%)
Number of People in Group	1	1
	2	17
	3	17
	4	34
	5	10
	6	9
	7	4
	8	1
	9	3
	10+	4
Main Activity	Mainly Beach	34
	Mainly Water (surfing)	12
	Both Beach and Water	54
Jellyfish Present During Survey[5]	Yes	19
	No	81

Throughout the following sections, the activities described above and the demographic characteristics of respondents (displayed in Table 6.1) such as gender, age and activity engaged in are investigated to assess the impacts potential bloom increases could have on a variety of stakeholders associated with coastal tourism in St Ives. The high proportion of respondents reporting that they were visiting the area specifically to recreate on the beaches for their entire visit and also engage in water activities suggested that encounters with jellyfish could be likely if future blooms were to either wash up on the beach or if they persisted in the water by the shore, depending on people's behaviour (both aspects which the survey was designed to explore). Indeed, this occurred during the field work as many *C. hysoscella* appeared across the study site in both the water and on land (photographed in Fig. 6.3) during the final five days of the fieldwork. As a

[5] 19% of respondents who were surveyed during the bloom had different characteristics to those 81% who were surveyed before the bloom.

result, of the 182 respondents, 19% witnessed jellyfish within the study location at the time of the survey. Where relevant indications are provided as to whether the data provided by respondents who were interviewed during the bloom were different to those interviewed before it occurred and the implications for data analysis.

6.4 Attitudes, Previous Experience and Knowledge of Jellyfish

Respondents' previous experiences, current attitudes and knowledge of jellyfish were elicited (with indications of affective valence, i.e. how negative or positive these were) from the initial questions about jellyfish (Appendix D, Section B) so that the influences on contingent behaviours in response to future blooms and associated impacts could be explored. This was of particular interest as these coastal resorts currently do not report jellyfish blooms as regularly as areas where other studies have quantified the impacts of blooms on seaside tourism (Ghermandi *et al.* 2015; Nunes *et al.* 2015). When jellyfish were initially discussed with respondents at the start of the survey, it became evident that they were viewed as an unwelcome presence. Of the affective associations with jellyfish provided by the respondents, 83% were revealed to be negative (e.g. terms such as "pain, horrible" and "slimy"). Common negative descriptions included mentions of undesirable morphological features (mainly referring to stinging) and referring directly to *P. physalis*, the most charismatic and dangerous species. Of responses, 10%were positive (e.g. "interesting, beautiful" and "misunderstood") and the remaining 7% displayed neutral attitudes towards jellyfish (which included descriptions such as “see through, ocean creature” and “don’t know”). There was a significant relationship between the reason respondents visited St Ives and the jellyfish descriptions they gave (Chi Square = 20.863, DF = 10, *P*= 0.022, Fisher’s Exact), with those who had come to recreate on land being more likely to use negative phrases when describing jellyfish, highlighting them as an unwelcome presence, compared those engaging in water recreation.

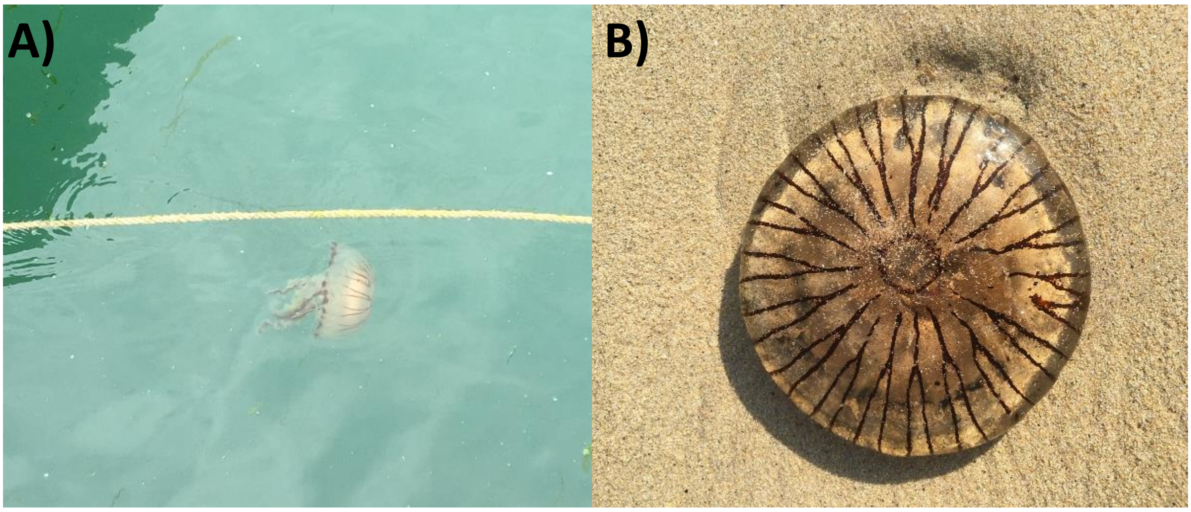


Fig 6.3 Photographs by the author of *C. hysoscella* taken during field work. A) Image taken of *C. hysoscella* in the water off harbour beach on 13/08/2016. B). Image of *C. hysoscella* washed up on Porthmintser beach on 16/08/2016

The presence of jellyfish during 19% of interviews would seem to have significantly altered the attitudes[6] displayed towards them compared to when they were not present (Chi square = 8.335, DF = 2, p = <0.05) (Table 6.2). When jellyfish were visible, no neutral feelings were reported, compared to the 7% displayed during times when jellyfish were not present. The only attitude that proportionally increased among respondents during the time the jellyfish were

[6] After jellyfish descriptions had been given (Question B1 of Section B of the survey, presented in Appendix D), respondents were asked to confirm whether their descriptions were positive, neutral or negative, providing the affected descriptions displayed in Table 6.2.

present, was the frequency of positive attitudes: 21% of descriptions were positive when jellyfish were present compared to the 10% of positive responses given when they were not. This suggests that individuals are more negative when they have less direct experience of jellyfish. This has implications for management and education, discussed in section 6.7. However, even with the shift towards positive attitudes during a time when large numbers of jellyfish were present, negative attitudes were still by far the most common response suggesting that scope for jellyfish management based on bloom experience is currently limited.

Table 6.2 Proportion of positive, negative and neutral descriptions associated with jellyfish during surveys when they were visibly present in the study site and periods when they were not.

		Respondent's affective description of Jellyfish		
		Positive	Negative	Neutral
Jellyfish Present During Survey	Yes	21%	79%	0%
	No	10%	83%	7%

Previous experiences that respondents reported of jellyfish included childhood memories, seeing them washed up on the shore, witnessing them on foreign holidays and experiencing stings. By categorising these experiences into water and land-based and examined in relation as to whether these experiences were positive, negative or neutral (Fig 6.4), it emerged that the most frequent experiences were related to water activities, which had negative associations. Of the respondents, 77% engaged in water activities. These results suggest that bloom increases could be viewed predominantly negatively in regard to water recreation.

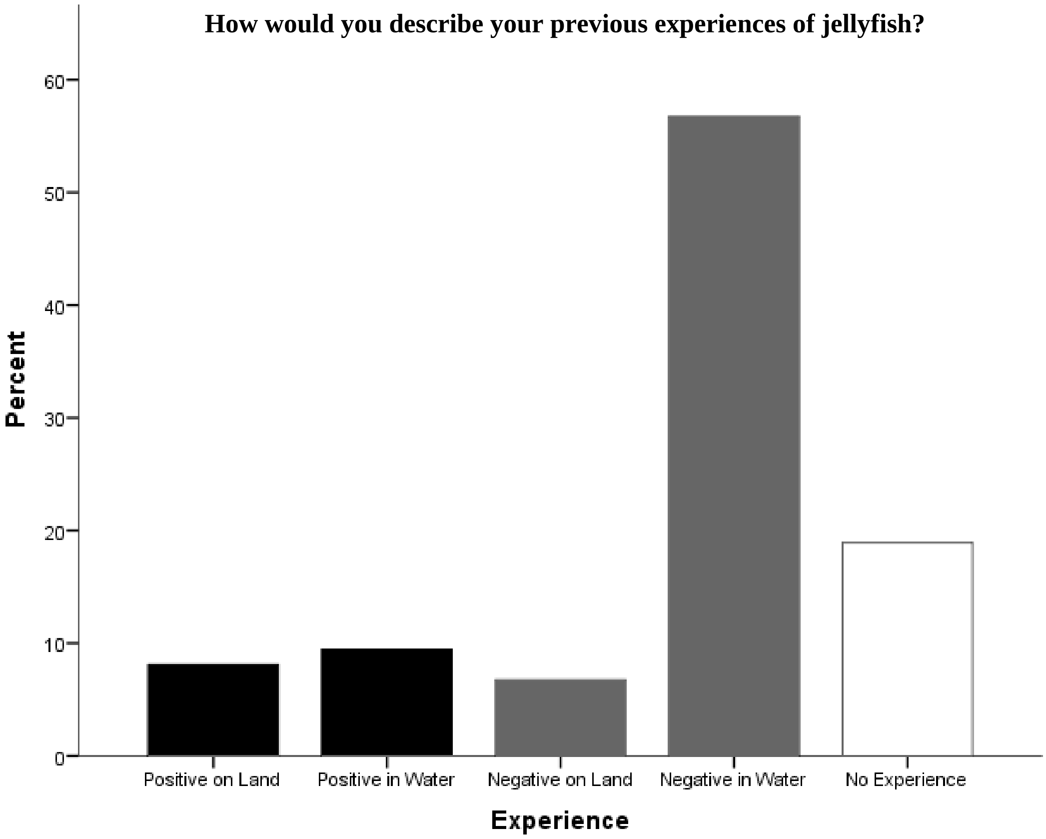


Fig 6.4 Numbers of previous jellyfish experiences reported of jellyfish on water and land and whether they were deemed positive (black bars), negative (grey bars) and no experience (white bars)

Of all respondents, 57% reported previous experiences of jellyfish in the water and described interactions as negative, including stings and generally finding their presence “intimidating,” specifically stopping them going into the water compared to the 6% who saw their experience of jellyfish in the water as positive. The remaining respondents only had pre-survey experiences of jellyfish that had washed up on the beach with 7% describing it as negative with more respondents describing washed up jellyfish as positive (10%). Recollections of previous experiences and feelings towards jellyfish suggest that the presence of large quantities of jellyfish may influence to a greater extent, the recreational activity that is carried out in the water rather than on land. Despite respondents reporting some form of experience of jellyfish, only 5 out of the 182 respondents were able to identify more than 2 of the species using the flash cards, with the highest number of correct identifications being 7 (achieved by a marine biology undergraduate). 148 (81%) of the respondents were unable to identify any of the species. Respondents were able to demonstrate marginally improved knowledge when it came to the identification of which species they thought were capable of stinging by viewing their morphological features on the flash cards (survey method described Chapter 3, section 3.7.1). Of all respondents, 35% were able to identify over half of the stingers with 14% identifying all of them; 25% of respondents were unable to identify any stinger with 71% of these reporting that they assumed that all jellyfish were able to sting humans (the other 29% provided no answer), indicating that most beach recreationalists were unaware of which species should be avoided the most, which could potentially influence future responses to their use of the sea with jellyfish present (investigated in section 6.7).

In summary, a high number of the coastal visitors that responded to the survey engaged in current activities that, if maintained, would bring them into contact with jellyfish blooms if they were to occur along the coasts of St Ives in the future. Opinions on jellyfish were predominantly negative and the majority of the respondents described unwelcome previous experiences of them, even on occasions when they did not come into direct contact with the jellyfish. However, knowledge of jellyfish types was poor. Survey results suggest that when jellyfish and humans co-occur on the same shoreline, attitudes may change, although marginally; which may have some influence on potential future responses to blooms and subsequent management of impacts (investigated in section 6.7). The next section of this chapter identifies the potential impacts of future blooms and quantifies the cost of them by generating an understanding of how respondents would recreate and respond to bloomed beaches compared to non-bloomed beaches.

6.5 Tourism Expenditure Changes Associated with Blooms

Initial consideration of costs associated with future blooming events on tourism was based on expenditure changes by beach visitors as a result of how they would react to future hypothetical blooms on beaches and the subsequent changes to recreation offered by the coastal area and ecosystem. As views on jellyfish and previous experiences of them were generally negative, as well as previous work suggesting that blooms trigger costs by causing coastal tourists to recreate differently (Ghermandi *et al.* 2015; Nunes *et al.* 2015), it was hypothesised that future hypothetical blooms would lead towards negative changes in expenditure patterns. How beach visitors would recreate under bloomed conditions within St Ives formed the basis of calculation of how tourism expenditure would change (data elicitation methods described in Chapter 3, section 3.7.1).

6.5.1 Visitor Expenditure at Risk from Blooms

Firstly, expenditure that occurs currently within St Ives from summer visitors was elicited and analysed (Table 6.3) to obtain an indication of the recreational benefits the coastal ecosystem provides. Respondents were asked about expenditure on accommodation, evening meals, daily consumables, souvenirs, general beach activities, local attractions, car parking and travel across the location (Appendix D, Section C). Average expenditure on each service was calculated per individual. For the total expenditure in St Ives deriving from visitors to the coast, estimations of the total number of coastal visitors who recreate on the beaches was required so per person expenditure could be up-scaled. However, visitor numbers to specific locations are hard to come by with no reports of average numbers of people recreating on the beaches of St Ives in existence. Beach visitor estimations therefore had to be gained through personal communication with key actors in this sector, who stated that some 1,500 people visit the 4 beaches on a typical day at the height of summer across St Ives. Expenditure within St Ives per day before blooms (Table 6.3) was then calculated by multiplying the average daily expenditure figures per person by the estimation of total beach users.

Table 6.3 Daily expenditure of recreational users of the beaches of St Ives based on the spending of survey respondents and estimations of the total numbers of visitors to the beaches on a typical summer day.

	Daily Per Person Expenditure			Total Summer[7] Daily Expenditure Across St Ives (based on estimations of the total number of those who use each service)[8]		
Service	**Lower Bound**	**Mean**	**Upper Bound**	**Lower Bound**	**Mean**	**Upper Bound**
Accommodation	£24.00	£27.00	£31.00	£36,000	£40,500	£46,000
Main Meals	£12.00	£13.00	£15.00	£18,000	£19,500	£22,500
Daily Consumables	£02.60	£03.20	£4.00	£3,900	£4,800	£6,000
Souvenirs	£00.60	£01.00	£01.40	£900	£1,500	£2,100
Beach Expenditure	£00.50	£00.90	£01.40	£750	£1,350	£2,100
Surf lessons	N/A	£35.00	N/A	N/A	£1,750	N/A
Surf Board Hire	N/A	£20.00	N/A	N/A	£1,200	N/A
Wet Suit Hire	N/A	£12.00	N/A	N/A	£360	N/A
Boots / Glove Hire	N/A	£03.00	N/A	N/A	£90	N/A
Local Attractions	£00.20	£00.50	£00.70	£300	£750	£1,050
Travel Across St Ives	£00.70	£02.00	£02.30	£1,050	£3,000	£3,450
Car Parking	£01.25	£02.80	£03.40	£1,875	£4,200	£5,100

It must be acknowledged that respondents did not incur expenditure on every aspect within table 6.3, influencing the average per person expenditure figures. This included respondents who had no expenditure on accommodation (they

[7] Summer = June, July and August

[8] Per person Accommodation, Main Meals, Daily Consumables, Souvenirs, Beach Expenditure, Local Attractions Travel across St Ives, Car Parking expenditure multiplied by estimated amount of beach user visitors (1500). Per person surfing expenditure multiplied by estimations of how many people pay for each service. Surf lesson multiplied by 50, surf board hire multiplied by 60, wet suit hire multiplied by 30, boots and glove hire multiplied by 30 people.

camped, owned holiday homes in the region or generally had access to free accommodation), resulting in per person expenditure which (without context) is lower than one would expect to pay in St Ives. The inclusion of respondents who spent nothing on accommodation along with those who did, aimed to provide per person average expenditure figures that could be scaled up to represent the whole of St Ives, due to the lack of regional tourism figures for the town. The aim was to assess all types of recreational user so that a cumulative bloom impact projection could be made, which included instances where no impacts would occur. Any changes to the recreational activities of these respondents may also have economic impacts on other aspects of tourism within St Ives, where they did incur expenditure. There are also potential social impacts to these respondents that are investigated later in the chapter.

As there was likely to be variation between each respondent's and the total expenditure, 95% confidence intervals were used to generate lower and upper bound limits around the mean (also displayed in Table 6.3). Additional expenditure figures were obtained on the water activities that could be impacted by blooms and potential increases through key actors. They indicated that on average 50 people have surf lessons, 60 hire surf boards, 30 hire wetsuits and 30 hire boots / glove on a typical day during summer season. The expenditure (per person per day) on each aspect of surfing was then multiplied by the number of people paying for each service (e.g. cost of surf board hire is about £20 per person per day and it is estimated that 60 are hired per day, resulting in total expenditure of £1,750) (Table 6.3). No upper or lower bounds were calculated as the prices were assumed to be the same for each beach user. This method has limitations that must be acknowledged that include the potential for high error associated with anecdotal evidence from key actors within the field, that could not be tested but served the purpose of testing the methodology for the St Ives case study. Also, the estimation in the number of beach users was for a typical summer day and does not account for any variation that occurs within the summer.

6.5.2 Losses through Jellyfish Interactions

The next stage of the survey was to introduce the concept of jellyfish blooms and potential future hypothetical blooms and increases to respondents, using the following description, designed for the survey:

"A jellyfish bloom is a large congregation that can contain thousands of adult medusae and are known to occur in coastal waters. Let's suppose that jellyfish populations in St Ives were to increase in the future with blooms becoming a prominent feature in the water as well as washing up on the beach."

The above definition was intended to be neutral, without introducing any components that could bias respondents' views. The piloting of the survey indicated that the statement was comprehensible to respondents and did not appear to affect respondents' perceptions of blooms. Then respondents were asked about their views, including concerns, about future blooms. More respondents were not at all concerned (16%) than ones that were extremely concerned (9%), but the overall pattern indicates that there was a greater proportion of respondents anxious about future blooms (61% moderately to extremely concerned) than those who showed slight to no concern (31%). Those who used negative phrasing when they initially discussed jellyfish (see section 6.4) and those who reported negative previous experiences of them (section 6.4) were significantly more likely to express increased concern about future blooms (Chi square = 8.866, DF = 2, p = <0.05 and Chi square 40.842 =, DF =12, p = <0.001 respectively). However, respondents' concern about future blooms was not influenced by their prior jellyfish knowledge, in relation to species (Chi Square = 29.367, DF = 29, p = 0.394) and knowledge about which jellyfish were capable of stinging humans (Chi Square = 26.632, DF = 24, p = 0.322). These findings suggest that in large proportions of respondents, jellyfish raise concern regardless of their species type and morphological features (i.e. an ability to sting) due to the influence of negative prior experiences and attitudes displayed towards them. In other words, people are poorly informed about jellyfish and have a general misconception about all species.

When considering future hypothetical blooms, 65% of respondents (greater than the 61% who stated future bloom concern) reported that there would be some form of alteration to their trip to St Ives. Questions within the survey asked about what these alterations would be. Two scenarios were discussed with respondents (section 6.5.2.1 and 6.5.2.2) in relation to future human-jellyfish interactions based on the differing morphological features of jellyfish. The first scenario was about recreation within St Ives in the event of bloom-induced beach closures (section 6.5.2.1). Beach closures have been known to occur in the Mediterranean when the *P. physalis* and *P. noctiluca* blooms come inshore resulting in costs to tourist resorts (Rosenthal, 2008; Mariottini and Pane, 2010; De Donno *et al.* 2014 Ghermandi *et al.* 2015) and was therefore considered as a plausible future management option within the coastal waters of St Ives due to the possibility of large and small stingers in Cornish waters (section 6.2).

The second scenario in this study was of the non-stinging species blooming (e.g. *A. aurita*) but not causing beaches closures. This is a scenario that also occurs in the present day as described by the high numbers of non-stingers reported to the marine conservation society citizen science scheme (MCSUK, 2017) and their widespread occurrence within coastal resorts abroad (Purcell *et al.* 2007). Despite this, no reports of beach closures have been attributed to non-stingers worldwide (that the author is aware of) and specific interactions between non-stingers and coastal tourism is poorly understood. The large areas of increased suitability of these species to Cornish waters are indicated in the GIS maps (section 6.2). Given that large proportions of respondents were unable to identify which species could sting humans and the increased levels of concern expressed through the survey, possible impacts of non-stinger blooms were considered within this study.

6.5.2.1 Scenario 1 – Closed beach.

Beach closures where discussed initially with respondents without referring to jellyfish and blooms, with respondents answering questions about how they would respond if there were days when they were not able to go on the beaches due to closures on the basis of safety (Appendix D, Section A, QA7). This was done to avoid introducing any biases associated with jellyfish that might influence their responses within the second scenario (section 6.5.2.2). In the event of the beach closures, 58% of respondents reported that they were likely to remain in St Ives and recreate in and around the town, with 66% of these indicating that they would visit the local attractions, indicating potential economic benefits to other parts of the town through an increase in expenditure on the attractions (Table 6.4).

However, the other 42% of respondents reported that they would recreate outside of St Ives, including searching for alternate beach locations for the day resulting in likely decrease of expenditure across St Ives. This was interpreted, for the purposes of this study, as a 42% decrease in day-to-day expenditure due to alternative recreation. Specifically, total expenditure on per day consumables while at the beach, beach activity, travel to the beach from hotels and car parking by the beach (initially displayed in Table 6.3) would decrease by 42%. This would be possible as the majority of the respondents (90%) had cars parked close to their accommodation which would enable them to leave the area for the day as they suggested in the survey, thus moving away from the area and recreating elsewhere (expenditure changes under the scenarios are displayed in Table 6.4). In addition to this, each day that the closures were enforced, there would be a 100% decrease in surfing expenditure (on lessons and equipment hire, see Table 6.3) as no one would be allowed into the water (expenditure change displayed in Table 6.4). Expenditure on accommodation and evening meals was assumed to not be impacted as respondents would still be based in St Ives for their trips; indeed many (73%) respondents were in St Ives for holiday lasting longer for a week, which often requires booking and paying for much further in advance than blooms can be forecast. The resultant expenditure changes (Table 6.4) based on the assumptions described above indicate net changes in total daily expenditure ranging between -£6,486 and -£9,166 total change.

Table 6.4 Assumed daily expenditure alterations as a consequence of hypothetical closed beaches (scenario 1).

