Participation, effort, catches, and impact of COVID-19 of sea anglers resident in the UK in 2016-21

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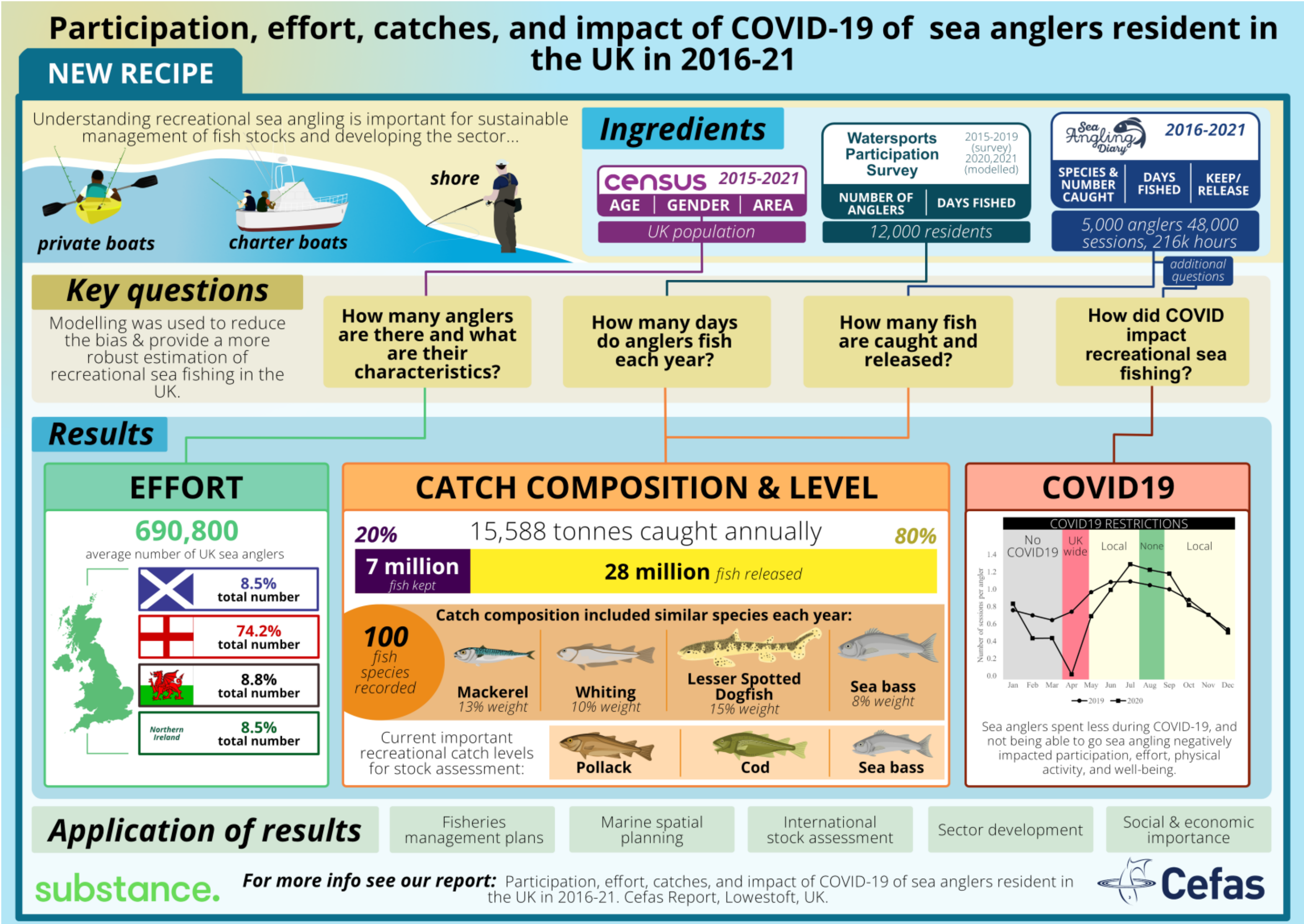
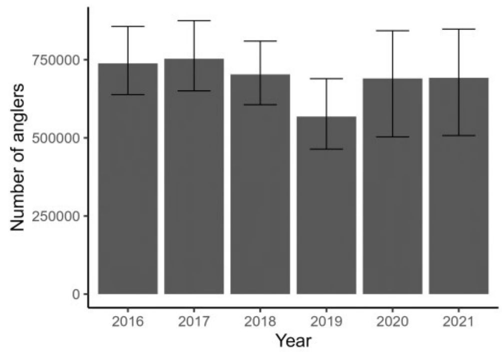
Graphical summary



Executive summary



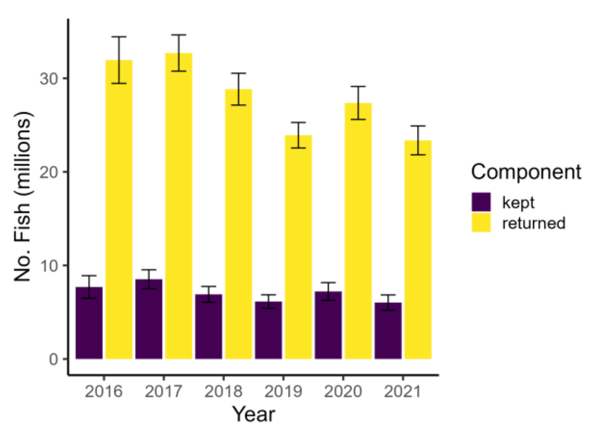
Box 1. Numbers of sea anglers (thousands).

Sea angling is a popular activity in the UK that has social benefits and economic impacts but may also impact on fish stocks. Data on participation, catch and economic value of sea angling are needed by government and stakeholders to support well-informed decisions, sector development and sustainable management of recreational fisheries. The Sea Angling Diary programme has been running since 2016 with the aim of estimating the number of sea anglers, how often they fish, what they catch, and the social and economic benefits that they generate. This is done through combining the outputs from two surveys: a survey of 12,000 individuals that generates estimates of the numbers of anglers and their characteristics; and sea anglers that volunteer as 'citizen scientists' to report their catches through the Sea Angling Diary. These estimates are combined accounting for differences in characteristics of sea anglers to generate the numbers and tonnages of fish kept and released by sea anglers in the UK.

Since 2016, over 5,000 sea anglers have provided data on over 48,000 fishing sessions and 362,000 catch records from 216,000 hours of angling activity. They have also contributed to understanding the economic benefits, and societal benefits around well-being. In this report, we build upon previous studies utilising the whole 6 years of data to develop new statistical approaches that generate more robust and consistent results, provide estimates for 2016-21, and assess the impact of COVID-19 on sea angling.

To estimate the participation and effort by UK sea anglers, questions were added to a survey of 12,000 residents (Watersports Participation Survey - WPS). Due to COVID restrictions, it was not possible to do face-to-face surveys as in 2016-19, so an online panel was used instead. The 2020 online panel generated much higher estimates than previous surveys, probably due to the different approaches. This meant that it was not possible to use the 2020 results in the analysis as it would impact on the consistency of the time series. Instead, data from the WPS from 2016-19 were modelled and used to derive estimates for 2016-2020, which ranged from 568,188 to 753,165 for the UK (Box 1). This approach utilised all existing data to generate more consistent and robust results than previous annual estimates.