Expenditure	Net Assumed Expenditure Change (%)	Assumed Expenditure Change (£)		
		Lower Bound	Mean	Upper Bound
Daily Consumables	-42	-£1,638	-£2,016	-£2,520
Souvenirs	-42	-£378	-£630	-£882
Beach Activities	-42	-£315	-£567	-£882
Travel Across St Ives	-42	-£441	-£1,260	-£1,449
Car Parking	-42	-£788	-£1,764	-£2,142
Local attractions	+ 58	+£474	+£1,185	+£1,659
Surf lessons	-100	-£1,750	-£1,750	-£1,750
Surf Board Hire	-100	-£1,200	-£1,200	-£1,200
Wetsuit hire	-100	-£360	-£360	-£360
Boots / Glove Hire	-100	-£90	-£90	-£90
Total Change		**-£6,486**	**-£8,362**	**-£9,166**

6.5.2.2 Scenario 2 – Blooms on Open Beaches

In the event of blooms of non-stinging species (*A. aurita, C. hysoscella* and *R. pulmo*) it is less likely that the beaches would be closed to the public. The variety of recreational activities (both on land and in water) the respondents reported earlier in the survey would therefore, lead them to occupy the same stretch of coast as present, during future inshore blooms. Questions asked how the respondents would recreate in St Ives upon arriving at the beach and discovering it was dominated by blooms, without being specific about jellyfish species or morphology (Appendix D, QB6). Respondents could answer using one of the predetermined categories or in their own words (which were written down by interviewers). The latter were then coded for analysis. The variety of responses are presented in Figure 6.5.

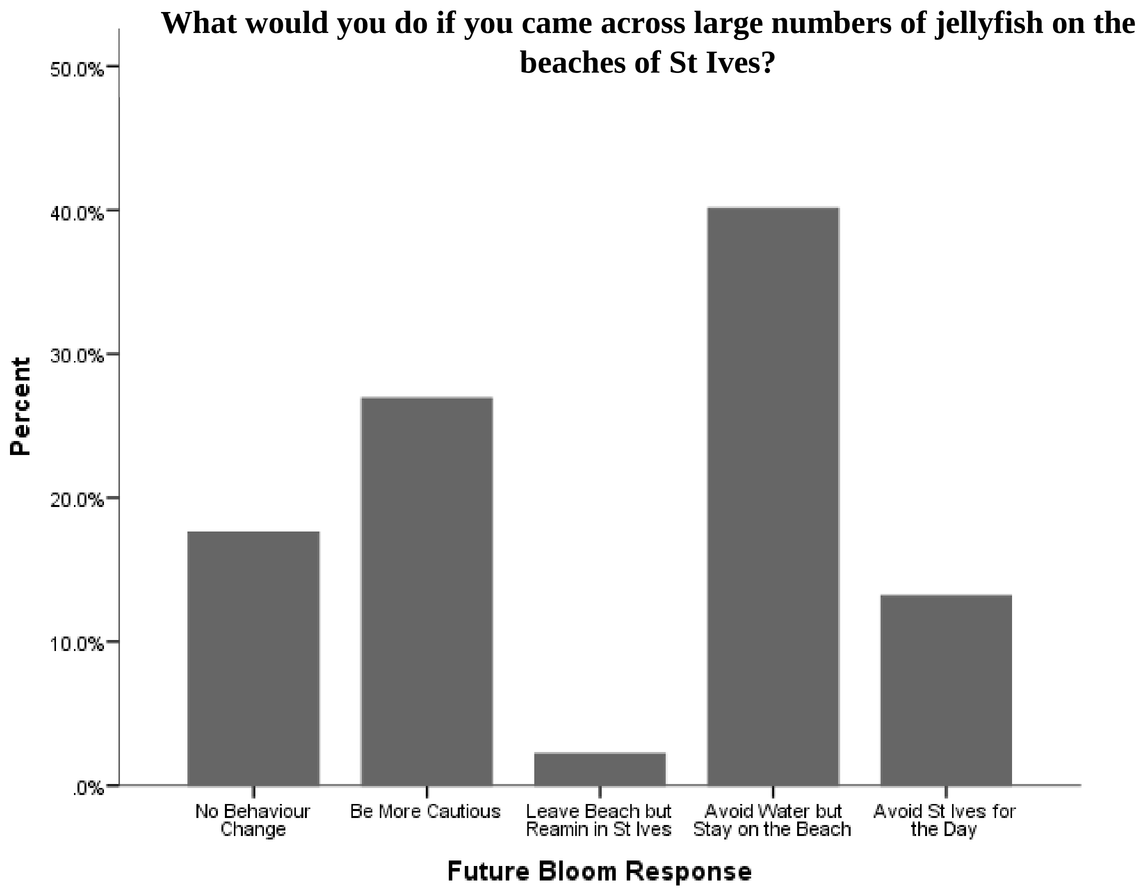


Fig 6.5 The frequency of responses (%) to future blooms on the beaches of St Ives from the 182 respondents.

Of the respondents, 18% indicated no behaviour change and 27% suggested that they would generally be more cautious while recreating on a beach that contains a bloom. There would therefore be no expenditure alteration associated with these 45% of respondents as there would be no overall change in their recreational activities, but potential welfare implications (discussed in section 6.6) for the more cautious beach users. However, 13% of respondents reported that they would avoid St Ives each day that a bloom was present, which can be assumed to result in a 13% decrease in the reported daily expenditures in the town (i.e. the day-time consumables, souvenirs, local attractions, travel within St Ives and car parking, as per Table 6.3). An additional 2% of respondents would avoid the beach but remain in St Ives, resulting in a corresponding decrease in the general beach expenditure. Combining these resulted in a cumulative decrease of 15% in expenditure related to the beach activities. However, the 2% increase in people visiting attractions in the town as opposed to the beach would provide some benefit to the town but not the coastal strip directly. Overall, therefore, this would result in a decrease of 13% to the area caused by not recreating in the sea resulting in a net decrease of 11% (2% increase in expenditure in the town of those avoiding the beach minus the 13% of those who would leave St Ives for the day).

The remaining 40% of respondents reported that they would avoid water but stay on the beach. The expenditure associated with water activities (surfing lessons and equipment hire) would therefore be at risk from the 40% decrease in respondents recreating in the water with blooms of jellyfish present. However, assumptions of expenditure change from the total amount of respondents who would avoid the water could not be made because the secondary data (displayed in Table 6.3) was based solely on surfing. As expenditure was different for the surfers, their individual responses are also discussed in this section (separate from the main data set). The percentage of surfers who reported they would avoid the water but stay on the beach (41%) was therefore used to calculate expenditure changes. This led to a 41% decrease in expenditure on surfing (lessons and equipment hire). Expenditure on water recreation would also be impacted by an additional 13% of surfers who reported that they would either avoid St Ives or avoid the water resulting in a total 54% cumulative decrease in surfing expenditure. Based on these assumptions, the net expenditure change for each element was calculated and used to quantify projections of total expenditure change across St Ives per day (in Table 6.5).

Table 6.5 Assumed daily expenditure alterations as a consequence of non-stinging blooms on the beaches (scenario 2)

Expenditure	Net Assumed Expenditure Change (%)	Assumed Expenditure Change (£)		
		Lower Bound	**Mean**	**Upper Bound**
Daily Consumables	-13	-£515	-£634	-£792
Souvenirs	-13	-£119	-£198	-£277
Beach Activities	-15	-£99	-£178	-£277
Travel Across St Ives	-13	-£139	-£396	-£455
Car Parking	-13	-£248	-£554	-£673
Local attractions	-11	N/A	-£83	-£116
Surf lessons	-54	-£952	-£952	-£952
Surf Board Hire	-54	-£653	-£653	-£653
Wetsuit hire	-54	-£196	-£196	-£196
Boots / Glove Hire	-54	-£49	-£49	-£49
Total Change		**-£3,103**	**-£3,893**	**-£4,440**

6.5.2.3 Comparing Scenario Impact

Due to the lack of reports and monitoring data on duration of blooms within Cornish waters (and therefore how many days the beaches of St Ives would be affected), an assumption of how long a typical bloom would last for was required to project the total expenditure change for a blooming event. Palmieri *et al*. (2015: 228) state that "typical mass jellyfish stranding events last 2 weeks" across the UK, mainly in the south west, based on public reports of bloom stranding events. The daily altered expenditure for St Ives was therefore multiplied by 14 days to provide a projection of the total expenditure alteration because of each of the two scenarios (Table 6.6).

Table 6.6 Expenditure alterations based over the course of a typical hypothetical bloom

		14-day Bloom		
Total Expenditure Change	**Scenario 1** **(closed beach)**	**Lower Bound**	**Mean**	**Upper Bound**
		-£90,804	-£117,068	-£128,324
	Scenario 2 **(beach open with blooms)**	**Lower Bound**	**Mean**	**Upper Bound**
		-£42,042	-£54,502	-£62,160

Despite the greater range in the changes to recreational activities that were projected as a result of the blooms on open beaches scenario (scenario 2), the future hypothetical beach closures (scenario 1) resulted in greater expenditure decreases. This is because net expenditure decreased between 24% (open beaches with blooms) and 53% (closed beaches) when the total expenditure most likely to occur during blooms was compared with the total expenditure that was reported in the present day. This difference is in part due to respondents in scenario 2 indicating they would adapt their daily activities in the event of non-stinging species occurring on open beaches. More land recreation was reported than water recreation (Table 6.1), meaning that a good proportion of respondents would not perceive to be impacted by scenario 2, resulting in fewer respondents suggesting they would avoid the beaches and the town, resulting in less expenditure decreases than scenario 1. Beach closures would impact all respondents and their recreational activities (whether it would be on land or water), resulting in greater expenditure decreases as more people would avoid the beach and sea, than in scenario 2, thus highlighting the importance – from this study - of the coastal environment in drawing people to St Ives and the potential impacts to the town's economy of scenario 1 (closed beach).

Negative views and experiences of jellyfish had no significant effect on the future responses displayed in Figure 6.5 to scenarios 1 (Chi Square = 5.875, DF = 8, p = 0.661) or scenario 2 (Chi Square = 6.763, DF = 12, p = 0.873 respectively), and the resultant projections of expenditure changes (Table 6.6). The level of concern also had no significant impact on future responses, such as avoiding the beach or entire area (Chi Square = 3.38, DF = 12, p = 0.496). However, jellyfish presence during the fieldwork had a significant influence on the responses (Chi = 37.632, DF = 4, p = <0.001) with 6% of the respondents interviewed during the bloom reporting that they would display no change in their recreational activities, compared to the 45% who reported this when no jellyfish were present during surveys. When jellyfish were present, behaviours such as avoiding the water and going elsewhere were reported more frequently which indicated that feelings were not indicative of behaviour in this case.

The evidence presented here therefore suggests that the summer visitors to the beach would not be able to fully enjoy the recreational benefits provided by St Ives' beaches when jellyfish blooms occur, although these varied by scenario, as demonstrated above, with subsequent impacts on the tourism in the town and further afield. Such findings need to be taken into account when considering possible management solutions. Further evidence of this is provided from respondents, with 12% of total respondents indicating that experiencing a bloom in St Ives would deter them from future visits (Appendix D, section B Q8). However, it is worth noting that for this study no additional information was available on how beach users would recreate under bloomed conditions, other than what they would specifically do on the beaches and any alternative activities that were suggested (few respondents were provided indications of this). For example, those that would avoid the beach were likely to decrease their day to day expenditure associated with this activity, but alternative expenditure or further expenditure decreases because of this, was not known due to the lack of alternative preferences proposed by respondents. Direct impacts were therefore assumed from the changes in beach activities to generate the projections of expenditure change. Further data on respondent preferences (either gained through additional surveying or secondary data that currently does not exist) would lead to more accurate bloom response projections which in turn could improve quantifications of potential future expenditure alterations of summer beach visitors.

6.6 Impacts of Blooms on Ecosystem Use Value and Welfare

The experience of recreation in coastal ecosystems (i.e. at the beach) has also direct non-market use value to visitors (Nunes *et al.* 2001; Blackwell, 2007;

Prayaga, 2017). The possible impacts of jellyfish on this was not captured during the assessment of expenditure changes in relation to future bloom increases (shown in the previous sections of this chapter), which constitute the market-based experiences and benefits the local area receives from visitors due to the presence of the coastal ecosystem. As coastal ecosystems such as beaches provide services with social and welfare benefits associated with recreation (such as spending time with the family and health benefits) (Nunes *et al.* 2001; Blackwell, 2007), an assessment of the non-market use values of the coasts of St Ives and how they could be impacted by future blooming events was undertaken. The value of welfare benefits was based on how much visitors were willing to pay for each visit beach based on their travel cost. The travel cost method (TCM) (see Chapter 3, section 3.7.2 for method selection, stages and analysis techniques) was therefore used for the assessment of potential future welfare impacts that may occur in the event of blooms decreasing access or altering the quality of the coastal ecosystem.

The inferred price of beach access was calculated and used as a quantification of the per visit welfare value of the beaches (resulting in a beach access value). The calculation was based on what survey respondents paid in travel, assessing how this cost influenced the number of beach visits made. Since demographic factors can influence the prices of each visit to a recreational location (Parsons, 2003), the effect of all the demographic characteristics (Table 6.1) on St Ives' beach access value was also tested.

To calculate the average travel cost for each beach day of the respondent's visit to the St Ives area, and therefore cost per beach visit (assumption was made of one beach visit lasting a day based on the recreational choices reported by respondents in section 6.3), the total return trip cost (distance in miles travelled based on post codes, multiplied by the cost per mile of the transport used) was divided by the number of days each respondent stayed in St Ives. The resultant travel cost per beach visit was incorporated into the Poisson regression model (Chapter 3, section 3.7.2 for methods of this stage of the analysis) that assessed how travel cost and respondent demographics influenced number of beach visits made. However, due to over dispersion (high variability around the mean for the empirical model) seen in the "number of beach visits" data set (Kolmogorov-Smirnov = 6.336, n = 182, p= <0.001), a Poisson distribution could not be assumed. Therefore, a negative binomial regression model that employed the same structure but relaxed the constraint of over dispersion (Chapter 3, section 3.7.2 discusses the two models) was used to test the influence of each demographic factor on the number of beach visits (Table 6.7).

Table 6.7 Negative Binomial Regression Model Output

Variables	β Coefficient	Standard Error	Wald Chi Square	*P*-Value
Constant	2.051	0.6957	8.690	0.003
Income	-0.016	0.0434	0.132	0.717
Gender	-0.261	0.1846	1.993	0.158
Age	0.093	0.1941	0.228	0.633
Average Daily Travel Cost	-0.058	0.0114	25.633	>0.001
Number of Children	0.106	0.1005	1.111	0.292
Number in Group	-0.030	0.0528	0.320	0.572
Education Level	0.480	0.0526	0.833	0.361
Employment Status	0.092	0.0758	1.484	0.223
Reason for Visit	0.245	0.1079	5.171	0.023

The negative binomial regression model initially indicated that there would be no variation in access value between respondents (and therefore any bloom impact due to respondent characteristics) because of the lack of significance the demographic factors (e.g. age) had on the number of beach visits. This indicates that different respondents value access to the coasts equally, despite the different activities that they engage in, but would respond differently to blooms, as demographics did influence different hypothetical bloom responses (section 6.5). The only two variables within the negative binomial regression (Table 6.7) that had a significant influence on the number of beach visits were the travel cost, as expected (Parson, 2003), and the reason respondents were visiting the area, with those that had come for a beach holiday significantly (p = 0.023) making more trips to the beach (caused by the high number of respondents specially visiting St Ives for the beaches).

The decrease in beach visits as travel cost increased is displayed in Figure 6.6. The trend that beach recreationalists in St Ives who had greater travel costs, made less visits to the area over the course of a year is consistent with what one would expect from the data sample, as most of the respondents stated that they were holiday makers, staying in the area for around 1-2 weeks, spending most of their days on the beach (section 6.3). A high proportion of the data points in Fig 6.6 therefore represented respondents with the highest travel costs and the fewest beach trips. More of the data points (88 %) represented respondents who made below 15 beach visits over the course of a year with above average return travel costs per person per day (above the £14 average). Several outliers also appeared amongst these respondents where only 1-3 beaches visits were made, and the highest travel costs were incurred (> £30 per person). There were far fewer respondents who made more than 15 trips per year (12% of the sample), but all incurring lower than average travel costs (less than the £14 average). There were also some outliers, who made over 40 trips per year and had the very lowest travel costs (£0-£3 per beach visit). They were likely local to the area and had easier access to the coastal ecosystem. Therefore, the per person access value of each visit to the beach that was revealed by travel costs is greater for the seasonal visitors, but over course of the year, there is a greater cumulative benefit for people local to the area due to the higher number of visits that they make.

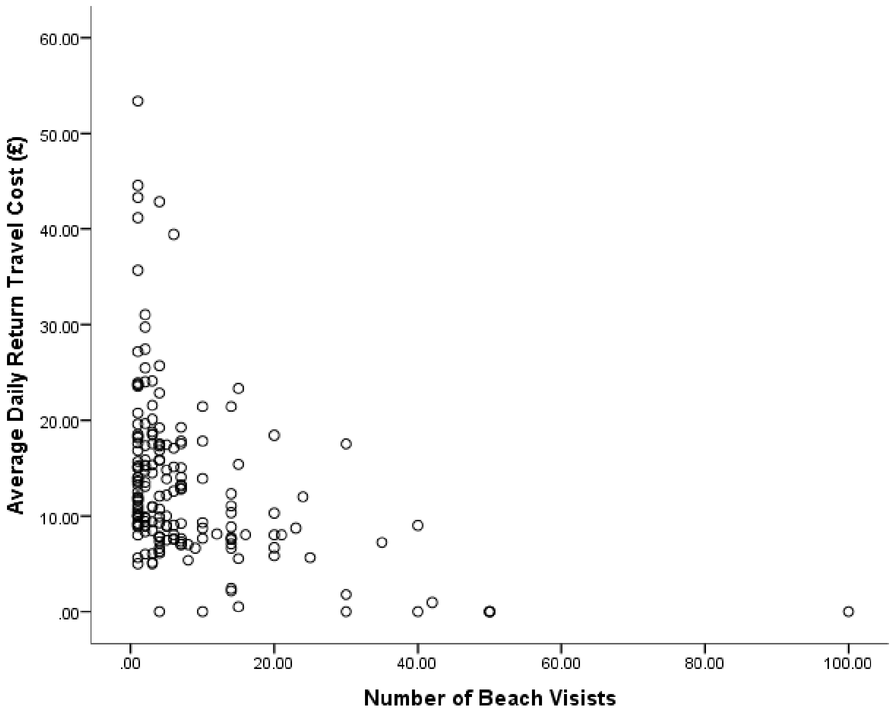


Fig 6.6 Correlation between the average daily cost of travel associated with holiday trips and the number of beach visits during the trip

The next stage of the analysis was to generate an estimation of the before bloom access value of the beaches of St Ives using the travel cost function described by

Parson (2003) (method discussed Chapter 3, section 3.7.2). The inferred access cost (S_n) of the beaches was calculated by dividing the constant (λ_n = each beach visit (assumed to be one visit per day that lasted the whole day)) by the travel cost coefficient generated during the negative binomial regression ($-\beta_{tcr}$ = -0.058) displayed in Table 6.6 (methods introduced in Chapter 3, section 3.7.1), thus:

$$S_n = \frac{\lambda n}{-\beta tcr} = 1 / -0.058 = £17.25 \qquad \text{[Equation 6.1]}$$

The resulting estimated access price of the St Ives beaches visit per person per day was £17.25 (1/-0.058) as shown in Equation 6.1. The aggregated welfare value of the beaches of St Ives based on the price visitors revealed they were willing to pay to access the beaches was estimated by multiplying the per person access cost of the beaches by the 1,500 people estimated to visit the beach on a typical summer's day (section 6.5.1), resulting in an aggregate use value of £25,875 per day for beach access.

To consider the impacts of blooms on the use values of the beaches, and the associated changes in the welfare benefits visitors receive from them, the responses to the open and closed beach scenarios were considered. For the closed beaches in scenario 1 (section 6.5.2.1), there would be a 42% decrease in the number of respondents who would remain in the area. It was therefore assumed that there would be a 42% decrease in the inferred use value of St Ives due to the decreases in visitors to the area accessing the beaches. The subsequent use value decrease was estimated to be a loss of £10,868 (= (£25,875 * 0.58) – 10,868) (see Table 6.7) for each day a bloom persisted.

In response to scenario 2 (section 6.5.2.2) where non-stingers were assumed not to be causing beach closures, 13% of respondents reported that they would avoid St Ives on bloom days and 2% would avoid the beach, resulting in a 15% loss in the use value of the coastal ecosystem, which was estimated to be £3,881 (= (£25,875 * 0.85) – 25,875) per day. Many respondents reported that they recreate in both water and land on the beaches of St Ives and therefore have a variety of alternative recreational options if the beaches are not closed, particularly if blooms do not wash up on land. Surfers however, are a group of beach users who could experience greater welfare impacts through decreasing use value of the coastal ecosystem if the inshore waters were to become compromised or access to them no longer becomes possible as a result of blooms and a lack of alternative recreational opportunities. As 34% of respondents primarily engaged in surfing, an assumption was made that 34% of the 1,500 estimated daily beach users also engaged in surfing, resulting in 510 daily surfers. This was multiplied by the £17.25 per person access value of the coastal ecosystem. Total surfer access value was estimated to be £8,798 per day. In the event of beach closures during scenario 1, the entire use value and therefore recreational benefit would be lost as the surfers would not be able to access the sea. In the event of scenario 2, 60% of the surfers reported they would either avoid the water, avoid the beach or leave St Ives each day a bloom persists, resulting in a £5,279 (= (£8,798 * 0.4) – 8,798) use value decrease. As with the expenditure change estimations, the per day use value decreases reported in this section were multiplied by the fortnightly bloom duration assumed by Palmieri *et al.* (2015) (section 6.5). The resultant welfare impacts are summarised in Table 6.8.

Table 6.8 Welfare impact incurred by beach visitors in the two bloom scenarios (scenario 1 (blooms closing beaches) and scenario 2 (bloomed beaches that remain open)) per day and over the assumed typical duration a bloom.