In 2020 and 2021, 2,237 and 2,729 diarists participated in the survey, respectively. Across both years a total of 15,064 sessions and 107,697 individual catches across over 100 species were reported by up to 900 sea anglers each year. These data were used

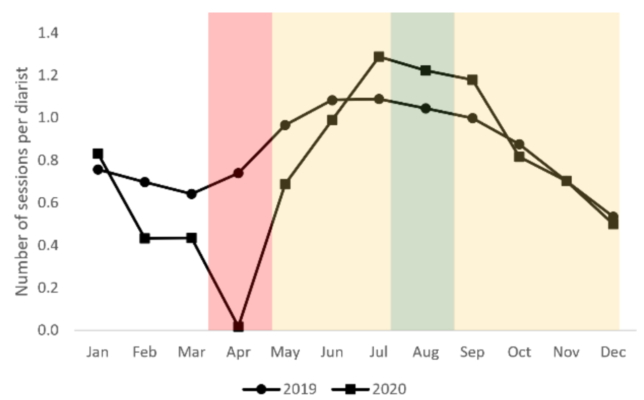


Box 2. Total number of fish kept and released by UK sea anglers from 2016-21.

alongside records from 2016-19 to model the number of fish kept and released by individual sea anglers each year and the weights of individual fish. Numbers of sea anglers were combined with diary panel catch per angler, to estimate total UK catches, after correcting for differences between the diary sample and the UK population.

Each year, around 7 million fish were retained and 28 million were released (Box 2), representing a release rate of around 80%. Catch was slightly larger than the previous annual reweighting approach, with the differences generated by the number of anglers. However, the Bayesian statistical modelling approach generated more consistent and robust results for the whole time series, so were used. Catch composition was similar between years with mackerel, whiting, lesser spotted dogfish, and sea bass the most commonly caught fish. All results can be accessed through the UKSAIL website (https://rconnect.cefas.co.uk/sea_angling_library/).

The COVID-19 pandemic resulted in several national lockdowns in the UK, and additional local restrictions as well as personal circumstances due to the pandemic have impacted people's ability to fish. Reduced sea angling effort was found in the Sea Angling Diary panel, including sessions and catches, between 2019 and 2020 (Box 3). A survey of diarists showed that sea anglers spent less money during COVID-19, and not being able to go sea angling negatively impacted participation, effort, physical activity, and well-being. Total catch estimates were higher than those in the English 2012 onsite survey. It is likely that a combination of survey bias, sampling error, or changes in fish abundance generated the differences. The consistent difference between the approaches indicated that it is likely due to the methods, both of which are uncertain and subject to bias. As a result, a side-by-side comparison between diary and onsite approaches should be done in future to validate the diary approach. Further work is also needed to improve the robustness of the survey and outputs including better estimates of participation, increasing the size of the diary panel, improving the models, and assessing the economic impact and well-being.



Box 3. Seasonal patterns of average number of sessions per diarist each month in 2019 and 2020, with COVID-19 lockdowns (red), local restrictions (yellow), and no restrictions (green).

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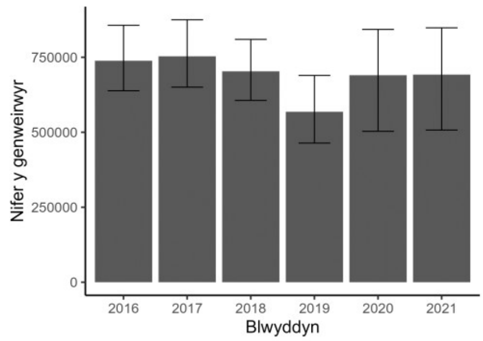


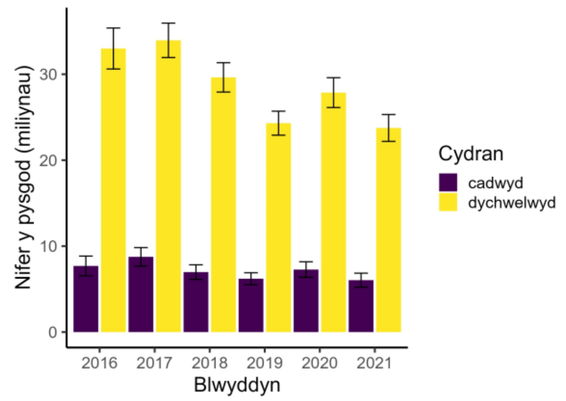
Blwch 1. Nifer y genweirwyr môr (miloedd).

Mae genweirio môr yn weithgaredd poblogaidd yn y DU sydd â manteision cymdeithasol ac effeithiau economaidd ond gall hefyd effeithio ar stociau pysgod. Mae angen i lywodraeth a rhanddeiliaid gael data ar gyfranogiad, daliadau a gwerth economaidd genweirio môr i gefnogi penderfyniadau gwybodus, datblygu'r sector a rheoli pysgodfeydd hamdden yn gynaliadwy. Mae rhaglen Dyddiadur Genweirio Môr wedi bod yn rhedeg ers 2016 gyda'r nod o amcangyfrif nifer y genweirwyr môr, pa mor aml y maen nhw'n pysgota, yr hyn maen nhw'n ei ddal, a'r manteision cymdeithasol ac economaidd maen nhw'n eu cynhyrchu. Gwneir hyn drwy gyfuno'r allbynnau o ddau arolwg: arolwg o 12,000 o unigolion sy'n cynhyrchu amcangyfrifon o nifer y genweirwyr a'u nodweddion; a genweirwyr môr sy'n gwirfoddoli fel 'gwyddonwyr dinasyddion' i adrodd eu dalfeydd trwy'r Dyddiadur Genweirio Môr. Mae'r amcangyfrifon hyn yn cael eu cyfuno gan roi cyfrif am wahaniaethau yn nodweddion genweirwyr môr i gynhyrchu'r niferoedd a'r tunelli o bysgod sy'n cael eu cadw a'u rhyddhau gan enweirwyr môr yn y DU.

Ers 2016, mae dros 5,000 o enweirwyr môr wedi darparu data ar dros 48,000 o sesiynau pysgota a 362,000 o gofnodion daliadau o 216,000 awr o weithgaredd genweirio. Maen nhw hefyd wedi cyfrannu at ddeall y manteision economaidd, a'r manteision cymdeithasol sy'n gysylltiedig â lles. Yn yr adroddiad hwn, rydym yn adeiladu ar astudiaethau blaenorol gan ddefnyddio'r 6 blynedd gyfan o ddata i ddatblygu dulliau ystadegol newydd sy'n cynhyrchu canlyniadau mwy cadarn a chyson, yn darparu amcangyfrifon ar gyfer 2016-21, ac yn asesu effaith COVID-19 ar enweirio môr.

Er mwyn amcangyfrif cyfranogiad ac ymdrech genweirwyr môr y DU, cafodd cwestiynau eu hychwanegu at arolwg o 2,000 o drigolion (Arolwg Cyfranogiad Chwaraeon Dŵr). Oherwydd cyfyngiadau COVID, nid oedd yn bosibl gwneud arolygon wyneb yn wyneb fel yn 2016-19, felly defnyddiwyd panel ar-lein yn lle. Gwnaeth panel ar-lein 2020 gynhyrchu amcangyfrifon llawer uwch nag arolygon blaenorol, mae'n debyg oherwydd y gwahanol ddulliau. Roedd hyn yn golygu nad oedd modd defnyddio canlyniadau 2020 yn y dadansoddiad gan y byddai'n effeithio ar gysondeb y gyfres amser. Yn hytrach, cafodd data o Arolwg Cyfranogiad Chwaraeon Dŵr 2016-19 ei fodelu a'i ddefnyddio i gael amcangyfrifon ar gyfer 2016-2020, a oedd yn amrywio o 568,188 i 753,165 ar gyfer y DU (Blwch 1). Defnyddiodd y dull hwn yr holl ddata presennol i gynhyrchu canlyniadau mwy cyson a chadarn nag amcangyfrifon blynyddol blaenorol.