Bloom Duration		**1 day**	**14 days**
All Beach Users	**Scenario 1**	£10,868	£152,152
	Scenario 2	£3,881	£54,418
Surfers	**Scenario 1**	£8,798	£123,172
	Scenario 2	£5,279	£73,906

In summary, the responses by summer visitors on how they would behave in response to hypothetical future blooming scenarios led to projections of negative impacts that would be incurred if blooming events were to be experienced by beach users and possibly become more common. This was because blooms were seen as capable of decreasing access and quality of the benefits (i.e. recreation) provided by the beaches of St Ives, leading to welfare impacts which had the knock-on effect of decreasing expenditure by visitors once in the local area. The actual behaviours in response to blooms were by beach visitors who had little or no knowledge and experience of jellyfish (section 6.4), as well as negative views of jellyfish (section 6.4) which likely contributed to the cost projections. The hypothetical responses reported by respondents once they had been introduced to the concept of possible blooms in St Ives lead to a variety of projections that suggest jellyfish could become an issue within the coastal waters of the south west UK which could be comparable with what currently is reported in the Mediterranean. To estimate the effects of future blooms, this chapter has applied aspects of well-established socio-economic techniques to jellyfish bloom impact an ecosystem services and benefits provision research. The study has also assessed potential future impacts of blooms and their increases to an area where previous attempts have quantified the impacts retrospectively or during a blooming event (e.g. Ghermandi *et al.* 2015). This study has provided an assessment of the impacts of blooms on coastal tourism in a location of the UK, which could be replicated in other areas of the UK However, acknowledging the limitations and constraints is necessary. The lack of readily available data sets that describe visitor number trends or the number of beach users in specific coastal locations such as St Ives presented a challenge when estimating total impacts based on per person expenditure and beach access value. It is likely that the estimations of total beach users on a typical summer day are subjective and based on experience. The study was also unable to capture variation in beach user numbers from day to day. Improvements in the secondary data used in this study would therefore increase the accuracy of the projections of potential socio-economic impacts that future blooms could cause or at least give an indication of any error.

6.7 Future Management of Jellyfish Blooms

The expenditure decreases of coastal recreationalists and the welfare implications that were projected as based on responses of recreational users of the marine environment to the presence of jellyfish blooms, highlighted that jellyfish management schemes require consideration. During the survey, respondents were introduced to a potential management scheme directly after they had completed discussions about their future responses to blooms (section B of the questionnaire). The proposed scheme consisted of nets used to protect sections of the beach (both water and the shoreline) from blooms. This hypothetical scheme was based on the MED-JELLYRISK nets deployed across the Mediterranean where there are currently greater issues associated with blooms (particularly stingers such as *P.noctiluca* (Purcell *et al.* 2007)) (see http://jellyrisk.eu for more information on the MED-JELLYRISK project) and nets that have been used for a long time in Australian waters in response to box jellyfish. Since Baumann and Schernewski (2012: 555) suggest that beach users with information on jellyfish are "less bothered by them," a method of informing respondents about the species that would occur was also considered as part of the hypothetical management scheme to assess whether it would contribute to reducing or eliminating the projected impacts of future blooms. Respondents were introduced to the hypothetical scheme using the following description and Figure 6.7:

"In some areas, jellyfish are a big issue and NGOs set up nets that create jellyfish free pools and separates sections of the beach from blooms. Stalls can also be set up that provide information about the species that are occurring so that beach users can understand their characteristics, including which ones can sting. Potentially, this could be used in the event of blooms occurring in St Ives."

Fig 6.7 Image used to introduce respondents to the anti-jellyfish nets. Credit: Stefano Piraino at MED-JELLYRISK

After respondents had been shown this information they were asked to rank how important they believed a scheme like this would be using a Likert scale (Exact question: How important do you think it would be that types of measures like the one that I mentioned are set up to manage issues associated with jellyfish blooms?). Of the 182 respondents who answered the question, 49% indicated it would be moderately or extremely important and 29% indicated not at all important or slightly important; only 23% indicated somewhat important. Specifically, nets that separate humans and blooms were selected by 46% of respondents to this question as the most important aspect of the hypothetical mitigation scheme, compared to those that thought jellyfish information (17%) was most important. This could be due to the immediate benefit respondents envisaged of being separated from blooms by the net, suggesting that respondents were acting on expectation of jellyfish blooms being an issue and something to avoid. The importance of a future management schemes to different types of beach users (based on members within their group and activity that they engage in) is displayed in Table 6.9 and suggests a few differences in how important the management scheme would be. Visitors who engage in both beaches and general water recreation indicated greatest personal importance of a net scheme. Surfers indicated the scheme was moderately or extremely important less than those that recreate on land. Surfer likely reported the importance of the net less because they would impact the suitability of section of the beach for them to engage in surfing.

Table 6.9 The importance of a future jellyfish management scheme to different beach users

Beach User	Not at all Important	Slightly Important	Somewhat Important	Moderately Important	Extremely Important
General Beach Users	16%	9%	22%	34%	18%
Groups with Children	19%	9%	21%	35%	16%
Groups with no Children	19%	11%	26%	24%	20%
Mainly Beach Activities	18%	12%	20%	31%	20%
Mainly Water Activities	19%	5%	19%	29%	29%
Beach and Water Activities	18%	10%	25%	34%	13%
Surfers	16%	11%	26%	29%	18%

The next stage of the analysis assessed the stated preferences of respondents for a coastal ecosystem where blooms are separated from beach users by the nets (methods introduced in Chapter 3, section 3.7.2). To do this, in section B of the survey (see Appendix D), respondents were asked if they would be willing to make a one-off annual donation to an NGO to set up jellyfish free pools in St Ives, and if yes, how much they would be willing to donate towards this (Table 6.10).

Table 6.10 Percentages of each type of beach user willing to donate to the hypothetical jellyfish management scheme and how much

Beach User	Willing to donate within each beach user group	Donations (£)		
		Lower Bound	Average	Upper Bound
General Beach Users	42%	£7.40	£11.10	£14.80
Groups with Children	41%	£6.10	£9.50	£13.10
Groups with no Children	36%	£4.20	£12.10	£19.90
Mainly Beach Activities	29%	£2.20	£9.30	£16.40
Mainly Water Activities	43%	£0.90	£13.10	£27.10
Beach and Water Activities	45%	£6.40	£10.10	£13.90
Surfers	48%	£6.50	£12.20	£18.00

Of the 182 respondents, 40% stated that they would be willing to donate towards such a management scheme. The majority of the percentages of different types of beach user willing to contribute (Table 6.10) was close to the 40% average, with those that engage in water-based activities suggest that they would donate the most, as it would be expected. The average amount stated was £10 per person (the average donation from all the respondents who suggested they would be willing to donate) with upper and lower ranges (falling within 95% confidence intervals) being £7 and £14 respectively. Interestingly, the percentage of respondents surveyed during the bloom who said they were willing to donate was less than the percentage who said they were willing to donate before the bloom on St Ives beaches (29% willing to donate during the bloom compared to the 42% willing to donate before the bloom). A range of payment vehicles for the donations were suggested by the respondents including increased car parking fees, taxes, and putting money in collection buckets (see Table 6.11).

Table 6.11 The frequency that each payment method was selected by responses who were willing to contribute to the hypothetical jellyfish bloom management scheme

Payment Vehicle	Frequency (%)	Average Donation amount		
		Lower Bound	Average	Upper Bound
Car Parking Charge	10	£6.70	£10.70	£28.00
Collection Bucket	35	£2.10	£2.70	£3.40
Donate at a Display	35	£9.40	£22.20	£40.60
Tax	20	£3.80	£5.60	£7.50

It was then interesting to consider how the donations would scale up to beach visitors in St Ives on the whole. Assuming that these survey responses would be similar across the numbers of visitors (1,500) to the beaches in St Ives on a summer's day (section 6.6), 600 (40%) would be willing to donate to a jellyfish management scheme. The average donation of £10 was multiplied by the 600 people resulting in a £6,000 to derive the total aggregated stated value of maintaining recreational activity within St Ives' coastal ecosystem setting up jelly free pools. These analyses enabled a comparison between the stated value of maintaining access and recreational potential of bloomed beaches using nets with the estimates of decreased values of the travel cost analysis (contingent valuations). The average stated value for having beach and sea access under bloomed conditions was estimated to be £6,000 (discussed above in this section, previous page), ranging between £4,200 (lower limit), and £8,400 (upper limit) from one off payments. The losses inferred value incurred from scenario 2 and estimated using the results of the travel cost method could, in theory, be avoided setting up anti-jellyfish nets. Separating blooms and people using nets could also mitigate the impacts projected as a consequence of closed beaches in scenario 1, as the beaches may not have to close in the event of the nets effectively stopping stinging interactions. However, further research with beach visitors as to whether they would remain on the beaches knowing that dangerous stingers were in the vicinity just outside of the nets would be required to explore this option in more detail. Safety, in particular, would have to be ensured as there are examples were jellyfish nets have been unsuccessfully implemented; in Australian waters, for example, jellyfish slipped between the mesh of the nets (Nimorakiotakis and Winkel, 2003).

6.8. Summary

Table 6.12 displays the various changes that have been projected to occur to the tourism sector across St Ives in relation to the impacts on beach recreation due to the scenarios of hypothetical blooming events. Estimates of the socioeconomic changes associated with use value of the beaches in St Ives, assessed using the travel cost and contingent valuation methods (see Chapter 2) are presented. The projections made in this chapter and the responses reported by users of the marine environment to blooms, indicates that if blooms of any species were to become more common across St Ives in the future, management schemes (such as the one discussed in section 6.7) should be considered.

Table 6.12 The overall estimates of projected changes to the tourism industry across St Ives in response to different bloom scenarios (bloom scenario 1, blooms of stinging jellyfish leading to beach closures and scenario 2, general occurrence of blooms of non-stinging jellyfish occurring across the coastline), assuming that a typical blooming event persists for 14 days (typical duration of historical blooms in the Northeast Atlantic stated by Palmieri *et al*. (2015))

Factor	**Bloom Scenario**	**Projected Net Change per Blooming Event**
Recreational value of the beaches in St Ives for all users (revealed valuations based on respondent travel costs)	Scenario 1	- £152,152
	Scenario 2	- £54,418
Recreational value of the beaches for the surfers of St Ives (revealed valuations based on travel costs)	Scenario 1	- £123,172
	Scenario 2	- £73,906
Recreational value of the beaches of St Ives stated through contingent valuation of hypothetical beaches with jellyfish bloom management.	Scenario 1 + 2	+ £84000

In terms of jellyfish blooms, use and non-use valuations of the coastal ecosystem are a key consideration (see Chapter 2), particularly as the expenditure on goods while in St Ives (Section 6.5) that benefits the local area is closely linked to the recreation that occurs within the coastal ecosystem. Therefore, it can be stated that seasonal visitors will incur losses in recreational opportunity if a jellyfish bloom will occur during their recreational period at St Ives, and the consequence of this would be the economic impacts on those who benefit from the tourism industry, as the seasonal visitors tended to state that they would avoid resorts impacted by blooms.

Scenario 1 (blooms of stinging jellyfish leading to beach closures) had the greatest effect on the beach recreation values for all beach users. The impacts associated with scenario 1 were greatest because most seasonal visitors come to St Ives specifically for the coastal ecosystem and the desired recreational opportunity would be lost during such a blooming event, which led to the greater projections of loss. There are similar recreational opportunities in other nearby locations that respondents were willing to travel to, if the other locations were unaffected by the blooming event, increasing the impact that would be incurred across St Ives.

In the event of scenario 2 (beaches remaining open when blooms of non-stingers occur), all impact projections were considerably lower to all users of the coastal environment. The lower impact of scenario 2 compared to scenario 1 suggests that blooms and some recreational activity on the coasts can co-occur, indicating that if the beaches can be safely kept open, some recreational value of the beaches can be maintained during blooming events. For example, keeping blooms from washing ashore would maintain a large proportion of the recreational value of the beaches, as land recreation was more common, and it was water recreation that was projected to incur proportionally greater impact. However, it must be acknowledged that net losses would still occur under scenario 2, which would require management measures to mitigate impact associated such blooming events.

The estimations of the total contingent valuation of recreation on beaches, based on the willingness to donate of the public to mitigation strategies (i.e. the anti-jellyfish nets) was greater than all the projections of impact that would occur in the event of scenario 2. Therefore, hypothetically, during blooms of non-stingers the donations would cover the total projected impacts, assuming the management scheme would successfully separate blooms from humans. However, as discussed in section 6.7, further investigation would be necessary to assess if the costs of setting up and running a project that maintains these values would exceed the donations it would receive or be greater than the projections of loss that would occur under scenario 2 (in other words, would management costs exceed benefit that would be maintained).

Assuming that the scheme was successful at stopping human-jellyfish interactions, the benefits would be greater than the costs of maintaining the array of use values associated with beach recreation and should therefore be implemented. Due to the large difference between the contingent valuation and the impacts projected under scenario 1, it can also be speculated that if the donations would not cover the costs of the management scheme, further funding could be considered. Further research should therefore assess whether further funding could be received and whether others who benefit from the beaches of St Ives would be willing to contribute, as well as the vehicle through which donations should be collected. Other sources of funding on top of the public donations are therefore discussed during Chapter 7 (Section 7.4), in relation to bloom mitigation strategies.

It must be acknowledged, however, that the suggested management scheme (Section 6.7) would have to be implemented over the course of an entire summer season, as it is not feasible to continually install nets in response to each blooming event and remove them when no blooms are present. Information would therefore be needed as to whether non-stingers or stingers would occur during the tourism season (which is currently not available), to conclude what the costs of a management scheme could be based on the recreational value that would be maintained. Such considerations are necessary due to the different levels of recreational value of the beaches that a scheme would maintain in relation the varying impacts of stingers and non-stingers. There are also some recreational activities that would be hindered by the suggested anti-jellyfish measures (such as surfing) which would require consideration when implementing such a management scheme.

6.9 Conclusion

This chapter investigated and estimated the magnitude of the socio-economic impacts to a coastal community and related visitors in the event of future blooming events and their potential increase, changing the coastal recreation and the tourism that occur. It finds that a variety of impacts could occur ranging from the financial implications to the local economy to the welfare impacts on those that visit the town of St Ives for beach recreation. The main impact of blooms was that they would cause recreational visitors to avoid the beaches of St Ives, and even the town itself, due to the presence of blooms. The welfare implications were measured based on how much respondents valued access to the coasts (based on their travel cost getting there) and by estimating how much welfare benefits would decrease with future blooms. The financial effects were assessed based on assumed expenditure decreases by seaside visitors to give an indication of the impact on the local economy. If blooms were to occur and increase, the severity of these impacts would depend on what species were occurring and the behavioural responses of recreationalists they would trigger. Scenarios of increasing blooms of stinging species understandably resulted in both greater economic and welfare impacts because they would impact all types of beach recreation; in these situations, a great number of respondents suggested that they would recreate elsewhere. In the event of increases in the non-stinging species, net negative socio-economic impacts were projected but some activity would not be impacted, and adaptive behaviours would allow for some beach recreation to occur. Beach closures would result in the greatest impacts and avoiding this would at least maintain some of the use value of the coastal ecosystem for some types of recreationalists.

This chapter also investigated the potential management implications in response to the blooms of different species and the response to these. Use of the sea was valued, based how much respondents would be willing to pay to separate sections of it from blooms, so that it could be accessed by bathers, using anti jellyfish nets. The willingness to pay for such schemes suggest that a management scheme like this could keep the beaches open, with notable benefits. As demonstrated elsewhere around the globe, managing jellyfish in relation to tourism is a notable challenge, due to the conspicuousness of blooms and the morphological traits of certain species. The suggested scheme showed potential to maintain the use value of the coastal ecosystem for at least some of the beach users under certain future bloom scenarios, but whether implementation is possible and if management can be tailored to the range of recreationalist in the area that could be impacted remains to be seen. Chapter 7 will discuss management and policy implications of jellyfish blooms in reference to the findings of this and the previous chapters.

CHAPTER 7

DISCUSSION AND CONCLUSIONS

7.1 Introduction

This chapter concludes the thesis by discussing the findings from the methodological and empirical Chapters in terms of the research questions outlined in Chapter 1 and the review of the literature in Chapter 2. This chapter discusses what has been achieved in relation to current knowledge of jellyfish populations in the Northeast Atlantic, potential socioeconomic impacts, actions required in response to blooms and how further research could build upon the findings that have been presented. Section 7.2 discusses the output of the GIS maps that represent how suitable certain characteristics of Northeast Atlantic waters are for jellyfish populations and how this could change in the future and relates this to existing debates on gelatinous futures of marine environments. Section 7.3 then discusses the bloom impact projections for fishery and seaside tourism activities in the Northeast Atlantic, considering how blooms would interact with these industries, the associated socioeconomic costs as well as future research that could build upon the findings presented in this thesis. Section 7.4 then examines relevant management suggestions in relation to reducing the effects of jellyfish blooms on coastal and marine activities; the management implications are also discussed. Section 7.5 concludes the chapter by assessing the general contributions to knowledge from this thesis, bringing together natural and social science methodologies, literatures and insights in relation to future jellyfish change.

7.2 Jellyfish Populations in the Northeast Atlantic

The first research question asked: what does existing knowledge of changes in the marine environment reveal about potential future jellyfish blooms across the Northeast Atlantic, based on their physiological thresholds / responses to the marine environment? The GIS maps that were developed as part of this research (Chapter 4) set about answering the research question by identifying areas in the Northeast Atlantic that could support jellyfish populations in the present day and how changes to key factors within the marine environment could increase or decrease these populations in the future. Categorisations of how environmental factors contribute towards changes in jellyfish reproduction (based on current physiological knowledge for each species) established specific areas within the Northeast Atlantic that could be more prone to future jellyfish blooming events. These enabled scenarios of future blooms to be considered in relation to fisheries and seaside tourism, which were examined through an ecosystem services approach.

The key findings of the research conducted to answer this question are:

1. the distributions of current suitability within the Northeast Atlantic defined by the GIS maps mostly coincided with current knowledge on the

distributions of actual populations, evaluated through comparisons with details of documented blooms (locations and seasonality of blooms),

2. several regions within the Northeast Atlantic could support large numbers of a variety of jellyfish species, based on water temperature, salinity and the prey index that was developed;
3. several areas were potentially suitable for bloomed populations (particularly off the coast of Britain and Ireland), including blooms of warmer temperate species such as *C. hysoscella*, (mainly in the Celtic Sea and south western waters during in summer), and blooms of more boreal species such as *C. capillata* (within northern and north-eastern areas such as the North Sea during spring),
4. for most of the species, a combination of increased prey availability and ocean temperature contributed to an area being identified as more suitable for jellyfish populations and blooms,
5. increases in future blooming events are a possibility, assuming certain changes in the marine environment occur (a combination of prey and temperature increases, with salinities remaining constant with present day conditions).

The GIS mapping also contributed to existing debates and discussions as to whether marine environments are heading towards a more gelatinous future. As discussed in Chapter 2, several publications within the literature mention that interactions between jellyfish blooms and people are being reported more often (e.g. Purcell *et al.* 2007). Reasons for the increased reporting include blooms becoming more common due to environmental change (Purcell, 2012), and fluctuations of jellyfish populations coinciding with increasing anthropogenic use of the marine environment (Condon *et al.* 2013). However, it has been argued such claims, are not based on long term jellyfish populations trends (Condon *et al*. 2012). Indeed, the need for recording bloom occurrences to produce time series data has been highlighted (Condon *et al*. 2012), as extensive historical data sets do not exist. It will take time before enough robust records are collected and collated about temporal variations of jellyfish numbers, bloom frequencies and their locations.

The methodology developed as part of this research contributes to this understanding by providing insights on the suitability for jellyfish populations in the present and the future, highlighting factors to be considered in relation to blooming events. The GIS maps were informed by the literature in relation to the most suitable conditions for jellyfish, highlighting suitable stretches of water for a variety of species across the Northeast Atlantic. They were based on how changes to environmental factors in relation to the physiological thresholds of different jellyfish species within the Northeast Atlantic would alter how suitable the area was for each species. The findings indicated that, based on changes to such thresholds, areas would become more suitable for jellyfish populations; these could increase within the Northeast Atlantic. The GIS maps produced in this research with the sensitivity analyses undertaken (Chapter 4, section 4.9), indicate that if rises in sea water temperature (within a reasonable limit, however such limits are unknown) and increases prey abundance were to occur concurrently, and salinity was to remain relatively consistent, bloom increases and interactions with anthropogenic activities could also increase further. In fact, water temperatures in the Celtic sea are projected to rise between 1.5°C and 5°C over the next 100 years (Philippart *et al*. 2011). Also, temperature increases within the North Sea during the last 40 years have been some of the most rapid on the planet and the area is vulnerable to further rises (Philippart *et al*. 2011). Such projections are greater than the difference between the varying thresholds (at what temperature survival, reproduction and reproduction that lead to blooms are possible) that were presented for each species in Chapter 4, used to examine if an area was suitable for a certain species. Such comparisons indicate that bloom increases could occur based on a certain range of future temperature changes, drawing upon the projections available and the current physiological data available on each species.

Interactions between factors characterising environmental change, and their effects on species' physiological thresholds, also require consideration. For instance, during an assessment of eutrophication (which could lead to increases in zooplankton species jellyfish are known to prey upon (Arai, 2001; Richardson *et al*. 2009)), Almroth and Skogen (2010) identified the entire south-eastern part of the North Sea as a problem area, due elevated nutrient levels and subsequent decreases in oxygen levels that have been recorded there. Such changes in the environment have been reviewed in the literature as favouring jellyfish and contribute towards blooms (e.g. Richardson *et al*. 2009).

7.2.1 Further Development

There are a number of ways in which the methodology could contribute further to knowledge about future jellyfish populations across the Northeast Atlantic, including addressing some of the limitations and challenges that emerged during the research (see also Chapter 4). Higher resolution versions of environmental data (including the temporal aspect) for each of the three environmental parameters (temperature, salinity and prey index) used for mapping jellyfish suitability areas could provide more accurate projections of the distribution of potential future jellyfish survival, reproduction and blooming events. However, as the marine environment is relatively stable (e.g. water temperatures do not fluctuate as readily as air temperatures) and jellyfish show plasticity to these factors (Nawroth *et al.* 2010), improvements in the resolution may have a limited effect on our understanding; nevertheless, assessment of this would be of scientific interest and relevance.

Another limitation was the paucity of detail on some of species-specific responses to environmental factors (particularly the prey index thresholds for which some assumptions had to be made). Improving knowledge on which thresholds in temperature, salinity and prey can support varying jellyfish populations would provide more accurate and detailed data that could be applied to the maps using the same GIS methodology as applied in this thesis.