Yn 2020 a 2021, cymerodd 2,237 a 2,729 o ddyddiadurwyr ran yn yr arolwg, yn y drefn honno. Ar draws y ddwy flynedd, adroddwyd ar gyfanswm o 15,064 o sesiynau a 107,697 o ddaliadau unigol ar draws mwy na 100 o rywogaethau gan hyd at 900 o enweirwyr môr bob blwyddyn. Defnyddiwyd y data hwn ochr yn ochr â chofnodion o 2016-19 i fodelu nifer y pysgod a gadwyd ac a ryddhawyd gan enweirwyr môr unigol bob blwyddyn a phwysau pysgod unigol. Cyfunwyd nifer y genweirwyr môr â daliadau'r panel dyddiadur fesul genweiriwr, er mwyn amcangyfrif cyfanswm daliadau'r DU, ar ôl cywiro am wahaniaethau rhwng sampl y dyddiaduron a phoblogaeth y DU.

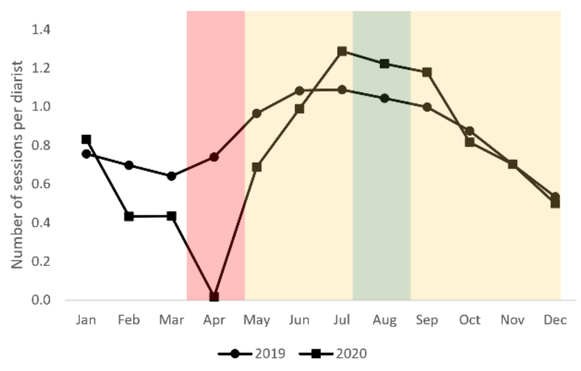


Blwch 2. Cyfanswm nifer y pysgod a gadwyd ac a ryddhawyd gan enweirwyr môr yn y DU o 2016-21.

Bob blwyddyn, cadwyd tua 7 miliwn o bysgod a rhyddhawyd 28 miliwn (Blwch 2), sy'n cynrychioli cyfradd rhyddhau o tua 80%. Roedd ychydig yn fwy o ddaliadau na'r dull ailbwysoli blynyddol blaenorol, gyda'r gwahaniaethau'n cael eu cynhyrchu gan nifer y genweirwyr. Fodd bynnag, cynhyrchodd y dull modelu ystadegol Bayesaidd ganlyniadau mwy cyson a chadarn ar gyfer y gyfres amser gyfan, felly cawson nhw eu defnyddio. Roedd cyfansoddiad daliadau'n debyg rhwng blynyddoedd; mecryll, môr-wyniaid, morgwn, a draenogod y môr oedd y pysgod a oedd yn cael eu dal amlaf. Gellir cyrchu'r holl ganlyniadau trwy wefan UKSAIL (https://rconnect.cefas.co.uk/sea_angling_library/).

Arweiniodd pandemig COVID-19 at sawl cyfyngiad symud cenedlaethol yn y DU, ac mae cyfyngiadau lleol ychwanegol yn ogystal ag amgylchiadau personol oherwydd y pandemig wedi effeithio ar allu pobl i bysgota. Gwelwyd llai o ymdrechion genweirio môr gan banel y Dyddiadur Genweirio Môr, gan gynnwys sesiynau a daliadau, rhwng 2019 a 2020 (Blwch 3). Dangosodd arolwg o ddyddiadurwyr fod genweirwyr môr wedi gwario llai o arian yn ystod COVID-19, a gwnaeth methu â mynd i enweirio môr gael effaith negyddol ar gyfranogiad, ymdrech, gweithgaredd corfforol a llesiant.

Roedd amcangyfrifon o gyfanswm y daliadau yn uwch na'r rhai yn arolwg ar y safle 2012 ar gyfer Lloegr. Mae'n debygol mai cyfuniad o duedd arolwg, gwall samplu, neu newidiadau mewn helaethrwydd pysgod oedd yn gyfrifol am y gwahaniaethau. Mae'r gwahaniaeth cyson rhwng y dulliau a ddefnyddiwyd yn arwydd bod hyn oherwydd y dulliau, fwy na thebyg, y mae'r naill a'r llall yn ansicr ac yn



Blwch 3. Patrymau tymhorol o ran nifer cyfartalog y sesiynau fesul dyddiadurwr bob mis yn 2019 a 2020, gyda chyfyngiadau symud COVID-19 (coch), cyfyngiadau lleol (melyn), a dim cyfyngiadau (gwyrdd).

destun tuedd. O ganlyniad, dylai cymhariaeth ochr yn ochr gael ei gwneud rhwng y dull dyddiadur a’r dull ar y safle yn y dyfodol i ddilysu'r dull dyddiadur. Mae angen rhagor o waith hefyd i wella cadernid yr arolwg a'r allbynnau gan gynnwys amcangyfrifon gwell o gyfranogiad, cynyddu maint y panel dyddiadur, gwella'r modelau, ac asesu'r effaith economaidd a'r llesiant.

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1. Introduction

The participation, effort, and catches of sea anglers resident in the UK each year have been estimated each year since 2016. An approach has been used combining estimates from two surveys (Hyder et al., 2020b; 2021). Firstly, the Watersports Participation Survey was used to estimate effort in terms of the numbers of anglers, their demographic characteristics, and angling experience. Secondly, the catches by individual sea anglers were collected through a diary panel of volunteers that provided information via a mobile app and online tool which included details of their sessions, numbers of fish kept and released, and the sizes of fish. Full details of the approach used to estimate participation, effort and catches by sea anglers resident in the UK are described in detail elsewhere (Hyder et al., 2020b; 2021), so are not repeated here. Instead, this report provides a summary of the full methods and references, detailed descriptions of methodological developments implemented, and an assessment of the results in the context of previous studies.

The approach used was similar to previous years with some exceptions. Firstly, an online panel was used for the Watersports Participation Survey as a face-to-face approach was not possible due to COVID-19. Secondly, a modelling approach was implemented to estimate effort and catches across years to improve confidence in the results and reduce potential biases. This built upon methods developed in 2020 to make the most efficient use of the data available (Hyder et al. 2021). Finally, a survey of diary panel members on the impacts of COVID-19 on sea angling activity, expenditure, and well-being was carried out to support interpretation of the 2020 results in the context of the pandemic.

The remainder of this section provides background information that is needed to interpret the results of the current study in the context of previous research. This includes: general information on the importance of recreational fisheries (Section 1.1); a description of the range of survey approaches for recreational fisheries data collection (Section 1.2); and the outcomes from previous studies of sea angling in the UK (Section 1.3).

1.1. Importance of marine recreational fisheries

Marine recreational fishing (MRF) is globally important in terms of catch (Hyder et al., 2017; 2018; Radford et al., 2018; Lewin et al., 2019), economics (e.g. Hyder et al., 2017; 2018), and the physical health and well-being of those who participate (McManus et al., 2011; Armstrong et al., 2013; Griffiths et al., 2017). Information on the social, economic, and biological impacts of MRF is needed to underpin fisheries management, so data collection programs have been introduced to provide evidence to help national and international policy makers make balanced and well-informed decisions (e.g. ICES, 2017; Hyder et al., 2017; 2018; 2020a). Sea angling data can be used to support local, national, and regional management of fish stocks, environmental protection, marine spatial planning, development of the blue economy, and physical health and well-being (ICES, 2015).

Catches of some species can be large enough to impact fish stocks (Hyder et al., 2017; 2018; Radford et al., 2018; Lewin et al., 2019). Within ICES, only European sea bass (*Dicentrarchus labrax*), western Baltic cod (*Gadus morhua*), Baltic sea trout (*Salmo trutta*), and Baltic salmon (*Salmo salar*) have MRF catches included in the stock assessment model, and MRF catches are highlighted in the advice for North Sea cod, Irish Sea cod, and pollack. Typically, the lack of inclusion of MRF catches within the stock assessment is due to insufficient MRF data being available. Exclusion of recreational catches from fisheries stock assessments and management may affect the ability to manage fish stocks sustainably (Hyder et al. 2014; 2017; 2018; 2020a).

Until 2020, it was a statutory requirement under the EU Data Collection Framework (DCF) for the UK to report recreational catches and releases of cod, sea bass, pollack (*Pollachius pollachius*), elasmobranchs, eel (*Anguilla anguilla*), salmon, and highly migratory species (the EU Data Collection Framework (Council Regulation (EC) No 199/2008[1]) and the Multi-Annual Programme (Council Regulation (EU) 2017/1004[2])). Since leaving the EU, the UK is an independent coastal state with control over its territorial waters. Marine recreational fisheries are now embedded in UK fisheries management through the Fisheries Act (2020)[3], alongside the provision for funding for recreational and commercial fishing development. This means that to meet the objectives of the Fisheries Act, it is important to have biological, social, and economic data on recreational fisheries to inform Fisheries Management Plans and sector development. In addition, the UK provides data to ICES on the numbers and tonnages of recreational catches of cod, sea bass, pollack, salmon, eels, elasmobranchs and highly migratory species.

1.2. Data collection methods

The diversity of gears and diffuse nature of MRF make surveying the activity complex (Hyder et al., 2020a), with a full description of potential approaches provided elsewhere (Pollock et al. 1994; ICES, 2010; Jones and Pollock, 2013). Often there are no comprehensive lists of fishers and their catches (e.g. through licences), so it is necessary to carry out independent surveys of MRF effort and catch per unit effort (cpue) to estimate numbers caught. In addition, collection of data on lengths or weights of individuals caught are needed to estimate tonnages (Pollock et al. 1994; ICES, 2010; Jones and Pollock, 2013). Typically, individuals are surveyed to ascertain the effort and cpue, which is then extrapolated to the whole population after correcting for differences between the compositions of the sample and the population in age, location, number of fishing trips (avidity), fishing platform (boat, shore), and/or gear.

There are many different survey approaches, so selecting an MRF survey design is a process of finding a suitable trade-off between logistics, staffing and resources needed, available budget, likely response of anglers, the potential for bias, and the types and

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02008R0199-20080312
[2] https://eur-lex.europa.eu/legal-content/en/TXT/?uri=CELEX%3A32017R1004
[3] https://www.legislation.gov.uk/ukpga/2020/22/contents/enacted

quality of information needed by end users. The survey approaches used can impact on the outcome as there are different challenges and biases, which can affect the magnitude of the estimates (Hartill et al., 2015). In addition, time series are needed for inclusion in stock assessments, so maintaining a consistent approach over time is essential.

1.3. Sea angling in the UK

Sea angling using rod and line is the most common form of MRF in the UK, so has been the subject of a number of studies (e.g. Drew, 2004; Simpson and Mawle, 2005, 2010; Radford and Riddington, 2009; McMinn, 2013; Armstrong et al., 2013; Roberts et al., 2017; Brown et al., 2019; Hyder et al., 2020b; MMO, 2020). These studies are summarised below and cover the participation, effort, economics, social benefits, and catches made by sea anglers in part or the whole of the UK.

1.3.1. Participation & effort

As there is no licence or other form of registration required for sea angling in the UK, several surveys have been conducted in the past to ascertain the number of people participating in MRF and how often they fish (e.g. Drew, 2004; Simpson and Mawle, 2005, 2010; Radford and Riddington, 2009; Armstrong et al., 2013; McMinn, 2013; Hyder et al., 2020b; 2021). Most recently, the most widely used survey to estimate sea angling participation and effort in the UK is the Watersports Participation Survey (WPS), which samples over 12,000 households in the UK and has included questions on sea angling since 2016. Between 2016 and 2019, the WPS estimated that between 551,000 to 902,000 people participate each year in the UK, fishing for 6.0 to 7.5 million days annually (Hyder et al. 2021).

1.3.2. Economic and social benefits

Several studies have been done in the UK to assess the economic value and impact of sea angling (Drew, 2004; Lawrence, 2005; Radford and Riddington, 2009; Armstrong et al., 2013; Monkman et al., 2015; Roberts et al., 2017; Brown et al. 2019; Hyder et al., 2020b; 2021), which have been described in detail within previous survey reports (Hyder et al. 2020b; 2021). In brief, initial estimates of expenditure by sea anglers in England and Wales in 2003 found substantial expenditure (£538 million), number of jobs directly supported (19,000), and supplier income (£71 million) (Drew, 2004). Similar studies conducted in 2009 have also confirmed this to be the case for Scotland (Radford and Riddington, 2009). More recent and comprehensive economic studies of sea angling (Armstrong et al. 2013; Roberts et al., 2017; Hyder et al., 2020b) have highlighted MRFs economic importance to the UK. Each year, sea anglers spend up to £1.3 billion, generating a direct impact of up to £847 million. In 2016-17, this resulted in a total economic impact of £1.6-£1.9 billion, supported 13.6-16.3 thousand jobs, and created £696-£847 million Gross Value Added (GVA).

There are both personal and societal benefits derived from sea angling. These include benefits to society from the individual actions of sea anglers, such as involvement in environmental improvement work and volunteering (McManus et al., 2011; Armstrong et al., 2013; Griffiths et al., 2017). The National Angling Survey in 2018 showed that 57% of anglers (of whom a quarter fished in the sea) had been involved in environmental improvement volunteering in the preceding 12 months (Brown, 2019), which was similar to earlier studies (e.g. Armstrong et al., 2013). Brown et al. (2019) showed that three-quarters of sea anglers would contribute to data collection. In terms of personal benefits, 72% of anglers in the National Angling Survey said that angling helped to keep them healthy, 27% said it was their main way of being physically active, and 70% said it helped them deal with stress (Brown, 2019).

1.3.3. Catches

An onsite roving creel survey was used to estimate the total annual catches of sea anglers in England (Armstrong et al., 2013). A total of 10.1 million fish were estimated to be caught in England in 2012 by all sea anglers, the most common of which were mackerel and whiting (Armstrong et al., 2013). Shore anglers released around 75% of the fish caught, and boat anglers around 50% of their fish (Armstrong et al., 2013). Numbers of fish kept and released were estimated for 20 species or groups. Tonnages were estimated for sea bass ranging from 380–690 t with 230–440 t retained, and cod was between 480–870 t with 430–820 t retained (Armstrong et al., 2013).

In 2016 and 2017, a diary panel was recruited to participate in an offsite catch diary programme to give estimates of cpue for each species in terms of catch per angler per year. These were combined with estimates of effort (number of fishers) from the WPS to generate estimates of catch (Hyder et al., 2020b). The same approach was used to estimates catches in 2018 and 2019 (Hyder et al. 2021). The total catch estimates in 2016-19 were similar each year (2016: 49.7 million; 2017: 54.5 million; 2018: 46 million; 2019: 43 million), as was the release rate of around 80%. However, large interannual variation for several species, such as pollock, were found (Hyder et al. 2021) and release rates varied between species. Furthermore, the total catches estimated in 2016-19 were substantially larger than those found in the 2012, this is primarily due to a higher released component in the offsite survey. As the 2012 data were for England in a single year and used different survey methods, it was not possible to determine the extent to which the higher catch estimates are due to survey bias, random sampling error, or changes in fish abundance. It is likely that a combination of these factors generated the differences (Hyder et al. 2021).

1.3.4. Impact of COVID-19

The COVID-19 pandemic has had an impact on MRF across the world (Gundelund & Skov, 2020; Pita et al., 2021). The potential for impacts on MRF varied between countries as the restrictions on activities differed (Pita et al., 2021). In the UK, the number and duration of lockdowns and associated restrictions varied regionally and were complex (Pita et al., 2021); this resulted in different impacts on sea angling. At the beginning of the COVID-19 pandemic, UK lockdowns restricted people's ability to participate in recreational angling in both fresh and saltwater. From the 23 March to the 13 May 2020, any form of angling was completely banned in the UK (Institute for Government, 2021). After this, there were varying restrictions at national, devolved administration, regional, and city levels. Other factors relating to the pandemic, including infection, requirements to 'shield', restrictions on travel and personal decisions about safety also impacted participation in sea angling. However, the impact of COVID-19 on the participation and effort, physical activity, and well-being of UK sea anglers prior to this study remains largely unknown.