It was also acknowledged in Chapter 4 (section 4.10.1) that other factors influence the jellyfish life cycle, including ocean currents (Licandro *et al.* 2010), water acidity (Richardson *et al.* 2009) and oxygenation (Purcell, 2001), nutrient levels (Perez-Ruzafa *et al.* 2002) and the exact location of hard structures (Holst and Jarms, 2007). A current lack of data on these aspects meant that they could not be incorporated into the GIS mapping for this thesis. It may be possible for some of these data to be obtained in the near future through lab studies (similar to the ones referenced in Chapter 4, section 4.2, e.g. Purcell *et al.* 2012) e.g. on effects of environmental factors to jellyfish reproduction. This would require resources, expertise and sampling effort, as well as corroboration through observational data through time. Information on factors that cannot be tested in a lab such as ocean currents that may contribute to blooms could be gained from tracking the movement of blooms in relation to ocean currents (Catapult, 2015). Incorporating the influence of these factors into the GIS mapping, alongside improvements in data resolution and more detailed data on temperature, salinity and prey abundance, would further improve the accuracy of the maps, to identify locations where changes to the marine environment and jellyfish populations could occur, and their potential effects on anthropogenic activities.

The GIS methodology applied in this thesis is transferable to other areas where similar data exists, and where analyses could be undertaken for understanding future changes to jellyfish distributions. For instance, the environmental data used in this study (including the continuous plankton recorder (CPR) data used to project the prey index (methods discussed in Chapter 3 section 3.3.1)) is also collected within Atlantic waters off the east coasts of North America where the stinging species *Chrysaora quinquecirrha* and invasive *Mnemiopsis leidyi* are native (Worms, 2017). Providing understanding on species like these in other geographical locations would further contribute towards discussion about future blooms and their frequencies, in conjunction with the findings from this thesis to expand on our understanding of jellyfish populations worldwide.

7.3 Bloom Impact Projections

This section reviews the research on interactions that could occur between blooms and coastal industries based on the information generated in the GIS maps, answering the second research question of this thesis: what would be the magnitude of the socio-economic impacts related to the tourism and fishing industries in the event of increased jellyfish bloom occurrence in the Northeast Atlantic? The GIS maps contributed to identifying areas suitable for jellyfish populations in proximity to locations characterised by high levels of commercial fishing and tourism that could potentially experience increases in blooming events in the future.

An ecosystem services approach based on the UKNEA (2011) framework was applied (Chapter 2) to value changes to ecosystem services and benefits to tourism and fishing at these locations. Scenarios were developed based on the locations, species and times of year that blooms could occur with a variety of established methods used to quantify impacts that would arise. Figure 7.1 indicates which services and benefits would be impacted by bloom, based on the research in Chapters 5 (fisheries) and 6 (tourism). In the Northeast Atlantic, it was concluded that blooms would impact provisioning and cultural benefits derived from the ecosystem services, not the services themselves (Fig 7.1). Jellyfish blooms were seen as an unexpected event within the ecosystem which would disrupt the fisherfolk and tourists in deriving benefit from ecosystem services. Depending on the activity in question, socioeconomic impact was either as a consequence of blooms impacting specific activities (e.g. trawling) or stopping certain activities from occurring (e.g. bathing) which also led to secondary impacts, (e.g. lost revenue for local businesses) (Fig 7.1).

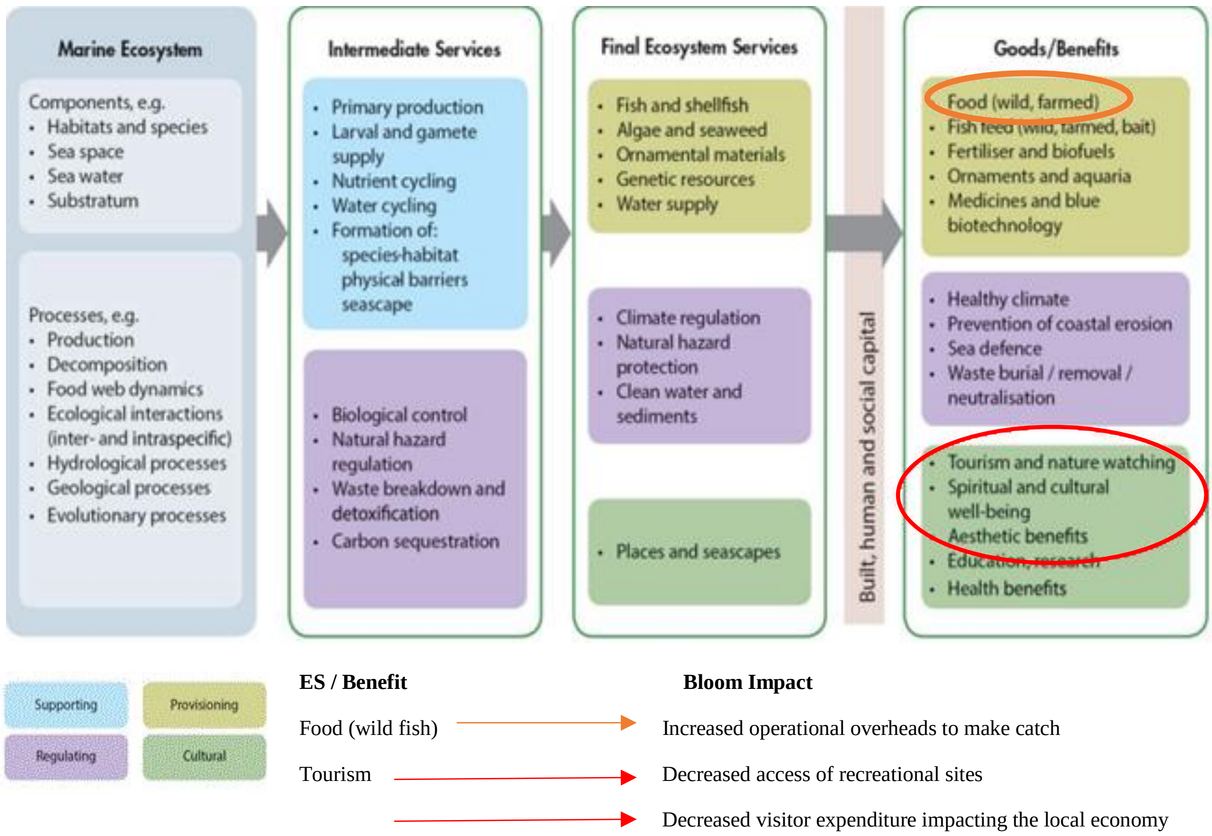


Fig 7.1 The classification of ecosystem services and benefits that can be derived from the Northeast Atlantic, adapted from the UKNEAFO (2014) (originally included in the thesis as Figure 2.1 in Chapter 2), which has been modified to give indications of which benefits would be impacted based on the research in Chapters 5 and 6. Red circles and arrows indicate impact to cultural services. Orange circles and arrows represent impact to provisioning services.

7.3.1 Fisheries

In terms of the fisheries, abundant jellyfish presence would affect fish caught for human consumption (as a benefit), although respondents did not envisage that there would be losses in catch. This contrasts with findings from studies in other geographical locations where blooms are more common (e.g. in the

Mediterranean, (Palmieri *et al*. 2014) and Asian waters (Uye 2008)). Additional costs would be incurred whilst catching fish under bloomed conditions. The main findings of this part of the research, presented in Chapter 5, were:

- bloom bycatch would be the primary impact on fishing, especially by large medusae species such as *R. pulmo*,
- bloom bycatch would clog nets resulting in less catch per haul,
- in response, fisherfolk would increase the number of trawls to compensate for reduced catch at a location, or avoid areas that contain a bloom,
- generally, fisherfolk based on different vessel types, using different fishing gear, reported the same impacts and responses,
- quantifiable impacts were calculated based on additional fuel use and additional time spent out to sea that would occur doing extra trawls or moving to alternative sites to maintain catch.

The adaptive behaviours indicated by fishermen suggest that the quantity of fish caught for human consumption would not decrease as a result of blooms. These responses however, suggest that fisherfolk would incur increased costs of making the catch during blooming events, with fuel costs being of particular relevance, in addition to the additional time required out at sea. The impacts of increased operational costs (particularly fuel consumption) on fishing communities has been reported by previous studies as affecting the viability of commercial fishing in the Northeast Atlantic (Abernethy *et al.* 2010). Abernethy *et al.* (2010) assessed the impacts of fuel increases that occurred during the years 2007 and 2008 (a period when fuel prices doubled) on fisheries in the Southwest of England (Newlyn harbour), using market data and interviews with skippers. It was found that fuel increases directly decreased vessel profits because of increased fuel costs and fish prices remaining consistent due to market price-setting. The consequences were lost income, diminished job security and decreased crew employment that threatened the viability of operations, with vessels that tow gear experiencing the greatest costs. Interestingly, respondents fishing with these types of vessels also indicated impacts from blooms in this study (Chapter 5). The fuel consumption increases outlined in Chapter 5 (section 5.6) could therefore be significant because in some instances they would seem to result in fuel consumption (and therefore cost) increases per trip that would exceed the fuel price increases reported by Abernethy *et al.* (2010) (e.g. the maximum distance pelagic trawlers >10m would travel to avoid blooms would result in 68% increase in fuel consumption per trip). If blooms were to persist over long time periods, the impacts could potentially be similar to the costs that occurred during times when world fuel prices were much higher. However, the research in this thesis also indicated that there was variation in the levels of fuel expenditure that could occur in response to blooms of the different species, which highlights the diversity among fishing vessels and within fishing locations, and differentiation of impacts of jellyfish presence in fishing waters.

7.3.1.2 Further Research

This study indicates that several aspects associated with the impacts of blooms on Northeast Atlantic fisheries would benefit from further research to improve the detail of the scenarios examined and the potential management suggestions deriving from these. One key aspect relates to improving engagement with fisherfolk before and during the study, to garner greater participation. Spending more time in the harbours and using different methods of approaching fisherfolk may increase participation in the study. During field work, successful contact was made with potential respondents using social media (see Chapter 3, section 3.5.1). Dedicating more time to engaging with potential respondents prior to field work instead of approaching them directly could increase the number of participants to the study and decrease the amount of survey rejections (e.g. pre-arranging interviews during times that are convenient). Also, survey responses could be supplemented by in-depth interviews, if participants to the study had the time and inclination to reflect on their fishing practices, to garner more contextualised understandings of how participants may view future fishing conditions, constraints and opportunities. Both approaches could provide further understanding of the consequences of blooms on fishery operations in the Northeast Atlantic, such as whether bycatch would be the only impact or if there would be a greater range of interactions in addition to those mentioned by the respondents in the study. This consideration stems from the fact that during the survey design, a greater range of impacts and responses to blooms was expected compared to what was actually reported during the fieldwork, based on the range of impacts reported on fisheries in other geographical locations (see survey design methodology in Chapter 3).

The initial aim was to identify the range of impacts that blooms could cause and elicit initial indications of the magnitude of the socioeconomic cost of each impact due to the paucity of studies of bloom impacts in the Northeast Atlantic.

However, it was not anticipated that bloom bycatch would be reported (almost) exclusively by respondents. This was an interesting finding, that suggests that further studies could explore whether such views emerge from other fishing areas as well, and if so, elicit more in-depth information on specific impacts, for instance, understanding some of the practices that contribute to fuel expenditure and costs, which would contribute towards more informed impact projections. For example, asking how many trawls each vessel does on a fishing voyage and how long each trawl lasts for, to obtain more specific information on the cost per trawl and how this could vary if fishermen did additional trawls during jellyfish blooms.

Other avenues of further study could also include repeating the study during times of different fuel costs, for instance, as Abernethy *et al.* (2010) stated that fuel costs alter the decisions of skippers whilst fishing (e.g. forcing them to fish closer to shore), which could have other implications for the industry. Carrying out research at different times of the year, such as during a jellyfish bloom, may elicit different responses based on immediate experience of the event. As the ways in which blooms could impact fisheries were fewer, according to responses in this study, compared to other studies undertaken in areas where blooms are more common, consideration must be given on how respondents perceived the scenarios they were provided (see section 7.3.3).

7.3.2 Tourism

In terms of seaside tourism, this research has found that the benefit of recreation within coastal ecosystems within the Northeast Atlantic would be diminished by bloom presence, which would bear direct welfare implications on visitors to the coasts as well as secondary impacts on the local economy (Fig 7.1). The main findings from the research were:

- bloom presence would decrease the recreational use value of coastal ecosystems (beaches) due to negative interactions with both stinging and non-stinging jellyfish, impacting visitor welfare,
- both water based, and land based recreational activities would be affected by blooms, but the water-based would incur proportionally greater costs despite land recreation being more common,
- stinging jellyfish would have the greatest impacts,
- fewer beach visits would be made to the coastal ecosystem and seaside towns as a consequence of bloom increases,
- consequently, tourism expenditure in seaside towns would decrease, impacting the local economy,
- such impacts already occur in the Northeast Atlantic, although these are not widely reported in the literature.

Generally, these findings were consistent with studies in the literature in terms of the impacts and response to blooms of coastal tourists, albeit in other geographical locations; there is a paucity of this type of work in the Northeast Atlantic. Chapter 2 (section 2.2.3) discusses responses and costs of blooms that have occurred across the Mediterranean coasts of Israel (originally reported by Ghermandi *et al.* 2015), for example; in their study a common response of recreational users of the coastal environment was to avoid the area during blooms, which was also reported in this research. Both Ghermandi *et al*. (2015) and the research in this thesis use inferred and stated valuation methods for cost projections of blooms within the respective case study locations. However, direct comparison cannot be made because of the time scales considered in the studies for bloom impacts. The research in this thesis is based on survey responses to understand the views of individual users of the marine environment each day a bloom would persist, and up scaled the impact based on the amount of days a typical bloom has been reported to occur in the area (Chapter 6 sections 6.5 and 6.6). On the other hand, the Ghermandi *et al*. (2015) study projected impacts and responses over a whole year, extended to the entire Mediterranean coast of Israel because the work sampled several case study sites. The work in this thesis focussed on a specific case study as it aimed to generate an initial understanding of blooms in the area as it could potentially experience more events in the future. Interestingly, despite some methodological differences between the studies, similar findings were obtained, as both studies documented similar responses to blooms (e.g. stopping bathing) resulting in similar mechanisms of socioeconomic cost (e.g. decreased ecosystem access value).

One indication from this study is that it is unlikely that the economic costs and welfare impacts coastal visitors in the Northeast Atlantic will be as severe to those in other parts of the world where blooms are currently more common. One of the reasons for this, is the greater influence of seasonality on jellyfish suitability across the Northeast Atlantic described by the GIS mapping (Chapter 4). It was suggested that the medusae considered in this research would not persist in the Northeast Atlantic as long as they currently do in areas such as the Mediterranean. Also, this study did not generate evidence suggesting that blooms will become a consistently regular feature (e.g. annual occurrence) of Northeast Atlantic waters like they are in other regions; therefore, it is possible that the impacts reported in this study would be more short term. However, the magnitude of impacts and costs within the Northeast Atlantic during such periods would still be significant due to the amount of seaside visitors who would change their recreational activities due to bloom presence which included avoiding effected areas.

7.3.2.1 Further Research

The study undertaken here also points to some fruitful avenues of further work. Drawing inspiration from other studies which generated bloom costs over larger geographical areas eliciting responses and calculating socioeconomic costs across more than one location, a sample of multiple case studies across a larger area over a longer time period across the Northeast Atlantic could be attempted. This could be achieved by repeating the survey in multiple locations at different times of the year, so a more complete picture of the total annual costs can be made. In addition, the scaling up of the costs per person, per day could be improved. Rather than relying on estimates from key actors, counting the number of beach users each day of the field work and averaging it out would provide more rigorous estimations of the number of beach users on a typical day, as well enabling the incorporation of ranges (through confidence intervals) that could use in the upscaling of the total costs projections.

7.3.3 Reflection on the Responses to Bloom Scenarios

Consideration is due in regard to the results on both fishing and tourism in this research on how respondents engaged with the hypothetical scenarios of blooms within the ecosystem that they benefit from. It is reported in the literature that most people initially respond to elicitations about the uncertainty and risk emotionally, 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 (Slovic *et al*. 2004). It is only after a while that more logical responses are enacted when analytical modes of thinking engage (Slovic *et al*. 2004). When blooms were introduced to respondents in both fishing and tourism contexts (Chapters 5 and 6), the influence of such ways of thinking in terms of impact and response must be acknowledged. There would seem to be some evidence from the manner in which participants in the studies responded to the surveys which suggests both modes of response were enacted. For example, the fishermen focussed primarily on the issues they would face in order to make their catches, which were based on issues they currently experience.

As discussed in Chapter 5 (section 5.4), bycatch is a present-day issue that negatively impacts fishery operations and could have been the immediate association they made in terms of bloom interactions. Therefore, asking respondents to discuss hypothetical issues and behaviours potentially led to underestimations in the range of impacts that could occur as the current day / experiential expectations might have been more salient to them; compared to the few studies (e.g. Palmieri *et al.* 2014) that have assessed the costs of historical blooms in other locations (see Chapter 2). It is also possible that people had difficulty envisaging a different future as thinking about aspects one is not familiar with is actually quite hard. Potentially longer interviews with individual respondents could distinguish any differences between experiential and more analytical responses to blooms, and those experienced versus imagined (hypothetical). Further research could also explore the impacts of the added overheads associated with blooms could have in terms of the health of crew members. During surveys, a determination to achieve fishing quotas, emerged (e.g. fishermen were willing to travel long distances to avoid blooms). It is possible that the determination to make catch takes precedence over considerations of the impacts certain actions would have. However, it is possible this type of research may be challenging due to the sensitivity associated with this.

In terms of the tourism respondents, an almost opposite experience occurred in relation to elicitation of hypothetical future responses. Blooms were not an obstacle, rather they were seen as a danger (most immediate associations with jellyfish deduced from the survey responses was their ability to sting even though many of the species considered did not possess potent stings, see Chapter 6 section 6.4). The most commonly reported response was to either avoid beaches or avoid the location. If further assessment of more analytical thinking patterns (that were likely not captured within the short surveys) in relation to what a jellyfish bloom may entail compared with the immediate associations (that likely influenced respondents), then the bloom responses that were reported could change. In other words, once the immediate association of risk makes way for more conscious thought, would alternative responses be made to what was reported during the surveys. Potentially, education and information systems could therefore mitigate individuals' behaviours in relation to blooms (tentatively suggested in Chapter 6); however, from the results of this study, this would require testing with people frequenting beaches with jellyfish. This study suggests that improved understanding of people's experiences of jellyfish is required so that they could be alerted to which type of jelly occurs on a particular day, and possible responses to this. However, there are also other aspects (e.g. how willing are beach recreationists to share the coasts with a bloom, regardless of whether they can sting or not) that will affect whether people bathe or want to be at the beach. Based on these conditions, the responses received, and the projected costs derived in this study provide an indication of future bloom impact and potential future scenarios as bases for future coastal management and decision making. When considering bloom management, consideration of both experiential and analytical thought processes of users of the marine environment in their responses and behaviours towards jellyfish blooms is required to inform and underpin decision making, which the following section is dedicated to.

7.4 Mitigating the Impacts of Jellyfish Blooms

The final research question was: what are the possible management and policy options that would address the socio-economic impacts of future bloom changes in the Northeast Atlantic? This section makes recommendations in relation to the findings of Chapters 4 (GIS mapping), 5 (investigation into impacts of blooms on fisheries) and 6 (investigation into impacts of blooms on tourism).

7.4.1 GIS Mapping

From the GIS mapping of locations that could be suitable for jellyfish blooms, the following recommendations can be made:

- Develop the methodology underpinning the GIS mapping to include higher resolution data and interactions, to further identify scenarios of bloom impact.

The more accurate and detailed the spatial and temporal information available (discussed in section 7.2) that may be included in refined versions of the mapping, perhaps integrated with other existing models, the more effective the maps will be at projecting blooms; these could then become more useful aids for decision makers on locations and impacts of future blooms. Further development (suggestion in section 2.2) would also contribute to the discussion on bloom increases in the absence of historical records of jellyfish populations to generate an understanding of changes to the marine ecosystem that they can cause. It is the opinion of the author that it will never be possible to make short term forecasts of bloom occurrences similar to a weather report, but accurately identifying bloom prone areas and the seasons they are most likely to occur, can enable management steps to be made, as opposed to responding to events when they occur.

- Based on the suitable areas for jellyfish, identify all the locations across the Northeast Atlantic where impacts similar to the ones examined in the case studies in this research, could occur.

Any similarities between locations of fisheries and seaside tourism in waters that could experience blooms, with the case studies examined in this research, could give initial indications of locations where further study would be appropriate. Generally identifying locations across the entire area (e.g. Northeast Atlantic) that was mapped would also give an indication of the scale of impact that could occur as well as locations where management of impacts could be required.

- Restrict eutrophication in waters suitable for species known to impact fisheries and tourism.

Of the environmental changes that contribute towards blooms, localised prey abundance spikes caused by eutrophication could be restricted (OSPAR, 2017). Within the Celtic Sea, eutrophication is limited mainly to the Bristol Channel and estuaries including Liverpool Bay (Carstensen *et al*. 2001) but large sections of the North Sea experience eutrophication issues (Almroth and Skogen, 2010), particularly within coastal areas (OSPAR, 2017). Some of these locations (including the case studies in Chapters 5 and 6) could be suitable for a number of groups of jellyfish capable of impacting fisheries and tourism; limiting eutrophication could contribute to reducing abnormal populations and their impacts.

- Where environmental data exist, apply the mapping methodology to other locations around the world perceived to be experiencing jellyfish increases.

Understanding of potential jellyfish populations in other geographical locations could further contribute to knowledge as to whether future jellyfish bloom increases are a possibility around the world, particularly if any similarities occur between locations, as a more general picture of bloom requirements are formed. The methodology could also suggest further locations that could be impacted as well as the management implications.

7.4.2 Fisheries

In terms of the research on the fishing industry and blooms within the Northeast Atlantic, the following recommendation can be made:

- Provide information for vessel skippers on the different fuel cost scenarios that fishing in bloomed waters could lead to.