There is a wealth of evidence that participating in sports and active recreation can improve physical health and well-being (McNally et al., 2015). Whilst some research has sought to identify the particular benefits that outdoor recreation has for participants (Eigenschenk et al., 2019), studies on the health benefits of angling in general, and sea angling in particular, are limited (McManus et al., 2011; Armstrong et al., 2013; Griffiths et al., 2017). The full impact on the health and well-being of individuals who undergo a reduction or possible loss in outdoor recreational sports due to direct or indirect effects of COVID-19 are not fully understood. Restrictive access to blue spaces to pursue outdoor recreational activities, such as angling, contributed to the negative effects of the pandemic on health and well-being (Guzman et al., 2020; Astell-Burt and Feng, 2021; Pouso et al., 2021). This was particular stark for those who were classified as vulnerable to the risks of COVID-19 outcomes (Geary et al., 2021). Outdoor recreational sports are important for physical and mental health and well-being, with the benefits of combining outdoor recreational sports with nature and the natural environment identified (St Martin, 2007).

1.4. This study

This study estimated participation, effort, and catch of sea anglers resident in the UK in 2020. The outputs from separate surveys of effort (Watersports Participation Survey) and catch per angler (Sea Angling Diary[4]) were combined using a modelling approach to minimise bias. An additional survey was done on the impacts of COVID-19 pandemic to support the comparison of the results with previous years and understand its effects. This report describes the methodology, participation, and catch results, and discusses the implications for future surveys. The description of the methods is complex and is written to be understandable and repeatable by a scientist working in this area. This is done to ensure that the robustness of approach can be evaluated by other scientists but may not be accessible to all readers.

[4] www.seaangling.org

2. Methods

The overall aim of the survey programme was to estimate the numbers and tonnages of fish of each species kept and released by sea anglers aged 16 and over resident in the UK, along with the associated estimates of uncertainty. Two independent surveys provided data on effort and cpue:

- Watersports Participation Survey (WPS): a survey of 12,000 households across the UK that provided a population-level estimate of the numbers, profile, and activity of sea anglers in the UK (Section 2.1.1).
- Sea angling diary: a year-long online catch diary tool and mobile app that provided a record of the session-by-session catches from a self-selecting UK-wide panel of sea anglers, from which mean cpue (annual catch of each species per angler) was estimated (Section 2.1.2).

The total annual catch of a species was calculated by combining estimates of numbers of anglers with catches by individual anglers from the Sea Angling Diary panel (Section 2.2). This accounted for the difference in composition of the diary panel in terms of age profile, stated avidity, fishing platforms and other characteristics from the composition of the WPS sea angling respondents. A statistical multi-level regression modelling approach was developed and tested against traditional approaches to assess the robustness of the new method (Section 2.2). A further survey was done to assess the impact of COVID-19 on sea angling in the UK and to support the interpretation of results (Section 2.3).

2.1. Data collection

2.1.1. Participation and effort

The WPS started in 2002 with the aim of monitoring participation in water sports and has run every year since. A full description of the survey approach is provided in Hyder et al. (2020b), with a short summary of the approach provided below. In 2020, the WPS had to be done using an online marketing panel as face-to-face interviews were not possible due to COVID-19. The method for this approach will also be described below.

From 2015-19, questions about sea angling were added to a face-to-face survey of 12,000 UK households. Across the UK, 605 sample points were selected from a sampling frame created from non-overlapping areas of similar population sizes within a single Government Office Region (see Hyder et al., 2020b for a full description). Sampling approaches differed in the area north of the Caledonian Canal and Northern Ireland from the rest of the UK. Sampling points were stratified by Government Office Region (GOR) and social grade and then subjected to random systematic selection. Within each selected area, a sample of 13, 15, or 17 individuals of 16 years or older in London, and 15, 17, or 19 individuals elsewhere was obtained. Interviewers were set quotas based on gender to ensure equal gender ratios within the sample. Each interviewer was given an interview script that included background information and a full set of questions to read from. This included information and a simple set of questions about sea angling using a rod and line from a kayak, private or rental boat, charter boat, and the shore and recreational fishing activity using other gears. If the respondent answered yes to any of these categories, they were then asked how many times they had participated in these activities in the UK in the last year and for some information on their angling experience. A minimum of 10% of surveys were checked by trained validators to ensure consistency of data collection and identify issues with survey approaches. Questionnaire responses were weighted based on the interviewee's location, age, sex, and social grade. A breakdown of demographics published by the Office of National Statistics (ONS) was used to raise the weighted samples (questionnaire responses) to the entire population of the UK over the age of sixteen.

In 2020, the WPS had to change from a face-to-face to an online marketing panel methodology due to COVID-19 restrictions. This meant that, whilst the interview questions were similar, the method for selecting the representative sample of 12,000 respondents was very different to previous years. In 2020, the marketing panel was delivered by Dynata[5] using a multi-sourcing panel recruitment model. A variety of contact methods were used to recruit: loyalty partnerships, which consisted of panels built via partnerships with loyalty programs from a globally extensive set of brands and communities; open sourcing, which referred to traditional online panels where members were recruited via online banners, social media influencers, and other means; and integrated sourcing, which came from trusted partners. Initial screening surveys were sent to the panel based on known response rates of different demographic groups, after which the final survey was deployed. Once the survey was completed by all participants some reweighting was required to account for differences in characteristics between the sample (respondents) and the UK population. This was done using a random iterative method that is commonly used in market research as it enables accurate weighing when not all characteristics of the target population are known. The UK population characteristics were taken from Office for National Statistics (ONS) regional and socio-economic data. Due to the different approach used to collect data in the 2020 WPS, it was not possible to use the 2020 results in the analysis as it would impact on the consistency of the time series.

2.1.2. Diary panel

The Sea Angling Diary has been running since 2016. Each year, sea anglers are recruited to keep catch diaries. A full description of the approach can be found in Hyder et al. (2020b), but the methods for recruitment (Section 2.1.2.1) and data collection from diarists (Section 2.1.2.2) are summarised below.

2.1.2.1. Recruitment Methods

In 2020 and 2021, diarists were recruited through a variety of different means including those adopted in previous years (people were directed to a website with sign-up survey via

[5] www.dynata.com

online and print recruitment materials) (Hyder et al., 2021), with increasing use of targeted social media and partner organisation mailouts. The target for 2020 and 2021 was to generate a diary panel of at least 1,515 sea anglers, including 90, 105, 165, and 1,155 from Northern Ireland, Scotland, Wales, and England, respectively. The partitioning was based on the proportion of the total number of sea anglers residing in each country from the 2016 WPS. To achieve this target number of diarists, participants from previous years were retained and new diarists recruited through a variety of different means described below. The rates of retention and volume of new recruits varies by year due to differing recruitment methods, timing, and contexts.

Recruitment for 2020 occurred mainly between November 2019 and March 2020 and for 2021, between November 2020 and March 2021, although diarists were able to sign up at any point during each year. Recruitment was done by contacting an existing database of anglers by email, through angling clubs, internet fora, adverts and articles in published media, paid for advertisements through social media. Posters and business cards advertising the study were sent to angling businesses (charter boats and tackle shops), angling federations and to sea angling clubs (Table 1). In addition, business cards were distributed via Fishing Megastore[6] to their mail order customers throughout the year.

Table 1. Recruitment methods utilised and number of contacts made. Direct email reflects contact with the Substance angler database. The numbers relate to each individual category of diarist related to timing of recruitment.