A main finding that arose from the surveys with fisherfolk based in Brixham and Newlyn was that depending on the interactions that occurred with blooms, certain responses that fisherfolk make would lead to different levels of added fuel cost. When comparing how far vessels were willing to travel to avoid blooms with the costs of additional trawls, it became evident that doing more trawls would result in less fuel cost up until a point. For vessels >10m doing 4 additional trawls would cost more than the maximum distance they were willing to travel to avoid blooms. For the vessels <10m it was 5 trawls (projections were made in Chapter 5, section 5.6). Demersal fisherfolk reported they would only do additional trawls rather than moving to alternate locations, therefore providing them with costs per trawl projections would inform them of bloom impact, which could result in considerations about changes in fishing decisions and behaviours. The fuel cost per mile increase in relation to blooms (presented in Chapter 5, section 5.6) could also influence skippers when making decisions whilst fishing during blooming events. Such information could result in a variety of different actions, such as those reported by Abernethy *et al.* (2010), who provided evidence to suggest that during times when fuel prices and consumption are increased, behaviours such as fishing closer to port occur.

- Investigate how many additional trawls blooms bycatch would actually cause and compare with the costs of the maximum distance fisherfolk were willing to move to find unaffected fishing sites.

To increase the applicability of recommendations, an understanding of how many additional trawls to compensate for any lost catch per trawl during a blooming event is required. If the number of trawls goes beyond 4 for the vessels >10m or 5 for the vessels <10 to achieve the same amount of catch then the decision to move to alternate locations before deploying gear should be made as the fuel costs would be lower, even if vessels were to travel the maximum distance reported to find unaffected sites. However, for such information to be generated research would have to investigate bloom bycatch when it actually occurs to understand how many additional trawls would be required and changing circumstances may also have additional influence on how many trawls are required.

- Continue to investigate how blooms would impact the variety of fishermen within the Northeast Atlantic.

It was unclear from the research whether fishermen were able to envisage the full range of different impacts that could occur in hypothetical futures; bloom bycatch and some stinging interactions were the most frequently reported impacts. Understanding if a greater range of impacts and responses would occur, could provide additional insight on how to mitigate changes to marine ecosystems caused by blooms and / or fishing practices. A study where bloom scenarios, potential impacts and responses are introduced to fishermen could provide more information as to whether issues other than bycatch would occur by comparing it to this research (where only blooms were introduced to respondents, not impacts and responses). Further research could also examine a greater variety of vessels than this research as a several other vessel types were not part of this study (e.g. shellfish vessels as fieldwork did not commence during the correct season) and repeating this research with these types of fishermen could further result in other different suggestions of management requirements or reinforce current findings.

7.4.3 Tourism

When considering the investigations into the impacts that blooms may have on coastal tourism within the Northeast Atlantic, the following recommendations can be made:

- In the event of blooms, deploy anti-jellyfish nets to preserve use value of the coastal environment for recreational users.

Specifically, beach recreation and bathing (typically done by families during the summer holidays) would benefit most from such nets in the event of blooms of any of the species that where considered in the study. In this study, the contingent valuations (projected through willingness to donate to an anti-jellyfish net scheme) of these users of the coasts were greater than their welfare loss projections, indicating that such as scheme would be of value.

- Funding for the anti-jellyfish nets through public donations.

The contingent valuation study revealed that there would be public support for the nets and also generated projections of potential funds that could be raised. However, the study indicated that individual donations would be minimal as the majority of donations would be made through minor payment vehicles such as of collection buckets, making it debateable if enough would be raised despite what the survey responses suggest. Different payment vehicles could be explored in further work as well as other funding schemes. For instance, public-private partnerships are a potential avenue of interest given that public and private bodies need visitor numbers to be maintained. Secondary impacts of blooms would impact the local economy due to less visitor expenditure caused by jellyfish deterring seaside visitors from staying in a seaside resort. However further research would enable the exploration of the viability of different options.

- Investigate the viability of jellyfish nets on Northeast Atlantic coasts.

Exploration is required as to whether it is physically possible to create jellyfish free pools and identify locations where nets could be deployed within locations that could experience blooms. Using the case study in Chapter 6 (the four beaches along the St Ives coastline), in St Ives, Porthgwidden and Porthmintser beaches could initially be suggested as locations for anti-jellyfish nets because they were visited by beach users who mainly engaged in activities that require separation from jellyfish (e.g. relaxing on the sand and bathing). Also, few activities that would be impacted by nets (discussed below) occur there. The two beaches also occur in generally more sheltered areas, decreasing the chances of damage occurring to the nets. There is also greater tidal movement off the coasts of St Ives compared to the locations where nets have been successfully implemented in the Mediterranean (Pugh, 1996), so there is the additional challenge of keeping the net functional exist and confirming that medusae do not enter the jellyfish free pools. These challenges would potentially make the scheme expensive and further research would provide projections of how much a scheme like this would cost and whether the donations reported in this study would cover the costs. An evaluation of the costs of implementation vs the benefits that it would bring would be required.

- Investigate further the effectiveness of education as a contributor to changing behaviours in bloom situations.

Some evidence emerged during the research that suggested beach recreationalists with information, experience and knowledge of jellyfish (particularly of the non-stingers) made them more resilient to the welfare impacts that were projected. However, suggestions were limited, and further research could result in the development of further mitigation suggestions. For example, the research could be repeated, but with two distinct groups of respondents, one that has been provided with education about jellyfish and another with no information. Comparing the future response to hypothetical blooming events between these groups would then give further indications as to whether educating the public about jellyfish could make them more resilient to the impacts projected in this thesis.

- Develop other means of mitigating impacts of blooms for users who would not be protected by anti-jellyfish nets.

Not all recreational users of the coastal environment would support a net project. Despite the evidence presented in Chapter 6 (section 6.7), that such a project would be used by a proportion of beach users, there are suggestions that it could have negative impacts. For example, 30% of respondents who discussed the nets during the surveys, reported that they were unnecessary, with 3% reporting that management would be important, but not in the form that was suggested. Those that were against net projects, reported that creating pools within the inshore area was “interfering with nature,” expressing concern for marine wildlife (in some cases this included concern for jellyfish) with others reporting that they needed more evidence that the nets worked. Other arguments include that during times when jellyfish are not present, the nets could restrict use benefits of the coastal ecosystem unnecessarily by separating the beach and the inshore area. There could therefore be times when bloomless waters are needlessly separated, impacting water-based recreation such as water sports that require areas bigger than the anti-bloom pools. It could also be argued that the nets would also unnecessarily impact the aesthetic value of the coast, but the impacts of this require further research. These issues would be particularly evident for surfers, who require access to large areas of water that nets would separate. Nets would therefore not achieve the aim of maintaining the use value of the beach for surfers. Due to this consideration, one recommendation to be considered is that no nets are placed on Porthmeor beach (surfing beach at St Ives) where all surfing activity occurs. The only option currently available to surfers in the event of closed beaches (a scenario that could occur it stinging jellyfish were to blooms), would therefore be to travel to other locations. However, in the event of non-stingers occurring and beaches remaining open, management of bloom impacts could still be achieved for surfers. Instead, information about jellyfish that are safe to surf amongst could act as effective management. As the respondents in this study were less likely to avoid the area during surveys when large numbers of non-stinging species were present, perhaps surfers would engage in the same behaviours and continue to surf, if they were assured they were not in any danger, particularly as they wear wetsuits that offer additional separation form them and blooms. Again, further research would be required to understand if surfers would be willing to surf in waters that contain a bloom of non-stingers or if the prospect of sharing waters with any jellyfish would be enough to trigger behaviours such as avoiding St Ives. There would also be inherent difficulty in making these decisions as stinging and non-stinging species are known to occur in the same locations at similar times.

7.4.4 General Recommendations

More generally, the following recommendations can be made from this study:

- Transfer the methodologies of the thesis to other case study locations.

Further research could explore whether the findings in this study could be relevant to other locations at risk from future bloom increases, due to the large areas of jellyfish suitability across UK waters (revealed by the GIS maps in Chapter 4). This included the locations of the majority of the principal seaside towns (seaside towns with an economy reliant on tourism described by Beatty *et al.* 2010, referenced in section 6.2) and several large fishery harbours (e.g. Plymouth) that also coincide with increased jellyfish suitability. The application of the methodologies in this thesis could potentially be used to assess what actions specific users of the marine environment at other locations would undertake in response to blooms based the responses reported in St Ives, Brixham and Newlyn. In terms of recreation, an initial example is Newquay, which is also renowned for beach recreation and surfing. An example of transferable methodologies includes the investigation into the surfers who would avoid a beach location in response to the bloom scenarios to estimate costs that would occur. Additional information would be required to estimate costs specific to other locations, such as estimation of the number beach users and the number of surfers. In terms of the fisheries Plymouth harbour could be a potential study site due to the locations the vessels fish in relation to potential jellyfish populations.

- Investigation of potential impacts on the aquaculture industry.

One industry where this research unsuccessfully attempted to examine the impacts of blooms within the Northeast Atlantic, was aquaculture. As discussed in Chapter 3 (section 3.6) data collection was restricted due to a number of commercial and sensitivity issues. However, due to the successes of this research with the fishery and tourism case studies, it can be recommended that similar research could be done with aquaculture, particularly as there are examples of successful collaboration between academics and the UK aquaculture industry (e.g. Kintner and Breirly, 2018). Perhaps, an institution that has an existing relationship with the Scottish aquaculture industry (the location of pens that could coincide with large stinging species (e.g. *C. capillata*) known to impact the industry) would have more success in approaching aquaculturists to survey. Any future scenarios of impacts and cost that would develop form surveys could then be linked to the requirements of the industry in terms of mitigating bloom impacts (e.g. improving technology that stops stinging interactions between jellyfish and finfish discussed in Chapter 2)

7.5 General Contribution to Knowledge

This thesis has made several contributions to the field of jellyfish bloom research. It has contributed to the wider understanding of the causes of blooms, future jellyfish populations and bloom impacts. It has also suggested further ways to improve such knowledge (e.g. using physiological information on individual species to project how populations will change in the future which is required due to an absence in long term records of jellyfish populations). It has also provided insights on how industries in the Northeast Atlantic may change in response to blooms and projected the impacts that could be incurred which is comparatively understudied compared to locations where blooms are more common (e.g. the Mediterranean).

Generally, it can be suggested that the impacts in the Northeast Atlantic may not be as far reaching as in areas where blooms are a more common feature of coastal waters, but it has been acknowledged that caution is required when making such comparisons as the scenarios in this study were hypothetical, where the literature reports responses and costs after a blooming event has occurred. There is also still large uncertainty about the mechanisms and interactions regulating jellies and their blooms in the area. However, from the specific impacts and costs that were identified, some suggestions have been made of how to mitigate issues, specific to Northeast Atlantic waters and how to understand them further. The main component of this investigation was that it was an initial attempt at using interdisciplinary research to assess jellyfish blooms in the Northeast Atlantic. It integrated methods from the natural and social sciences as well as environmental economics to identify where impacts could be incurred and to then quantify the magnitude of such socioeconomic costs for the consideration of management requirements. Looking forward, such approaches have an important role to play in understanding jellyfish populations and their impacts more generally, so that further management consideration can be made, particularly in areas where understanding is currently lacking. To be able to achieve a better understanding of the interactions between marine users in the Northeast Atlantic and jellyfish, new data have been collected from case study sites and examined using established techniques and approaches. Although the research has used well established techniques, it is novel in the way that it has brought them together to make projections of impact in response to hypothetical scenarios associated with a taxon of species that are currently understudied in the area. The research demonstrated how findings from the natural sciences and social sciences can improve information for management and policy suggestions. The GIS maps on their own suggest many different activities could be at risk (many locations of fishery and tourism activity could occur in the same locations as blooms). By combing the GIS map outputs with the survey responses and economic impacts projections, more in-depth understanding has been obtained, highlighting the importance of the circumstances of the varying users of the marine environment that could incur socioeconomic costs from blooms, and their difference to those experienced and expected by similar users in other geographical locations. This research has demonstrated the utility of applying an ecosystem services approach to the valuation of the impacts of jellyfish blooms because it developed information that included the locations of where blooms could cause impacts, what the impacts of blooms would be, quantifiable indications of the scale of such impacts and the resources required to maintain benefits that humans derive form the environment. This has been achieved for the Northeast Atlantic, an area where comparatively understudied in terms of jellyfish blooms occurrence and their impacts.

7.6 Concluding Remarks

The overall rationale of this study was to generate an initial understanding of the future relationship between blooms and people in the Northeast Atlantic, as jellyfish populations and their impact in the area are understudied compared to other geographic regions (where blooms are currently more common). The main focus of this thesis was to improve the understanding of the potential distributions of large jellyfish populations, including the potential for blooms, identifying locations that may be impacted, the magnitude of any socioeconomic consequences and any management considerations in response to evidence presented in the literature that blooms may increase in the area. The research has achieved these aims and projected several impacts that could occur (including suggestions of magnitude), ranging from losses of all benefits of the marine ecosystem to added costs associated with an activity under bloomed conditions. Although the magnitude of the impacts is not comparable with other locations where bloom impacts have been quantified (due to seasonality and the context of the studies), the ways in which blooms would cause such impact were comparable. Some similarities were reported (e.g. the way tourists would avoid bloomed coasts) as well as a few differences (e.g. the differences in what gear damage to fishing equipment would be caused in the Northeast Atlantic compared to what has been reported in the Mediterranean) in response to blooms by users of the marine ecosystem in different regions, leading to suggestions of future research to assess the discrepancies (e.g. do similar industries in different geographic locations interact differently with blooms or are there more methodological considerations to be made). As impact was projected (in some cases significant impact), management suggestions have been made which could potentially preserve the use value of marine ecosystems if blooms were to occur.

The research has shown that a case study approach is effective at exploratory investigations, as the responses of individuals who would be affected by blooms in the Northeast Atlantic have been achieved in a way that a more national assessment could not, allowing for hypothetical responses to bloom scenarios to be analysed. The individual impacts have been based on responses of users of the marine environment if they were to experience blooms in each case study, enabling the subsequent per person impact to be scaled up to provide indications of the magnitude of socioeconomic costs that could occur within the Northeast Atlantic. The research has also demonstrated the value of using social and natural science approaches in an interdisciplinary fashion as it has emphasised a diversity of findings. The combination of the understanding of changes to the marine environment brought about by blooms and the responses of society to them offer useful insights for managers and policy makers on where impacts could be incurred, who will incur impacts and a comparison of the value of protecting certain activities compared to potential management costs. Studying impacts in terms of ecosystem services has contributed to these findings further because it enabled the valuation of welfare (that doesn't have standard market value) as well as market goods, highlighting how blooms could impact both. The valuations in terms of ecosystem services and benefits (both use value and non-use value) allowed for more informed projections of the total impact of blooms in the case study locations to be made, which were then used to suggest implications within the Northeast Atlantic as a consequence of jellyfish blooms.

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APPENDIX A

CONTRIBUTIONS OF LITERATURE SOURCES TO SPECIES THRESHOLDS

A) The thresholds deduced form the OBIS species pages

	Species	Threshold	Contribution	
			SST⁰C	**PPT**
OBIS	*A. aurita*	Below Survival	<5	<10
		Survival	5	10
		Reproduce	10	30
		Bloom	15	35
	P. noctiluca	Below Survival	<5	<30
		Survival	5	30
		Reproduce	10	31
		Bloom	15	35
	C. capillata	Below Survival	>16	<25
		Survival	16	25
		Reproduce	14	30
		Bloom	10	35
	R. pulmo.	Below Survival	<14	<30
		Survival	14	30
		Reproduce	15	36
		Bloom	20	36
	C. hysoscella	Below Survival	No data	No data
		Survival	No data	No data
		Reproduce	No data	No data
		Bloom	No data	No data
	C. lamarkii	Below Survival	<16	No data
		Survival	16	No data
		Reproduce	14	No data
		Bloom	10	No data
	P. physalis	Below Survival	<2	<30
		Survival	2	30
		Reproduce	15	31
		Bloom	20	35

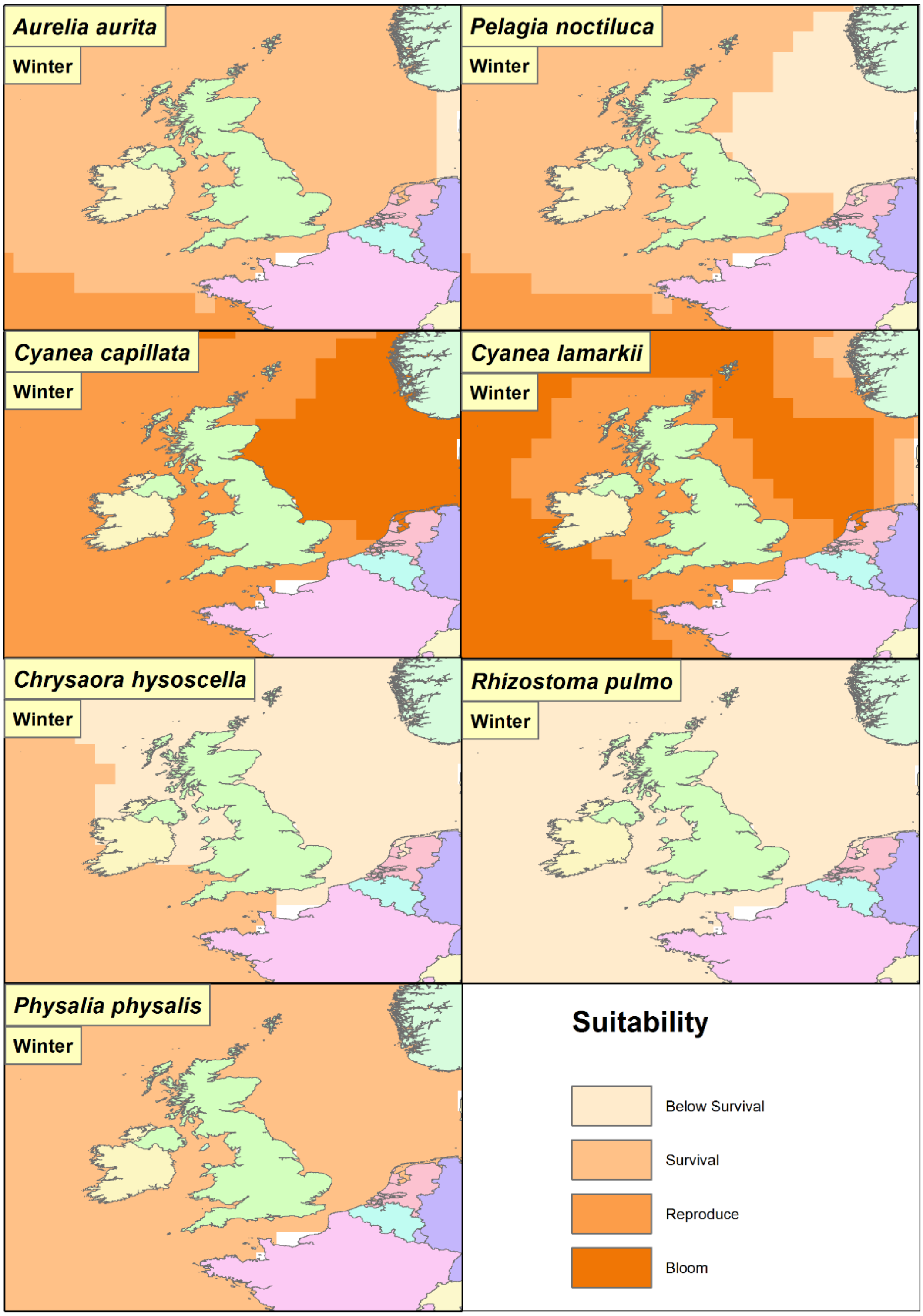
B) Specific adjustments to OBIS thresholds based on the literature search of specific studies on physiological responses to the environment by jellyfish medusae.