Publicity	Method	2020 number sent	2021 number sent
Direct email to Substance database	Email	24,152	27,748
Charter boats	Email/telephone/post	255	312
Clubs	Email/telephone/post	208	242
Tackle shops	Email/telephone/post	356	401
Federations	Email/telephone/post	34	19
Events/angling sites	Face-to-face	1*	0
Magazines, etc.	Press release sent	3	4
Forums/websites/Social media	Press release sent	13	13
Posters	Print distributed	500	586
Leaflets	Print distributed	5,000	0
Business cards	Print distributed	25,000	20,000

Potential diarists completed a sign-up survey providing information on their demographic characteristics (e.g. age, gender, location), fishing habits (e.g. avidity), and fishing skill and experience (e.g. self-assessed skill level, number of years sea angling, and consistency of sea angling across their lifetime). They were also asked about their intention to fish in the sea in 2020 or 2021, and if they wished to take part in the diary panel. Once they had signed up to the diary project and entered one month of data, diarists were sent a pack including a fish identification booklet, tape measure, and waterproof notebook or phone holder. An explanation was provided of the recording requirements (including location, duration, method, and catches) and access was given to the online diary system and app to record catches each month. Guidance documents were produced and made available

[6] www.fishingmegastore.com

on the tool and via the app. Videos containing guidance on using the mobile app and online tool were also produced and distributed.

2.1.2.2. Data collection

The Sea Angling Diary tool was developed in 2016 for data entry (see Hyder et al. 2020b; 2021 for a full description). Diarists had to record whether they fished in a month or not, as an absence of data entry could not be assumed to indicate that no fishing had taken place. Diarists were asked to 'lock' their month once all data had been entered for the period, so that it was clear that data entry was complete. To maximise data entry, significant effort was put into development of a system that was user-friendly and provided summary statistics, a dashboard, and an 'annual report' of an individual angler's catches. The structure was hierarchical and started with a 'Calendar' page with a simple one click to record fishing or no fishing activity in each month. If fishing had occurred, then a 'Session' was added that included location, duration, platform and gear. If a catch was identified on the 'Session' screen, then a 'Catch' page was generated where all catch details were captured including species, length where known, and numbers kept and released.

In additional to the online interface, data could be entered through a mobile app on iOS and Android (Figure 1). The app precisely mirrored the functions, data fields, and style of the diary tool, and data was synced between the two so users could use both interfaces. The app allowed diarists to record data during a fishing session and was designed to: make data entry easier and more immediate; reduce recall bias and inaccuracy; and improve data completion. The mobile app aimed to make participation more appealing to a wider group of recreational sea anglers and provided new ways of contacting and engaging with diarists. Diarists were able to choose to share sessions with other sea anglers, with 41% of sessions shared in 2020 and 38% shared sessions in 2021. Where sessions were shared, each fishing location recorded was 'jittered' (moved a small distance in a random direction) and only provided as a 5 km area to protect the location of angler's individual marks.

One of the challenges with diary panels was to ensure completion of data entry by sea anglers (Hyder et al. 2020b; 2021). As a result, significant effort was put into following up with diarists to ensure that data entry was completed each month. Diarists were sent reminders by email three times every month to help maximise response rates. Two of the emails used a mail merge to specify for each diarist which data were missing for that month and one email was in the form of a newsletter. Reminder push notifications were sent to those with the app twice a month. Text polls were used for the first time in 2020 to improve data completion. These were sent to diarists who were missing data twice a month in 2020 and 2021. Diarists could respond by saying whether they had fished in the month concerned or not. Where a diarist had not fished, this was recorded in the database and their diary account. Individuals who responded to say that they had fished were contacted via email or phone, to complete details about their sessions and catches. In addition, at various stages, diarists who had not logged in, had not entered data, or had missing data were contacted by telephone. This approach was expanded in 2021 to further encourage data entry, with incentives provided in the form of prize draws for tackle vouchers from FishingMegastore, Amazon vouchers, and subscriptions to Sea Angler magazine.

Due to UK wide COVID-19 restrictions in April 2020 which mean that no fishing was possible, all diaries were entered as ‘Not Fished’ for that month. Given the varied relaxation and re-tightening of restrictions in different parts of the UK in 2020, this was only done in April.

Data were anonymised, so that individual anglers could not be identified. Simple descriptive statistics of the recruitment, data entry activity, and catches were generated each quarter throughout the year and annual summaries provided in the results.

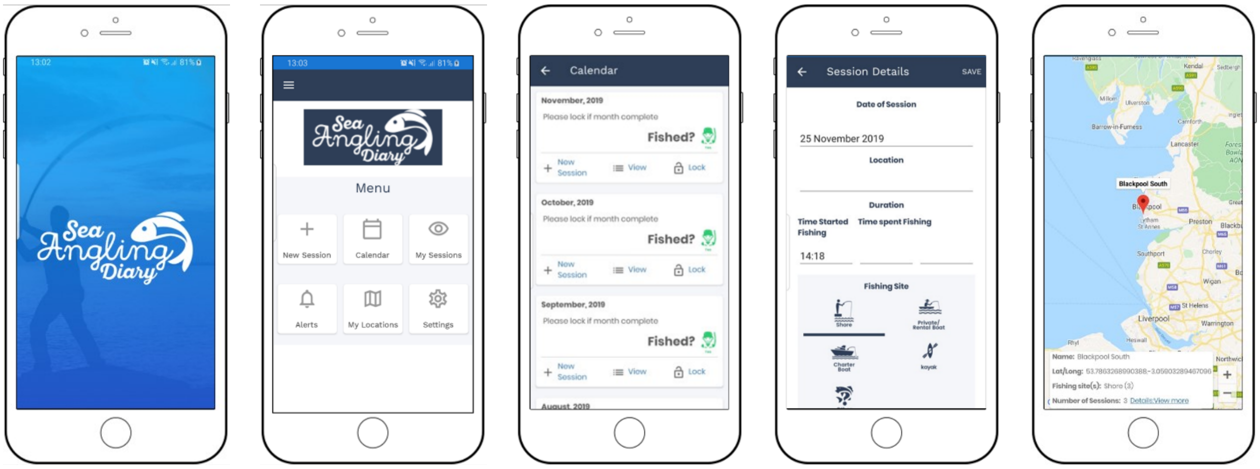


Figure 1. Screenshots from the Sea Angling Diary mobile app.

2.2. Catches by UK sea anglers

To quantify catches by UK sea anglers, it was necessary to combine estimates of the numbers of anglers (effort) and catches by individual anglers (catch per unit effort) accounting for the difference in composition of the diary panel in terms of age profile, stated avidity, fishing platforms and other characteristics from the composition of the WPS sea angling respondents. All results can be accessed through the UKSAIL website[7].

A process for estimation of catches by UK sea anglers was adapted from previous studies that involved thresholds for completeness of individual angler data, numbers of catches recorded and the numbers of diarists and sessions reporting species, and the number of lengths measurements provided (Figure 2). To improve the number of species that could be reported, all blenny, goby, grey mullet, rockling, sandeel, sea scorpion, shad, and wrasse species were grouped together. Bayesian multi-level regression models were developed using the WPS and combined with UK census data[8] (ONS, 2017) to give an estimate of effort (number of anglers; Section 2.2.1.1) as well as their avidity (days fished;

[7] https://rconnect.cefas.co.uk/sea_angling_library/
[8] https://www.nomisweb.co.uk/query/construct/summary.asp?mode=construct&version=0&dataset=2002

Section 2.2.1.2). Furthermore, Bayesian models were developed using the diary data to estimate the catch per angler (Section 2.2.2) and weight of fish caught (Section 2.2.3). The estimates for the number of sea anglers at each avidity level, catches per angler, and weight of fish caught were combined to give an estimate of the overall UK catch (Figure 3). Two methods were used to generate effort and catch estimates: a standard reweighting approach as used in previous years (Hyder et al., 2020b; 2021) and a model-based approach called multi-level regression and poststratification (MRP; Gelman & Little, 1997; Park et al., 2004). These were compared using simulated data to assess which of the approaches was most robust (Figure 4). A summary of the approaches and testing is provided in Table 2.

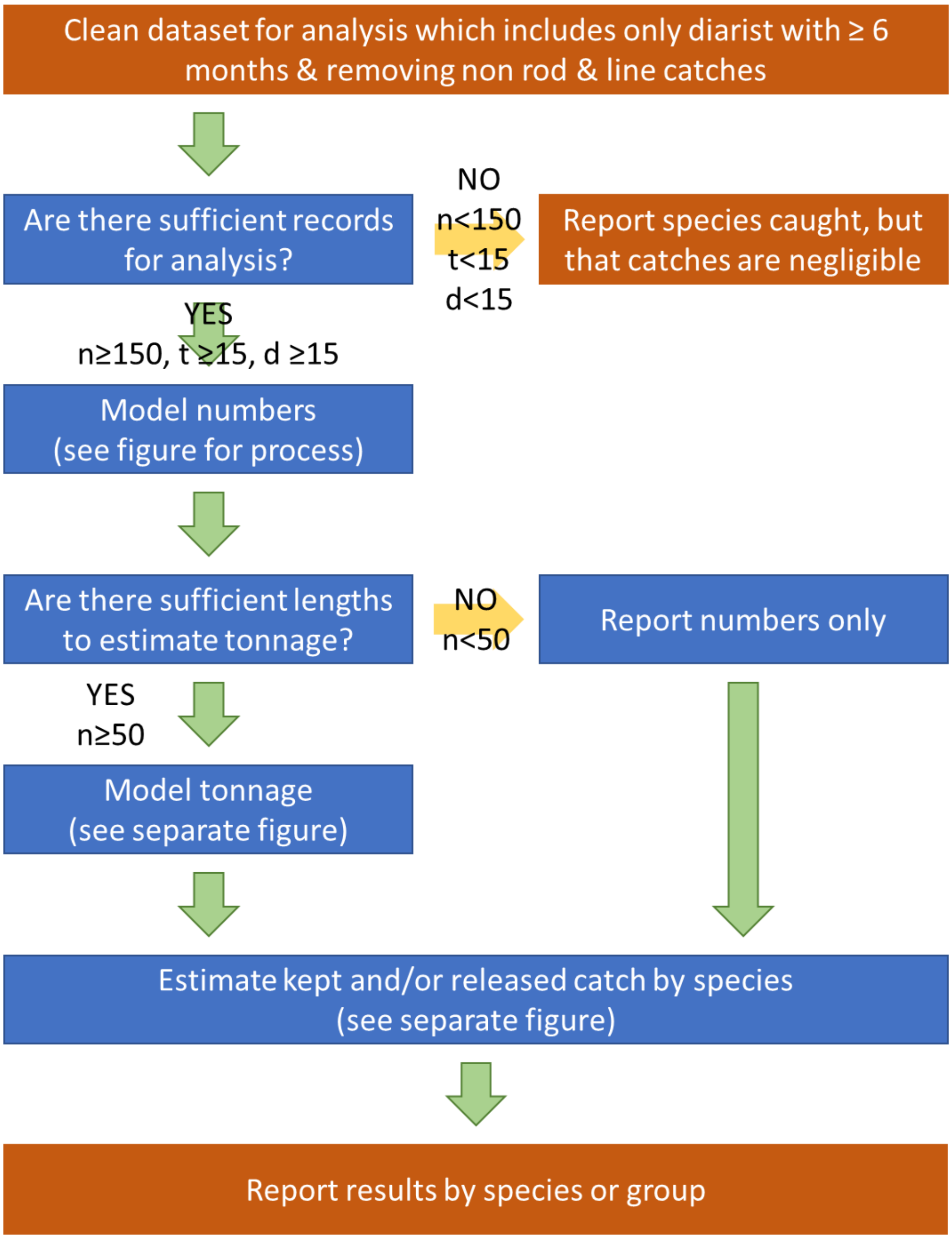


Figure 2. Schematic demonstrating the overall estimation procedure for each species and/or group. This includes the thresholds used to identify which species can be modelled and if sufficient data was available to generate tonnages. Thresholds are given for number of records (n), trips (t), and diarists (d).

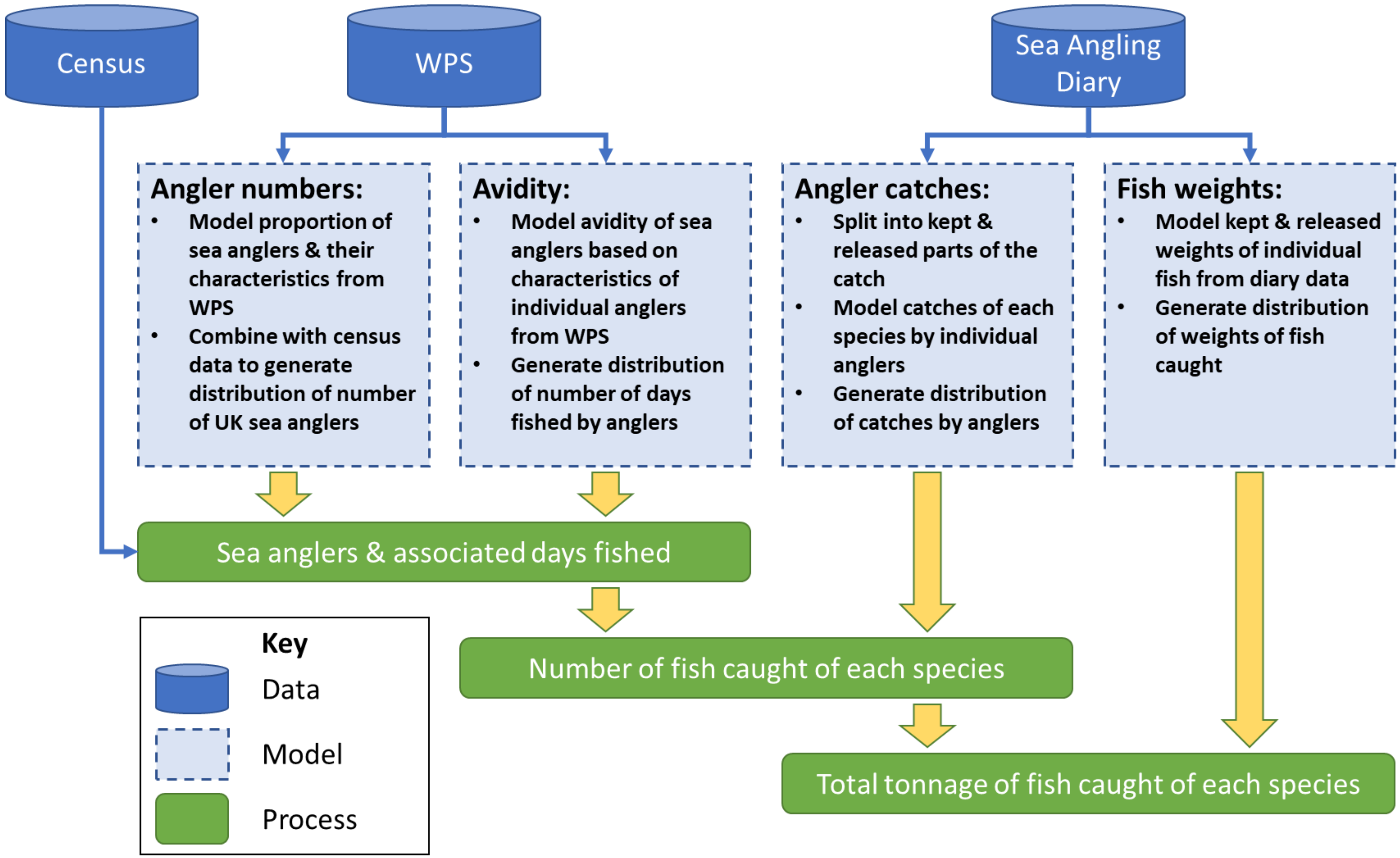


Figure 3. The data, models, and processes developed to estimate the numbers of sea anglers, numbers of fish kept and released, and the tonnages of fish kept and released. Census relates to demographic data on the population of the UK collected by the Office for National Statistics and WPS is the Watersports Participation Survey. Detailed descriptions of the modelling approach and testing are provided in the sections below.