Source	**Species**	**Threshold**	**Adjustment**
Lucas (2001)	*A. aurita*	Survival Temperature	Confirmed to be 5^0C
		Survival Salinity	Changed to 17^0C
Purcell (2007)	*A. aurita*	Reproduction Temperature	Changed to 13^0C
Holst and Jarms (2010)	*C. capillata*	Below Survival Salinity	Confirmed to be less than 25 PPT
		Survival Salinity	Confirmed to be 25 PPT
		Reproduce Salinity	Changed to 32 PPT
		Bloom Salinity	Confirmed to be 35 PPT
	C. lamarkii	Below Survival Salinity	Confirmed to be less than 25 PPT
		Survival Salinity	Confirmed to be 25 PPT
		Reproduce Salinity	Changed to 32 PPT
		Bloom Salinity	Confirmed to be 35 PPT
	C. hysoscella	Below Survival Salinity	Set to below 20 PPT
		Survival Salinity	Set to 20 PPT
		Reproduce Salinity	Set to 32 PPT
		Bloom Salinity	Set to 36 PPT
	A. aurita	Survival Salinity	Confirmed to be 5 PPT
Purcell *et al.* (2012)	*R. pulmo*	Below Survival Salinity	Set to below 14^0C
		Survival Salinity	Set to 14^0C
		Reproduce Salinity	Set to 15^0C
		Bloom Salinity	Changed to 21^0C
	A. aurita	Reproduce Temperature	Confirmed to be 13^0C+
	C. hysoscella	Reproduction Temperature	Confirmed to be above 14^0C
	C. lamarkii	Reproduction Temperature	Confirmed to be less than 15^0C
Pascual *et al.* (2014)	*A. aurita*	Reproduce Temperature	Confirmed to be 14^0C+
Morand, (1987)	*P. noctiluca*	Survival Prey Index	Confirmed to be 5
	A. aurita	Survival Prey Index	Confirmed to be 5
Doyle *et al.* (2008)	*P. noctiluca*	Reproduce Temperature	Changed to 12^0C
		Bloom Temperature	Confirmed to be 15^0C
Rosa *et al.* (2013)	*P. noctiluca*	Reproduce Prey Index	Confirmed to be 40
		Bloom Temperature	Confirmed to be 15^0C+
Lilley *et al.* (2014)	Small medusae	Survival Prey Index	Set to 5
		Reproduce Prey Index	Set to 40
		Bloom Prey Index	Set to 60
Fancett, (1988)	Large medusae	Survival Prey Index	Set to 30
		Reproduce Prey Index	Set to 60
		Bloom Prey Index	Set to 100
Brewer, (1989)	*C. lamarkii*	Survival Prey Index	Set to 15
Purcell, (2003)	*C. capillata*	Below Survival Prey index	Confirmed to be <30
Perez-Ruzafa, (2002)	*R. pulmo*	Survival Prey Index	Set to 40
Lilley *et al.* (2009)	*R. pulmo*	Survival Prey Index	Confirmed to be to 40
Fuentes *et al.* (2011)	*R. pulmo*	Survival Salinity	Confirmed to be 30 PPT
		Survival Temperature	Confirmed to be 14^0C
Sparks *et al* (2001)	*C. hysoscella*	Below Survival Temperature	Set to $<10^0$C
		Survival Temperature	Set to 10^0C
		Reproduce Temperature	Set to 15^0C
		Bloom Temperature	Set to 16^0C
Flynn and Gibbons, (2007)	*C. hysoscella*	Survival Prey Index	Set to 30
Holst, (2012)	*C. capillata*	Reproduce Temperature	Changed to 15^0C
	C. lamarkii	Reproduce Temperature	Changed to 15^0C
	C. hysoscella	Survival temperate	Confirmed to be 10^0C
Purcell, (1984)	*P. physalis*	Prey index Survival	Confirmed to be 30

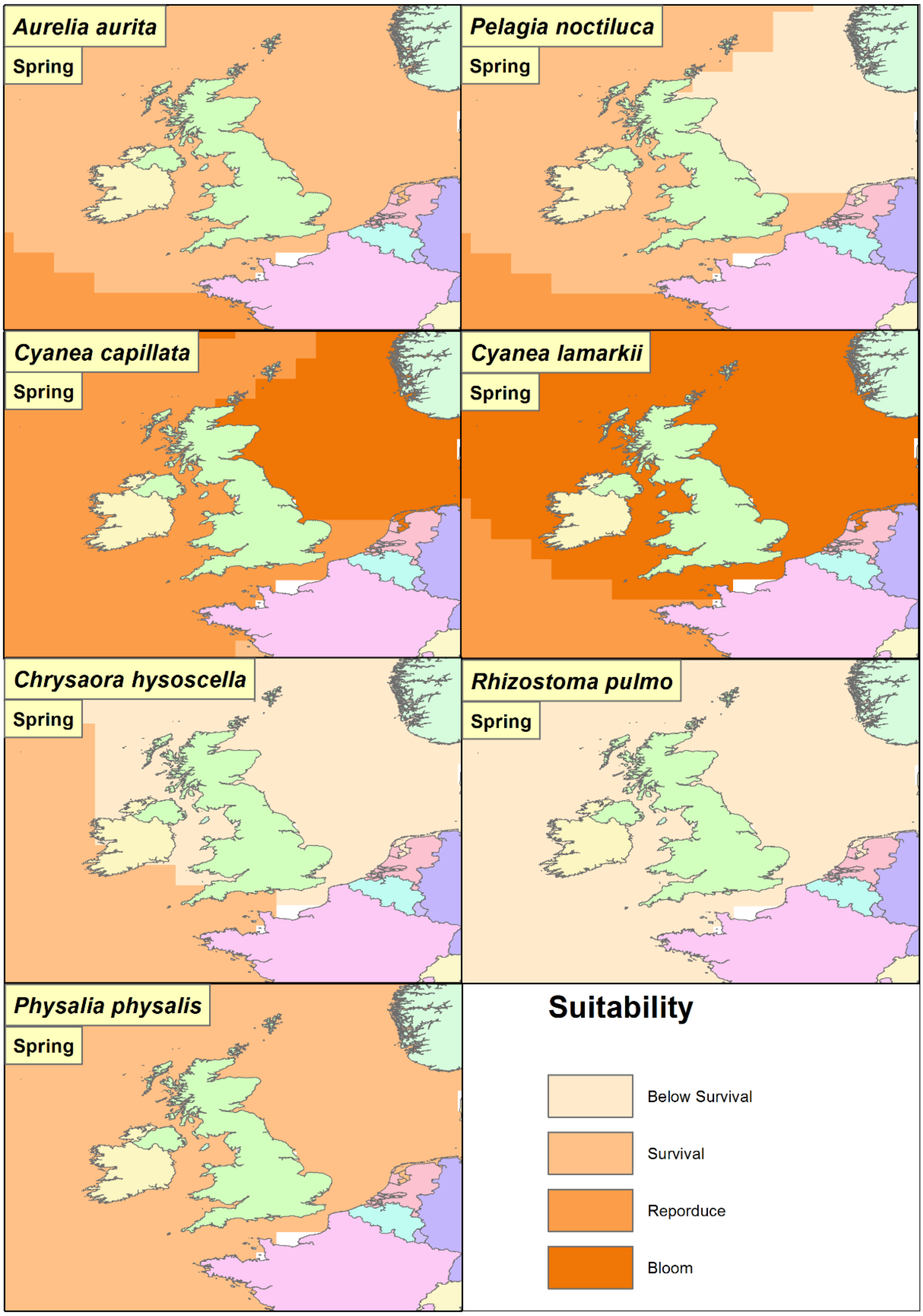
APPENDIX B

SPECIES SPECIFIC RECLASSIFICATIONS OF THE ENVIRONMENTAL DATA LAYERS IN ARCMAP

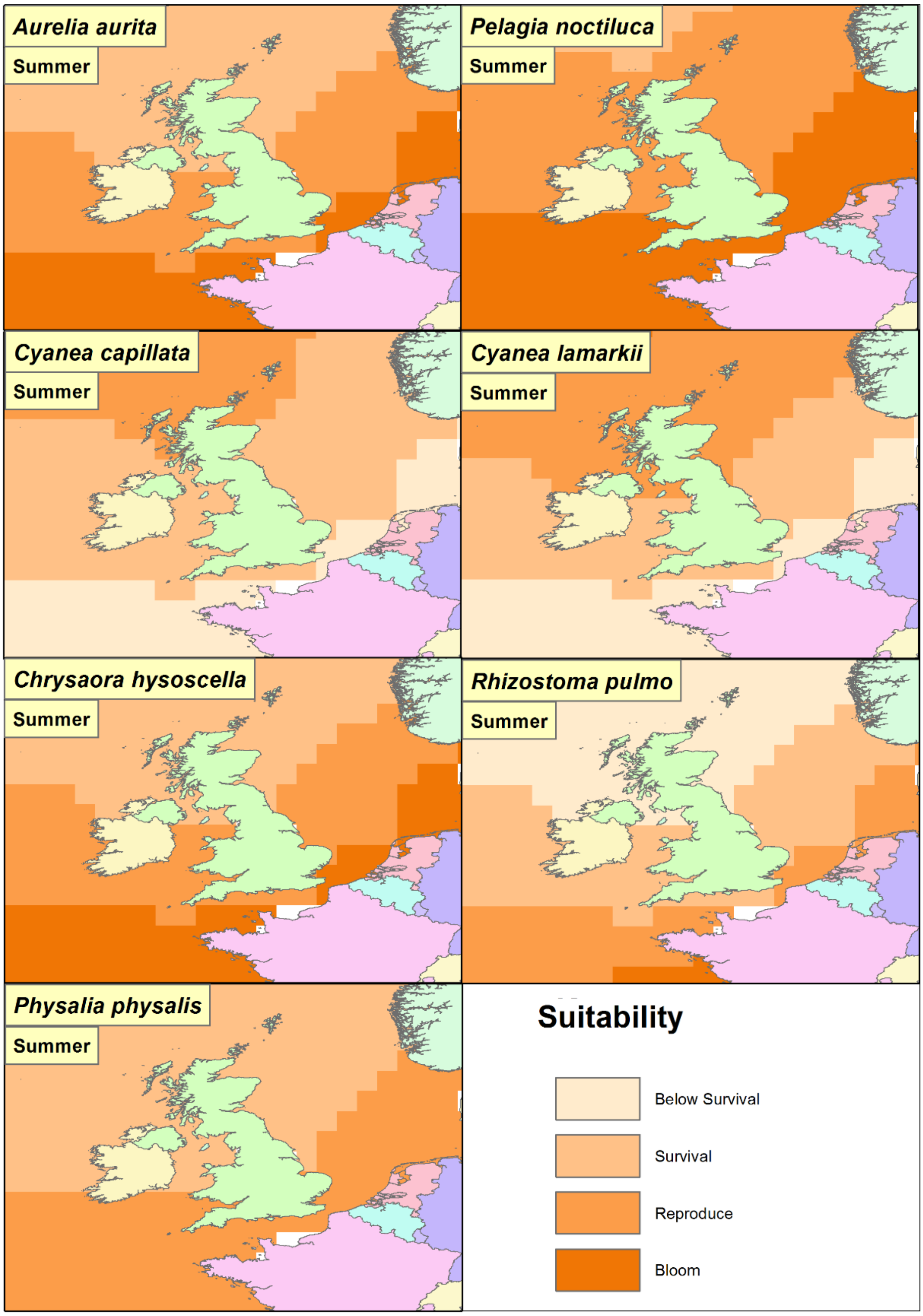
Reclassifications of the SST Data Layers in winter for Each Species



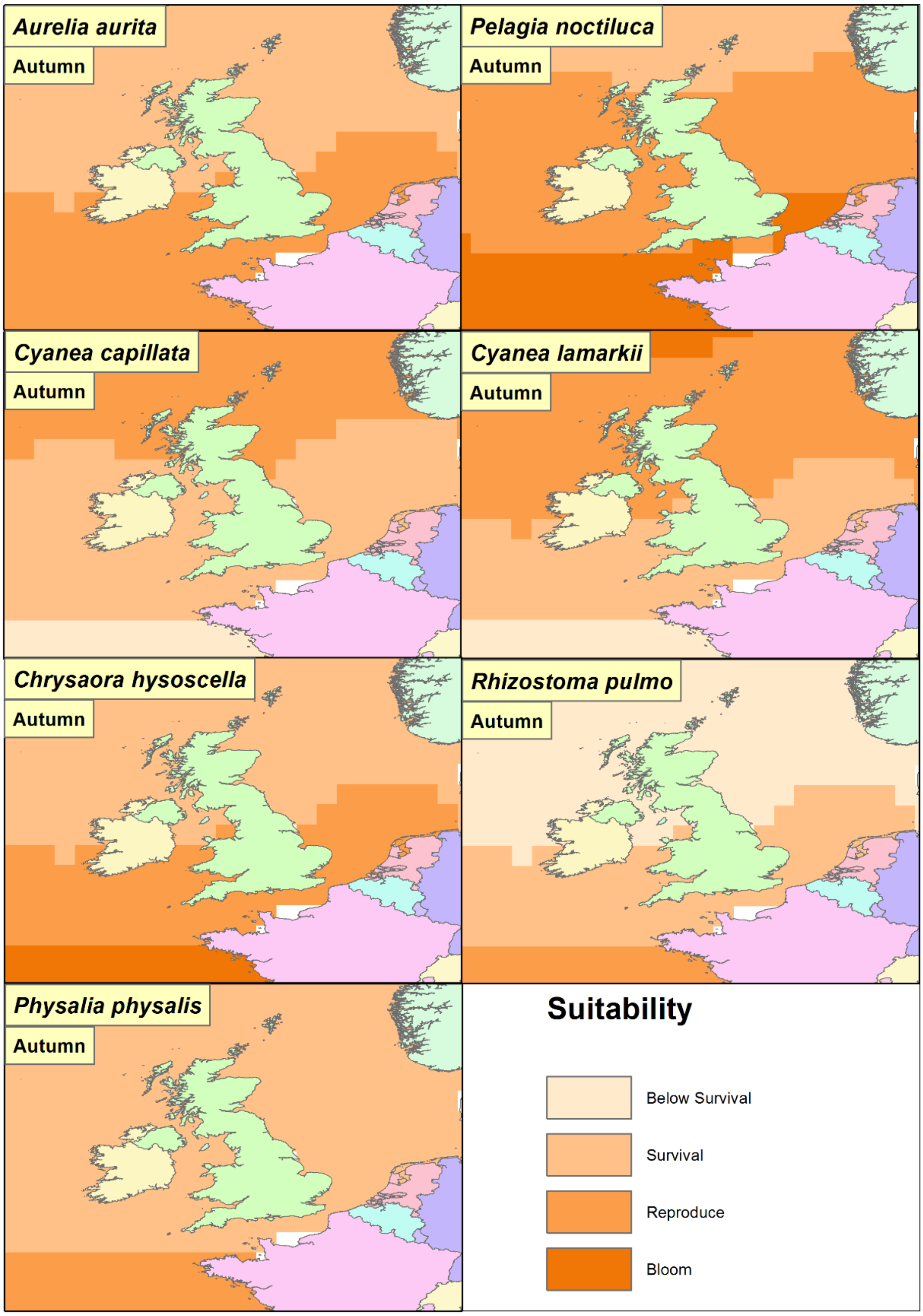
Reclassifications of the SST Data Layers in spring for Each Species



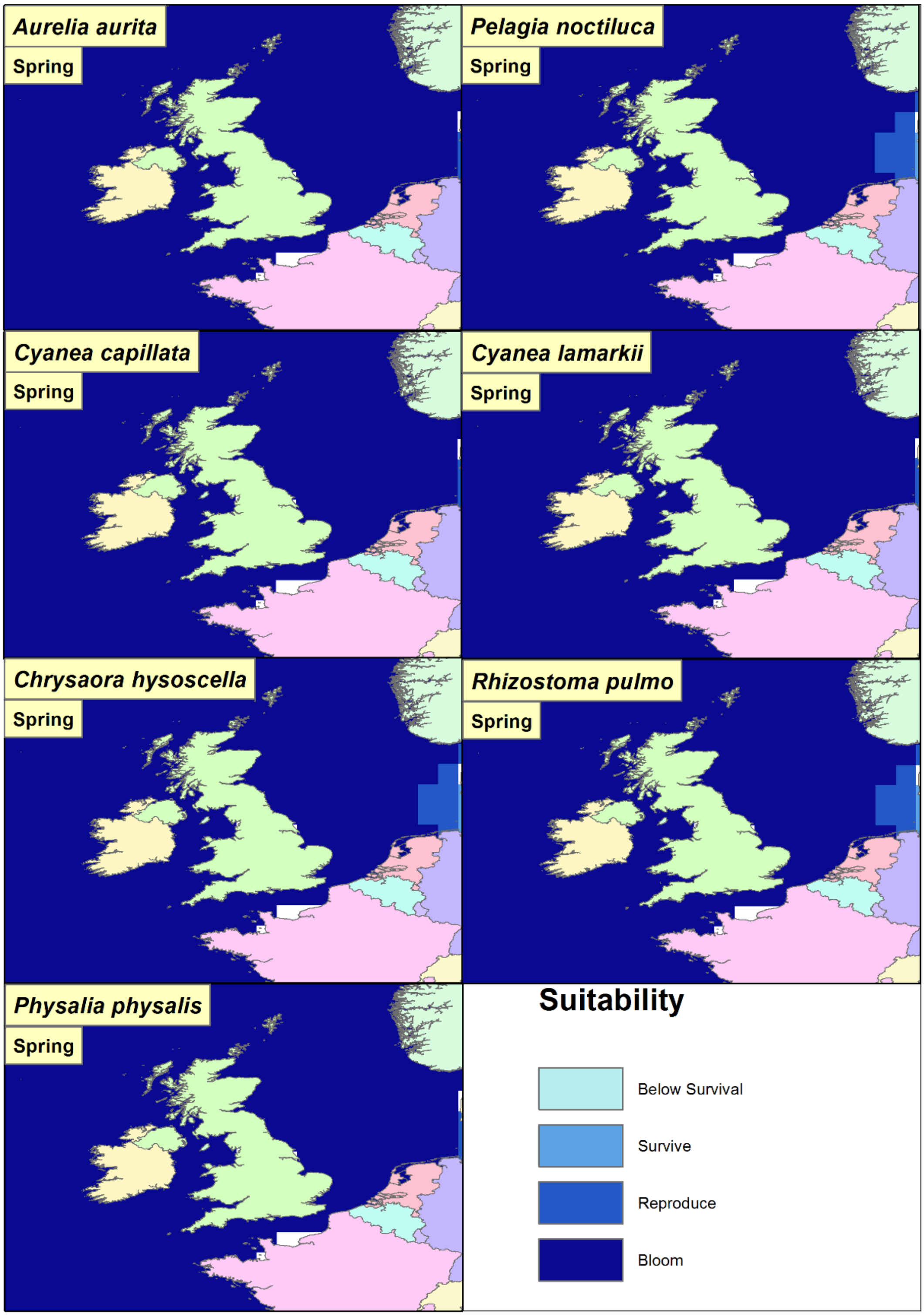
Reclassifications of the SST Data Layers in summer for Each Species



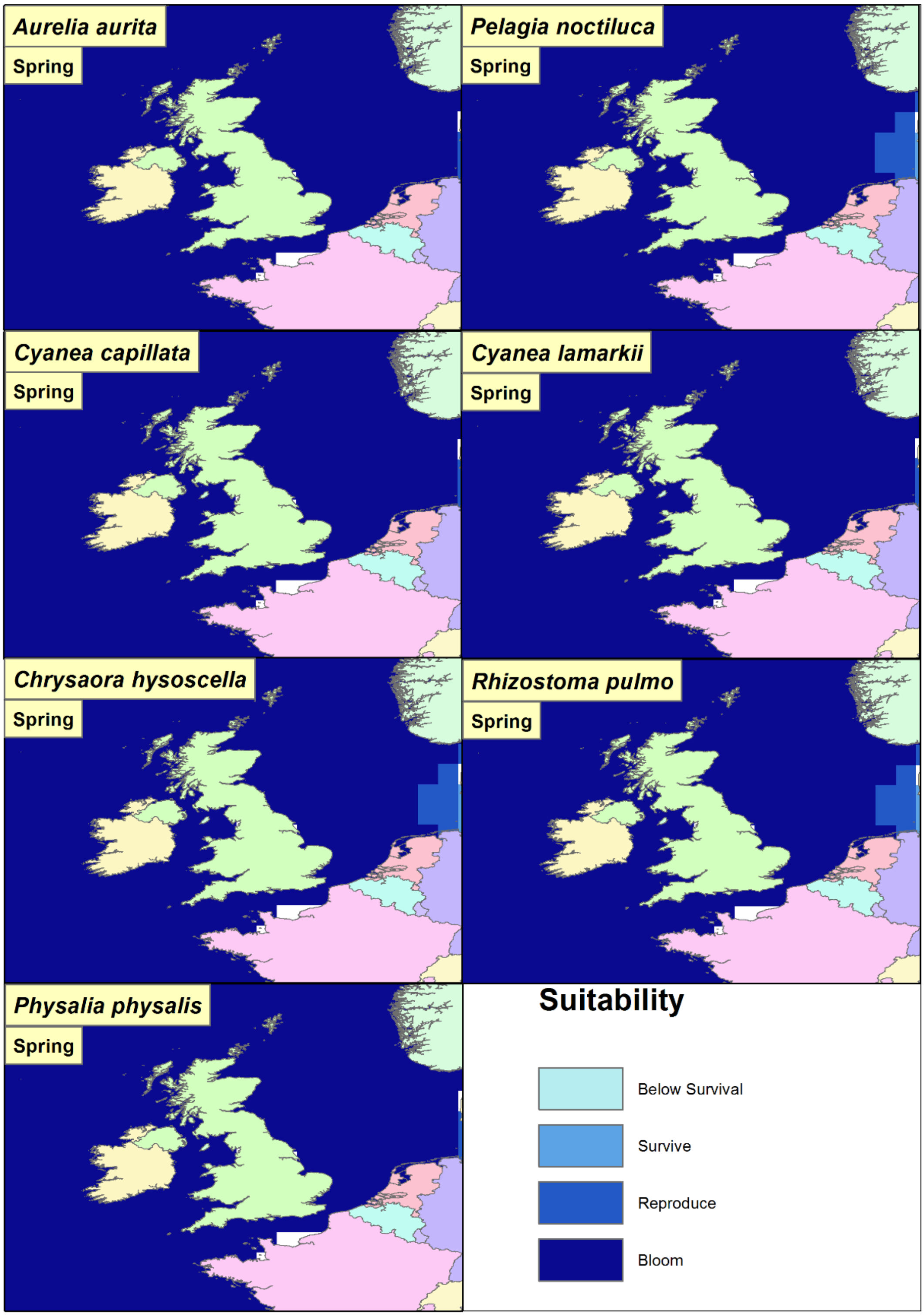
Reclassifications of the SST Data Layers in autumn for Each Species



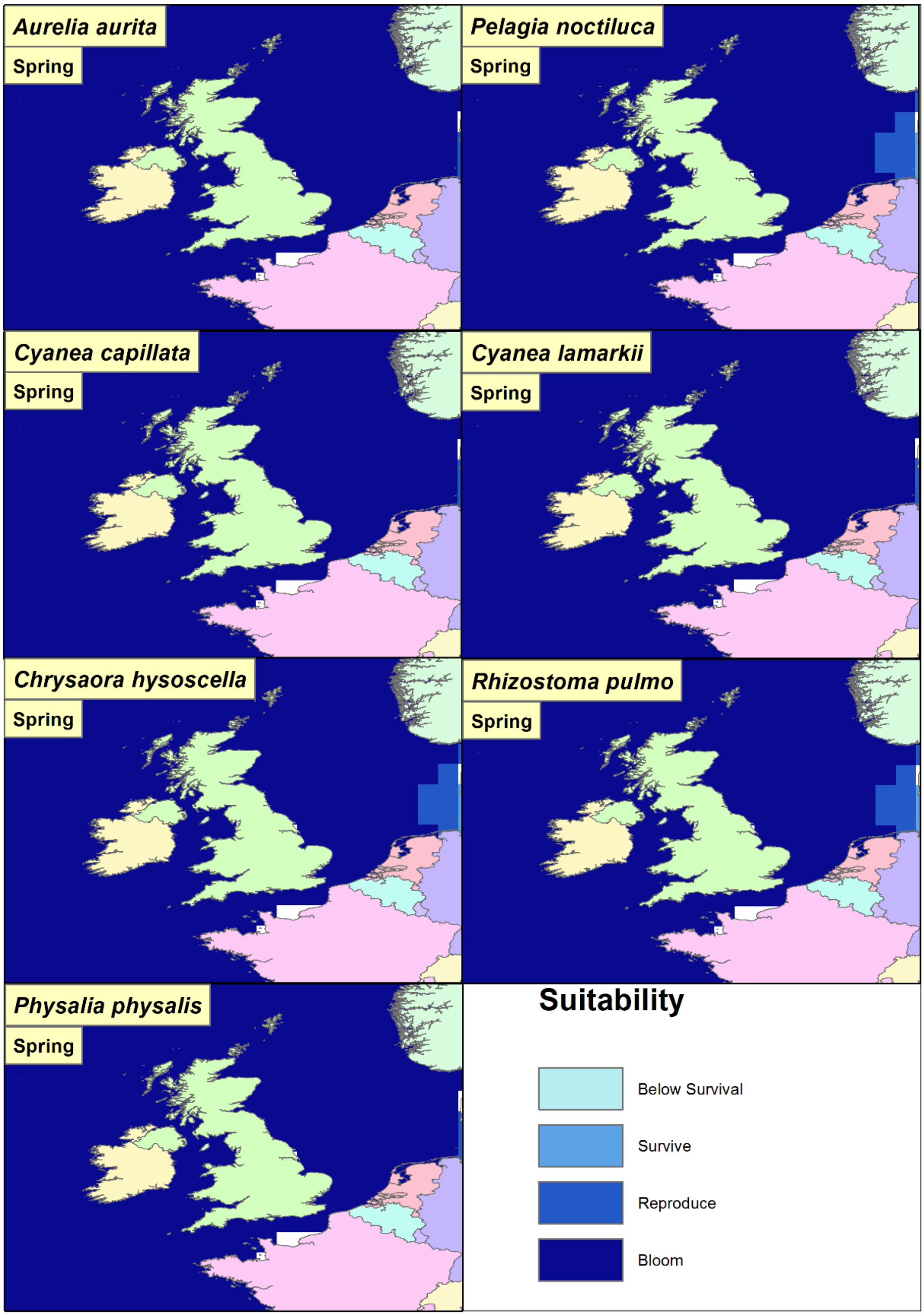
Reclassifications of the PPT Data Layers in winter for Each Species



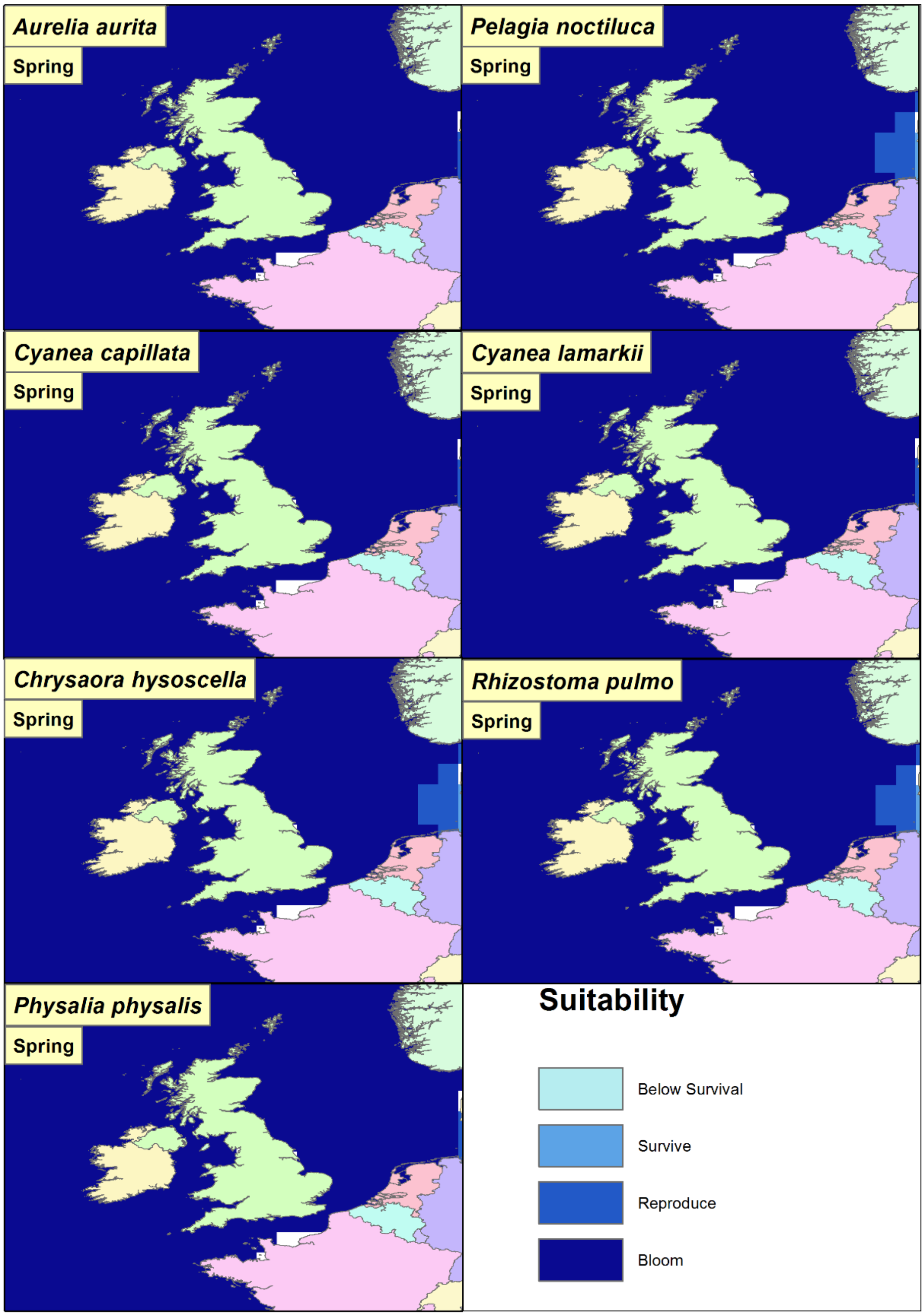
Reclassifications of the PPT Data Layers in spring for Each Species



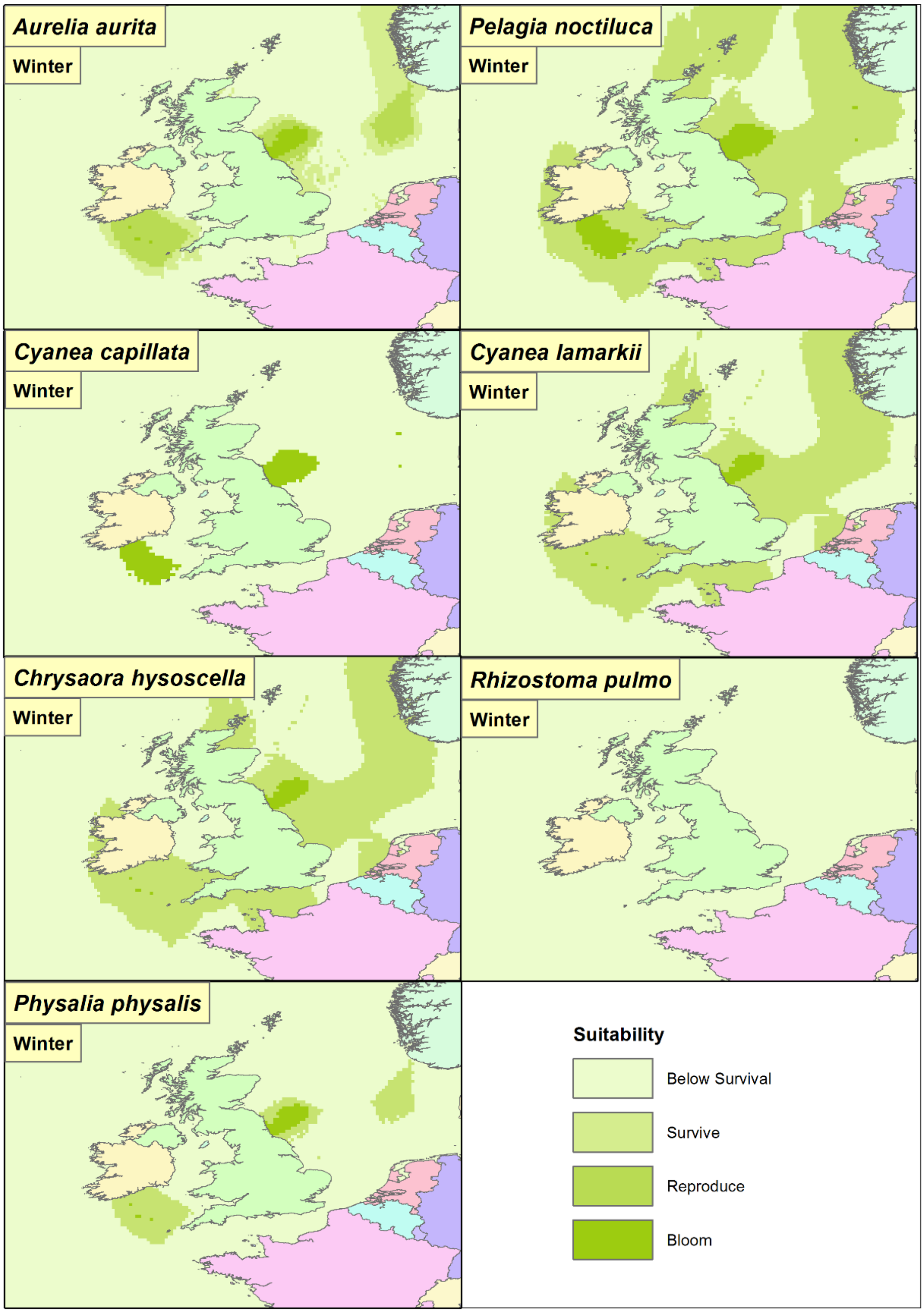
Reclassifications of the PPT Data Layers in summer for Each Species



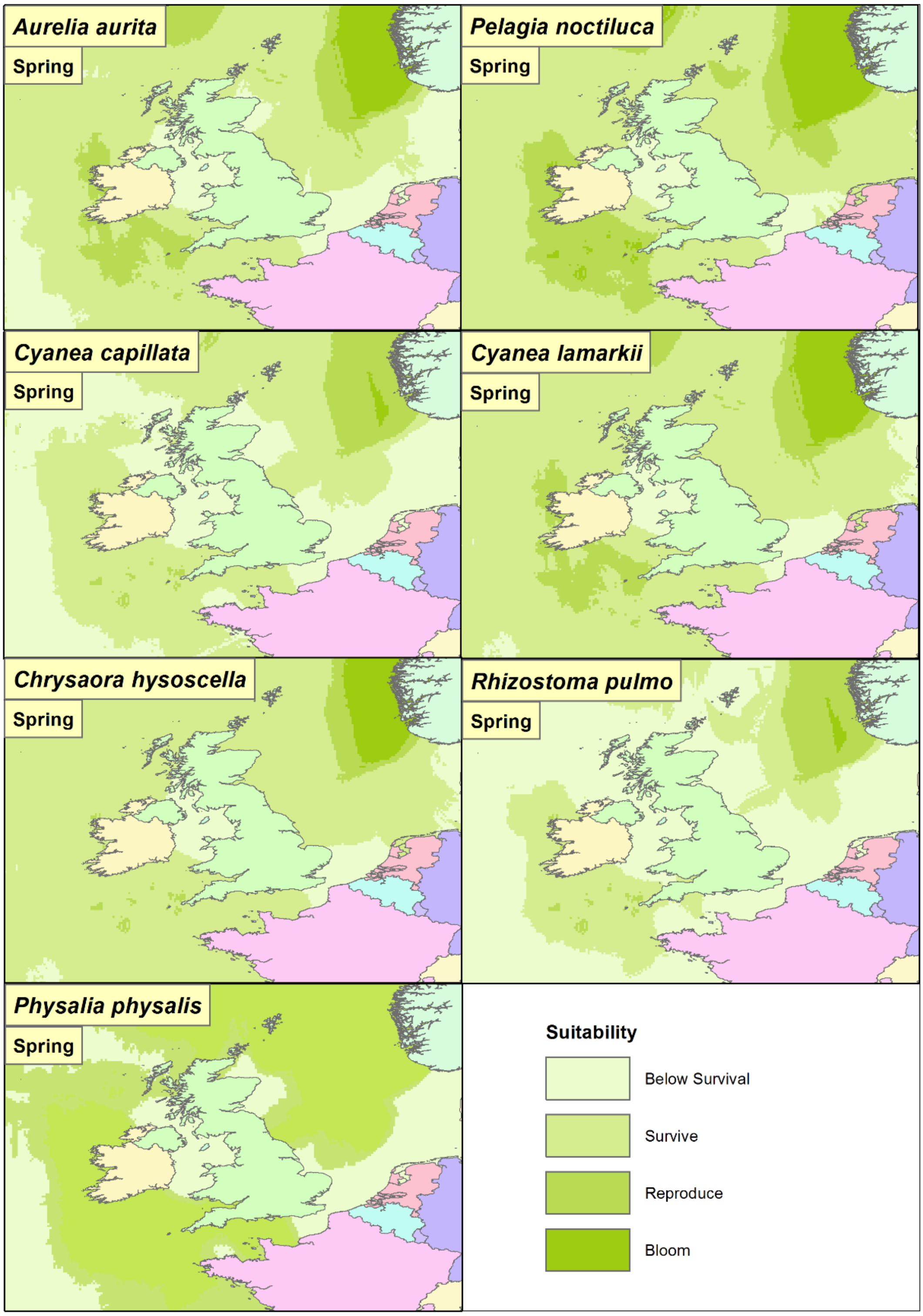
Reclassifications of the PPT Data Layers in autumn for Each Species



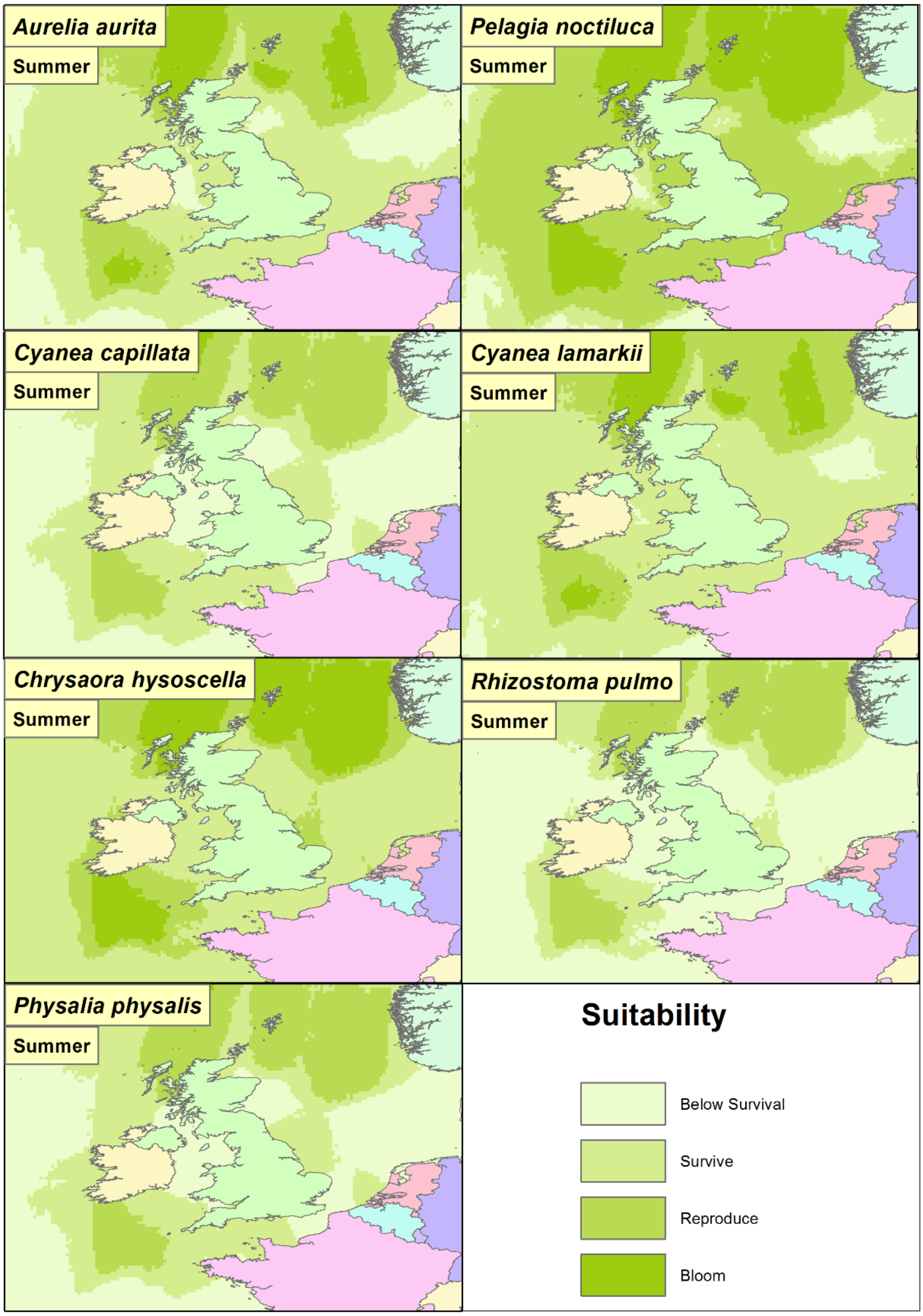
Reclassifications of the Plankton Index Data Layers in winter for Each Species



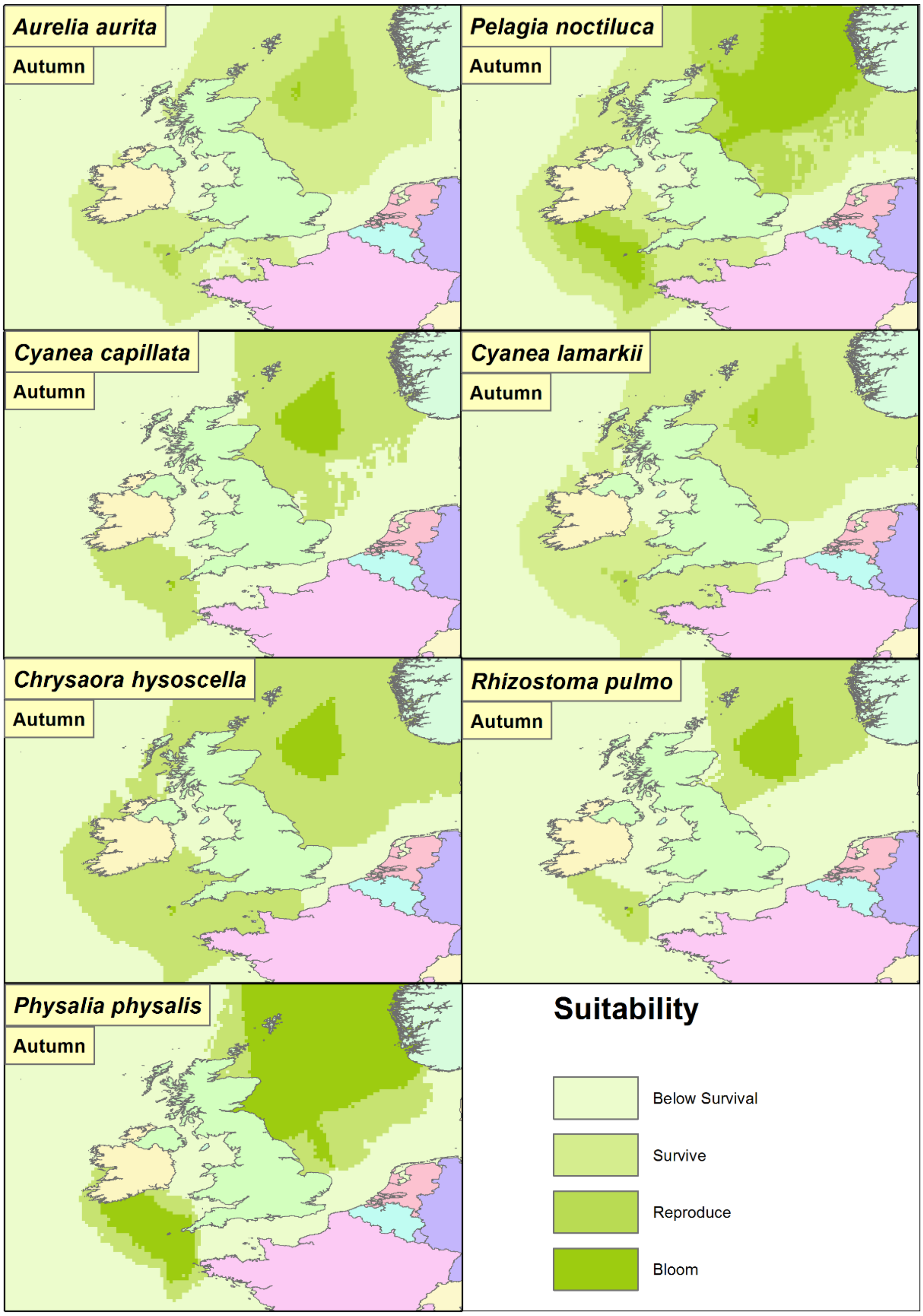
Reclassifications of the Plankton Index Data Layers in spring for Each Species



Reclassifications of the Plankton Index Data Layers in summer for Each Species



Reclassifications of the Plankton Index Data Layers in autumn for Each Species



APPENDIX C

FISHERIES SURVEY

Hello,

I am doing some research that is funded by the University of East Anglia and Cefas on the challenges that coastal industries face in relation to changing marine environments.

My focus is on aquaculture, tourism and fisheries. More specifically, I am interested in estimates of current and future costs of changing conditions, with an idea of comparing the impacts between industries.

The insight of people with experience of fisheries are key to this research. Therefore, I would very much appreciate it, if you would take part in this short survey. It will enquire about your expertise as a fisherman to gain an understanding of what impacts, and costs are incurred to your operations.

It will take anywhere between 15 and 30 minutes depending on the information you provide. Your input will be treated completely anonymously (i.e. responses provided will be anonymised so that no-one will be identifiable from the answers) and the answers you give will only be used for the purposes in this study.

Many thanks,

Adam Kennerley

Section A) Fishing Activities

In this section, I'd like to ask you some questions about your fishing activities and the vessel that you work on. This is just to get to know you and how you operate, which will influence what questions I will ask in later sections. I'd like to remind you at this point, that all answers you provide will be treated anonymously.

A1) How many years have you been working as a fisherman in this area?

A2) On the vessel that you work on, are you:

The vessel owner	
An employee	
Other please state	

A3) What is the length of the vessel you work on?

Metres

A4) Which fishing practice is carried out most frequently (more than 50% of the time) on the vessel that you work on?

Demersal Trawling / Seining	
Pelagic Trawling / Seining	
Small Scale Fisheries	
Pots and Creels	
Long Lines	
Other (please specify) ……	

A5) How many nautical miles from the coast do you normally fish?

miles

A6) How many litres of fuel would you say you use on an average fishing trip?

litres

A7) What fish species do you catch the most during each season? For each one can you estimate how much you catch in Kgs during each season? (Please name up to 5 species and specify which fish you are referring to for each season).

Species						
	Species 1	Weight	Species 2	Weight	Species 3	Weight
Winter		Kgs		Kgs		Kgs
Spring		Kgs		Kgs		Kgs
Summer		Kgs		Kgs		Kgs
Autumn		Kgs		Kgs		Kgs

A8) If you are the owner of the vessel, can you estimate the average cost of running the vessel during a typical fishing day?

£

Section B) General Challenges of Modern Day Operations

This section, is a general series of questions about the challenges that you currently experience, related to floating objects in the water that you would consider as out of the ordinary. The term "floating objects" could include (but not limited to) flotsam such as bits of wood, debris and other sea life.

B1) Have you ever experienced damage to fishing gear as a result of out of the ordinary objects floating in the water (i.e. flotsam, other sea life and the like)?

Yes		No	

If no, please skip to **B5**

B2) Can you name the floating object in the water that caused this issue?

1	
2	
3	

B3) For each one, can you estimates the costs in terms of repairs and loss in catch that day?

1		2		3	
Gear Repair Cost (£)	Fishing hours lost (day)	Gear Repair Cost (£)	Fishing hours lost (day	Gear Repair Cost (£)	Fishing hours lost (day)

B4) Can you estimate the size of the area that contained the object for each issue that you mentioned?

	1	2	3
0–5km^2 (small)			
5-10km^2 (Medium)			
Greater than 10km^2 (Large)			

B5) Have you ever had to avoid an area as a result of objects in the water (i.e. flotsam, other sea life and the like)?

Yes		No	

If no, please skip to **B11**

B6) Can you give a brief description of what caused you to avoid the area?

1	
2	
3	

B7) Can you estimate the size of the area that contained the objects that forced you to avoid the fishing site for each issue that you mentioned in B6?

	1	2	3
0–5km^2 (small)			
5-10km^2 (Medium)			
Greater than 10km^2 (Large)			

B8) For any of the issues that you mentioned, were your forced to return to port for the day?

1	Yes		No	
2	Yes		No	
3	Yes		No	

If **all are yes**, please skip to **B11**

B9) For each issue that you were able to continue to fish, how many nautical miles did you travel to find alternate fishing grounds?

1	Miles
2	Miles
3	Miles

B10) For each one, if similar incidents were to occur in the future, what is the maximum distance you would be willing to travel to find alternate fishing grounds?

1	Miles
2	Miles
3	Miles

The rest of the questions in this section are about wildlife in the water and how they interact with your fishing operations (if at all). I'd like to remind you that your responses will be anonymised.

B11) Does accidental bycatch of any other sea life affect the amount of fishing hours possible within a day?

Yes		No	

If no, please skip to **B13**

B12) If yes, roughly how many fishing hours per day does it cost you?

hours

B13) Have you or any shipmates ever been injured by an animal that you caught?

Yes		No	

If no, please skip to **Section C**

B14) Please give a brief description of the incident.

B15) Did it require any special treatment?

Yes		No	

If no, please skip to **Q17**

B16) Please give a brief description of the treatment that was required.

B17) Did the event affect fishing operations?

No, kept fishing as normal	
Yes, injury forced individual to stop work, but operations continued	
Yes, had to return to port	
Other, please specify	

Section C) Previous Experiences of Jellyfish

A specific focus of this study is jellyfish and jellyfish blooms as an object in the water. In this short part of the questionnaire, I would like to find out if you have had any previous experiences of jellyfish whilst operating as a fisherman.

C1) Have you had any issues associated with jellyfish whilst fishing?

Yes		No	

If no, please skip to **C3**

C2) Can you give a brief description of any issues?

1	
2	
3	

C3) Have you ever noticed increased numbers of jellyfish within your regular fishing grounds?

Yes		No	

If no, please skip to **section D**

C4) Please look at the all species figure. Please tick any species that you recognise as occurring in the waters that you fish in the tick box below?

Adult medusae 10 – 30cms across 	Adult medusa 25 – 40cms across 	Adult medusae between 30-40cms 
The Mauve Stinger (*Pelagia noctiluca*)	*The Moon Jellyfish* (*Aurelia aurita*)	The Fried Egg Jellyfish (*Cotylorhiza tuberculata*)
 Adult medusae around 40cms. Can grow beyond 90cms.	Adult medusae up to 30cms 	Adult medusae between 30-40cms, can be larger 
The Barrel Jellyfish (*Rhizostoma pulmo*)	The Compass Jellyfish (*Chrysaora hysoscella*)	The Portuguese Man o' War (*Physalia physalis*)
Adult medusae between 15 and 30cms across 	UK poppulation = adult medusae between 20cms and 1m 	Adult medusae between 5 and 15cms 
The Blue Jellyfish (*Cyanea lamarkii*)	The Lion's Mane Jellyfish (*Cyanea capillata*)	The Sea Walnut / Gooseberry (*Mnemiopsis leidyi*)

Mauve Stiner	
Moon Jellyfish	
Fried Egg Jellyfish	
Barrel Jellyfish	
Compass Jellyfish	
Portuguese Man o' War	
Blue Jellyfish	
Lion's Mane Jellyfish	
The Sea Walnut	

C5) How frequently have you witnessed increased jellyfish numbers?

More than once a year	
Once a year	
Every 2 – 4 years	
Every 5 – 10 years	
Less than once every 10 years	

C6) In your opinion, how long do these increases last for?

Less than a week	
One Week	
Two Weeks	
Three Weeks	
One Month	
Over a month	

C7) During which season were these increased numbers of jellyfish most frequent?

Winter	
Spring	
Summer	
Autumn	
There isn't a set period	

C8) Have you noticed a general increase in the number of jellyfish in last 10 years?

Yes		No	

Section D) - Future Jellyfish Interactions

Evidence suggests that the jellyfish populations we discussed in section C could increase, characterised by more instances of blooming events. If this was to occur, there would be potential for increased interactions with the fisheries here.

In this section, I would like to ask you to draw upon your expertise as a fisherman to imagine hypothetical future oceans where blooms are more common, to answer questions on how you think they would interact with your fishing operations (if at all) and how you would fish in bloomed waters.

Group 1 – Larger Non-Stingers

		• Body up to (and sometimes over) 1 metre, weighing up to 35 kilos (5.5 stone) • Often congregate in large numbers • Capable of minor stings.
The Barrel Jellyfish (*Rhizostoma pulmo*)	The Fried Egg Jellyfish (*Cotylorhiza tuberculata*)	

DI1) Do you envisage any disruption to your fishing operations if groups of large non-stinging jellyfish were to bloom regularly in areas where you usually fish?

Yes		No	

If you don't think there will be issues associated with blooms of larger non-stinging species, **please skip to group 2, larger stingers.**

DI2) Using the flash card, imagine that a group of large, non-stinging species of jellyfish were to bloom within the areas that you fish:

What gear / activity do you think will be affected?		**Disruptions? i.e. % landings decrease**
1		
2		
3		
4		
5		

DI3) What actions would you take (if any) that would enable you to keep fishing in the event of large, non-stinging jellyfish blooming?

Travel to alternate fishing sites		If yes how far would you be willing to travel? ________ miles
Return to port		
Carry on fishing, accepting interactions with jellyfish		
Increase use of protective gear for crew		If so what gear?
Other (please specify)		

Group 2 – Larger Stingers

		• Body up to (and sometimes over) 1 metre • Congregates in relatively large numbers • Capable of significant stings to humans.
The Portuguese Man o' War (*Physalia physalis*)	The Lion's Mane Jellyfish (*Cyanea capillata*)	

DII1) Do you envisage any disruption to your fishing operations if groups of large stinging jellyfish were to bloom regularly in areas where you usually fish?

Yes		No	

If you don't think there will be issues associated with blooms of larger stingers, please skip to **group 3, smaller non-stingers.**

DII2) Using the flash card, imagine that a group of large, stinging species of jellyfish were to bloom within the areas that you fish:

What gear / activity do you think will be affected?		**Disruptions? i.e. % landings decrease**
1		
2		
3		

DII3) What actions would you take (if any) that would enable you to keep fishing in the event of large, stinging jellyfish blooming?

Travel to alternate fishing sites		If yes how far would you be willing to travel? ________ miles
Return to port		
Carry on fishing, accepting interactions with jellyfish		
Increase use of protective gear for crew		If so what gear?
Other (please specify)		

Group 3 – Smaller Non-Stingers

		• Body usually between 5 and 30cms • Aggregations can be intense (sometimes thousands within small areas) • Capable of minor stings
The Moon Jellyfish (*Aurelia aurita*)	The Sea Walnut (*Mnemiopsis leidyi*)	

DIII1) Do you envisage any disruption to your fishing operations if groups of small non-stinging jellyfish were to bloom regularly in areas where you usually fish?

Yes		No	

If you don't think there will be issues associated with blooms of smaller non-stinging species, please skip **to group 4, smaller stingers.**

DIII2) Using the flash card, imagine that a group of smaller, non-stinging species of jellyfish were to bloom within the areas that you fish:

What gear / activity do you think will be affected?		Disruptions? i.e. % landings decrease
1		
2		
3		

DIII3) What actions would you take (if any) that would enable you to keep fishing in the event of small, non-stinging jellyfish blooming?

Travel to alternate fishing sites		If yes how far would you be willing to travel? ________ miles
Return to port		
Carry on fishing, accepting interactions with jellyfish		
Increase use of protective gear for crew		If so what gear?
Other (please specify)		

Group 4 – Smaller Stingers

			• Body usually between 5 and 50cms • Aggregations can be intense (sometimes thousands within small areas) • Capable of significant stings to humans.
The Mauve Stinger (*Pelagia noctiluca*)	The Compass Jellyfish (*Chrysaora hysoscella*)	The Blue Jellyfish (*Cyanea lamarkii*)	

DIV1) Do you envisage any disruption to your fishing operations if groups of smaller stinging jellyfish were to bloom regularly in areas where you usually fish?

Yes		No	

If you don't think there will be issues associated with blooms of smaller stinging species, **please end the survey**

DIV2) Using the flash card, imagine that a group of smaller stinging species of jellyfish were to bloom within the areas that you fish:

What gear / activity do you think will be affected?		**Disruptions? i.e. % landings decrease**
1		
2		
3		

DIV3) What actions would you take (if any) that would enable you to keep fishing in the event of smaller stinging jellyfish blooming?

Travel to alternate fishing sites		If yes how far would you be willing to travel? ________ miles
Return to port		
Carry on fishing, accepting interactions with jellyfish		
Increase use of protective gear for crew		If so what gear?
Other (please specify)		

Thank you very much for your help and the time you have dedicated in completing this questionnaire. If you are interested in any aspects of my work or the results of the research that this survey has contributed towards, please feel free to send me an email.

APPENDIX D

TOURISM SURVEY

(Interviewer: offer this page to respondents. Tear page off, give to respondents along with the study information card *if* they want it)

Hello,

I am doing some research relating to jellyfish and the tourism industry.

I am interested in your activities as a visitor to Cornwall as well as your experiences and thoughts on jellyfish. I would very much appreciate it, if you would discuss this with me during this short survey.

It will take about 10 minutes and your answers will be treated with complete confidentiality. Any information you give will only be used for the purposes of this study and any reports / publications that may result from this work. Results from all participants are being collated and aggregated so that your individual preferences cannot be retrieved.

Many thanks,

Adam / Dave / Beth / Tom / Faith / Nyasha

Section A) Activities

In this section, I'd like to ask you some questions about your activities when you're in Cornwall for recreational purposes.

A1) Are you?

1	A resident of St Ives			
2	In St Ives for a day trip			
3	On a short break, away from home for 2-6 days		Specifically, how many days?	
4	On a longer break, away from home for 7 days or more		Specifically, how many days?	

A2) Including yourself, how many people are in your group today?

Adults	
Children	

A3) (**Don't ask if resident – skip to A4**) What is your main reason for vising St Ives?

1	Visit family	
2	Beach holiday	
3	Cultural holiday	
4	Activity holiday	
5	Passing through the area	
6	Work	
Other (**please state**)		

A4) Including today, how many times have you visited the beaches of St Ives in the last 12 months?

A5) How many hours do you think you will spend on the beach today?

1	0 – 1 hours	
2	1.01 – 2 hours	
3	2.01 – 3 hours	
4	3.01 – 4 hours	
5	4.01 – 5 hours	
6	5.01 – 6 hours	
7	6.01 – 7 hours	
8	7.01 + hours	

A6) What activities do you do most when you visit the beaches on St Ives?

1	Relax	
2	Sunbathe	
3	Surfing or windsurfing	
4	Going in the sea / swimming	
5	Playing sports	
6	Dog walking	
7	Fishing	
8	Nature / bird watching	
9	Rock pooling	
10	Kayaking / boating	
11	Spending time with friends and family	
12	Playing with the children	
13	Walking along the shore	
Other (**please state**)		

A7) If the beaches were closed due to safety concerns, how would you recreate?

A8) What mode of transport did you use to get to the beach today from the place that you are staying in Cornwall?

1	Bike			
2	Walk			
3	1 Car		Fuel type?	
4	2 cars		Fuel type?	
5	3 cars		Fuel type?	
6	Motorbike		Fuel type?	
7	Bus		Total cost of ticket for your group?	£
8	Train		Total cost of ticket for your group?	£
9	Taxi		Trip cost	£
Other (**please state + cost if applicable**)				

A9) What is the postcode of where you are staying / started your journey from to get to the beach today?

If no answer to A9 given, try to get the following alternative information about where they are staying?

Town:	**OR**	County:	**OR**	Place name

A10) How far did you travel to get to the beach from where you are staying?

Miles	**OR**	Kilometres	**OR**	Yards

A11) How long did it take you?

Hours	Minutes

A12) How important or not important are the following aspects of the beach to you?

	1. Very important	2. Fairly important	3. Not very important	4. Not at all important	5. Don't know
Water quality	☐	☐	☐	☐	☐
Safety in the water	☐	☐	☐	☐	☐
Safety on the beach	☐	☐	☐	☐	☐
Cleanliness of the beach	☐	☐	☐	☐	☐

A13) Would you say that today is a typical day for you on the beaches of St Ives?

Yes		No	

If no, why was is today different?

Section B) Jellyfish Opinions, Experience and Responses

This second section is about your experiences and opinions of jellyfish. There are also questions on how you would react, if you ever came across large groups of jellyfish.

B1) What comes to mind when you hear the word ‘jellyfish’?

Positive ☐ Neutral ☐ Negative ☐

B2) Have you had any previous experiences of jellyfish during trips to the beach?

Yes (**Ask B3**)		No (**Skip to B4**)	

B3) What happened?

1	Saw them in the water	
2	Saw them washed up on the beach	
3	Jellyfish presence in the water was interesting to us	
4	Jellyfish presence on the beach was interesting to us	
5	Jellyfish presence was intimidating to us	
6	Stung me or a member of my group	
7	Stopped us from going into the water	
8	Stopped us from doing water activities	
9	Stopped us from going to the beach	
10	Stopped us from doing beach activities	
11	Spoilt the scenery	
Other (please state)		

B4) Do you think there will be any alterations to your holiday activities if large groups of jellyfish were to occur off the beaches of St Ives?

Yes (**skip to B6**)		No (**go to B5**)	

B5) Can you expand on why you don’t think increased jellyfish populations would cause alterations?

If B5 answered skip to B7

A jellyfish bloom is a large congregation that can contain thousands of adult medusae and are known to occur in coastal waters. Let's suppose that jellyfish populations in St Ives were to increase in the future with blooms becoming a prominent feature in the water as well as washing up on the beach.

B6) What would you do if you came across large numbers of jellyfish in the sea and on the beaches?

1	Enjoy the beach as normal, accepting any interactions with jellyfish	
2	Enjoy the water as normal, accepting any interactions with jellyfish	
3	Avoid the water, but stay on the beach	
4	Avoid the beach, but stay in St Ives	
5	Do alternative activity within St Ives	
6	Be more cautious	
7	Travel to alternative locations (**if selected ask 7a and 7b**)	
	(**7a**) Can you please specify which beach you would go to?	
	(**7b)** How far would you be prepared to travel ________ miles	In Time (H:M)?
Other (please specify)		

B7) If large jellyfish numbers were to occur here more regularly in the future, how concerned, if at all would you be?

1. Not at all concerned — 2. Slightly concerned — 3. Somewhat concerned — 4. Moderately concerned — 5. Extremely concerned

B8) If you ever experienced a lot of jellyfish in St Ives, would it deter you from returning in the future?

Yes		No	

In some areas, jellyfish are a big issue and NGOs set up nets that create jellyfish free pools and separate sections of the beach from blooms. Stalls can also be set up that provide information about the species that are occurring so that beach users can understand their characteristics, including which ones can sting. Potentially, this could be used in the event of blooms occurring in St Ives.

B9) How important do you think it would be that types of measures like the one that I mentioned are set up to manage issues associated with jellyfish blooms?

1. Not at all important	2. Slightly important	3. Somewhat important	4. Moderately important	5. Extremely important

B10) Which aspect is most important?

1	Separating jellyfish and swimmers with nets	
2	Jellyfish Information Stalls	
3	Other scheme could be more effective	
4	None	
Other (please specify)		

B11) Would you be willing to make annual donations to such projects?

Yes		No	

If no, why not?

If no answered go to B13

B12) How much would you be willing to donate annually to such a project?

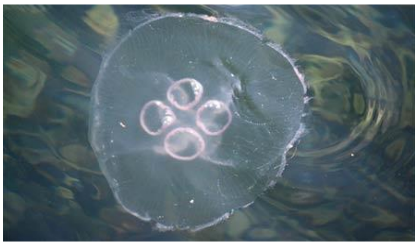
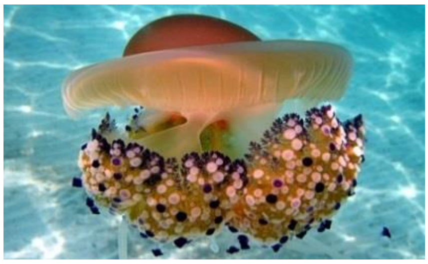
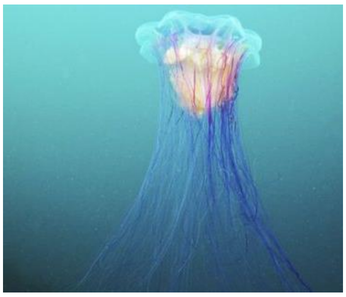
£

B13) For how many years would you be willing to make this annual donation?

	Why is this?

B14) **Looking at this card**, are you able to identify any jellyfish species and which are capable of stinging?

		Identified correctly	Identified as a stinger
1	Mauve Stinger	☐	☐
2	Moon Jellyfish	☐	☐
3	Fried Egg Jellyfish	☐	☐
4	Barrel Jellyfish	☐	☐
5	Compass Jellyfish	☐	☐
6	Portuguese Man o' War	☐	☐
7	Blue Jellyfish	☐	☐
8	Lion's Mane Jellyfish	☐	☐
9	The Sea Walnut	☐	☐
10	No	☐	N/A

1 	2 	3 
4 	5 	6 
7 	8 	9 

Section C) Socioeconomics

In this final section, I'd like to ask you some questions about you. This is to check if different types of people answer the questions about jellyfish differently. I would like to remind you at this point, that the survey is completely confidential.

C1. Can you give a rough estimate of how much you spend on each of the varying costs of your trip per day or for the total trip?

		Per day	Trip total
1	Accommodation (**Don't ask if local**)	£	£
2	Eating and drinking in cafes, pubs, restaurants and hotels	£	£
3	Buying food, drinks or snacks from shops	£	£
4	Shopping, such as souvenirs and items for the beach	£	£
5	Beach activities	£	£
6	Tourist activities, such as local attractions	£	£
7	Travel to and from locations within St Ives	£	£
8	Car parking	£	£
Other (please state)		£	£
9	Overall cost of the holiday		£

C2. (**Don't ask C2-C5 if they are residents of St Ives**) if you are staying here for a number of days, what is the town or post code of where you usually live?

Town	Postcode

C3. What mode of transport did you use to get to St Ives from where you live?

1	Car		Fuel type?			
2	Train		Ticket cost per person £		**OR**	Ticket cost for the group £
3	Other (please state)					Trip cost?

C4. How long did the journey take?

	Hours	Minutes

C5. If there were any delays, how much additional time was added to your journey?

Hours	Minutes

C6. (**Do not ask**) record the respondent's gender

1	Male	
2	Female	

C7. (**Pass the card with table C7, C9 and C10**). What age category do you fit into?

1	18 – 24	
2	25 – 34	
3	35 – 44	
4	45 – 55	
5	56 – 65	
6	66 – 75	
7	75 +	
	Refuse	

C8. Could you tell me your employment status?

	Occupation:

C9. Bearing in mind that this survey is completely confidential, can you please give me the number on table 9C that gives the best representation of your total household income before or after tax?

	Before tax	**or**	After tax	
1	Up to £10,000		Up to £10,000	
2	£11,000 - £20,000		£11,000 - £20,000	
3	£21,000 – £30,000		£21,000 – £30,000	
4	31,000 – 40,000		31,000 – 40,000	
5	41,000 – 50,000		41,000 – 50,000	
6	£51,000 - £60,000		£51,000 - £60,000	
7	£61,000 - £70,000		£61,000 - £70,000	
8	£71,000 - £80,000		£71,000 - £80,000	
9	£80, 000 +		£80, 000 +	
		Refused		

C10.What is the highest educational level that you achieved?

1	GCSE	
2	A level	
3	Certificate of higher education	
4	Diplomas of higher education/ Foundation Degree	
5	University degree (BSc, BA)	
6	Master degree/ Postgraduate certificate	
7	Doctoral degree	
	not sure	
	Refused	

Thank you very much for your help and the time you have dedicated in completing this questionnaire. If you are interested in any aspects of my work or the results of the research that this survey has contributed towards, please feel free to send me an email.

Do not ask respondents

1. Name of Interviewer: __________________________

2. Date of interview (DD/MM): ____________________

3. Exact start time (24Hour clock): __________________

4. Interview duration: _______ minutes

5. Beach (circle): Porthminster Porthmeor Gwithian Carbis Bay Porthgwidden Harbour beach Porthkidney sands

6. Weather at the time of interview

Cold .... ☐
Average .... ☐
Hot.. ☐
.... AND
....
Overcast .... ☐
Sunny.. ☐
Wet... ☐

7. Are people in the sea at the time of the interview?

Yes .... ☐

No .... ☐

8. Are there any jellyfish present on the beach or in the water at the time of the interview?

Yes .... ☐

No .... ☐

9. Was the respondent enthusiastic about the survey?

Yes.. ☐

No... ☐

(**For interviewers**) Any additional information of relevance at the time of the survey?