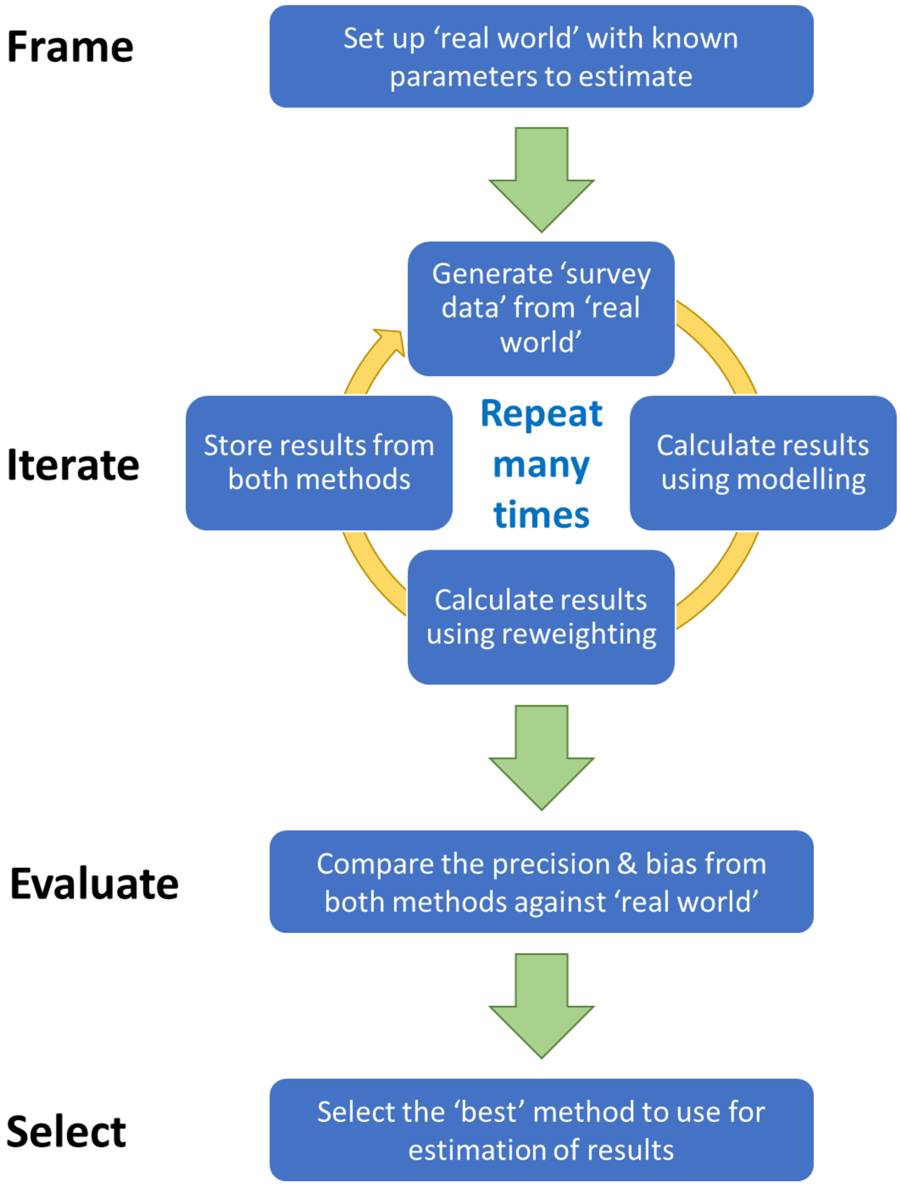


Figure 4. Simulation study approach used to assess the 'best' method for estimating numbers of anglers and catches.

Table 2. Summary of overall modelling approach alongside assessment of the validity of the model and comparisons against the reweighting approach. See methods for further descriptions of the individual modelling and testing approaches.

Quantity	Model	Assessment of model
Participation (number of anglers)	Bayesian logistic regression including gender, age, region, number of angling clubs, and year. Priors informed by expert elicitation.	Done using leave-one-out cross-validation (LOO-CV) against a minimal model, and posterior predictive checks. A simulation approach was used to assess the robustness of MRP against a traditional reweighting approach. An assessment was made of the drivers of the differences between the two approaches.
Avidity (days fished)	Bayesian beta-binomial mixture model including gender and region. Priors informed by expert elicitation.	Done using leave-one-out cross-validation (LOO-CV) against a minimal model, and posterior predictive checks.
Catch per angler	A zero inflated Bayesian negative binomial model including avidity, region, and year. Hyperpriors were used that followed a normal distribution	Done using leave-one-out cross-validation (LOO-CV) against a minimal model, and posterior predictive checks.
Individual fish weight	Bayesian lognormal model of individual fish weights for kept and released components that included the uncertainty. This included a predictor variable of ‘midpoint weight’. Priors were based on standard normal distribution.	Done using posterior predictive checks.
Total catch (number)	Estimated using the effort and the catches per angler models, accounting for differences in avidity, age, gender and region.	A simulation approach was used to assess the robustness of MRP against a traditional reweighting approach. An assessment was made of the drivers of the differences between the two approaches.
Total catch (tonnage)	Estimated by combining the posterior distributions of the total catch and the weight models for each species kept and released.	An assessment was made of the drivers of the differences between the two approaches.

2.2.1. Effort

Due to the different approach used to collect data in the 2020 WPS, it was not possible to use the 2020 results in the analysis as it would impact on the consistency of the time series. Instead, data from the WPS from 2016-19 were used to derive estimates of effort. Each year, around 12,000 responses were generated from a face-to face survey that included questions about participation in sea angling alongside collecting information about socio-demographic characteristics (e.g. location, age, social group). Responses were weighted based on the interviewee location, age, sex, and social grade. A breakdown of demographics published by the ONS were used to raise the weighted samples (questionnaire responses) to the entire population of the UK over the age of sixteen each year. This generated an estimate of the number of sea anglers and the associated level of error. The issue is that sea angling is relatively rare in the population (<2%) and so there are few sea angling respondents, even across the multiple years. Hence, statistical approaches were needed to generate robust estimate of the number and profile of sea anglers across the UK.

Model-based approaches are often used when data sets are small or biased as they can make efficient use of the information in a dataset. In addition, information from other sources, such as previous studies and expert elicitations, can be included in the models to provide more accurate estimates. For survey analysis, a model can be combined with post-stratification to create an alternative to survey weighting. This approach, called Multi-level Regression and Poststratification (MRP; Gelman & Little, 1997; Park et al., 2004), has been used frequently in survey analysis, and the models developed here were part of an MRP analysis. In particular, MRP has become an important approach for analysis of sparse and non-probabilistic surveys. It was first used to adjust a survey of Xbox players (overwhelmingly young men) to give estimates as accurate as leading polls for the 2012 US election. It has since been adopted for use in diverse areas such as sports policy (Downes et al., 2018), public health (Pouwels et al., 2021), and public opinion research (Ghitza & Gelman, 2020).

Like reweighting, MRP uses poststratification, splitting respondents from a survey into mutually exclusive categories. However, instead of taking the mean of a stratum for the estimate, the method uses a multi-level model to predict the variable of interest (in our case whether someone is a sea angler). The key benefit of using a multi-level model is that this allows information to be shared across categories. While there may be differences between, for example, 35-54 year old men and 55+ year old men, there is still a great deal of similarities between them. Modelling effort allows this extra information to be used to separate the underlying patterns of effort across individual respondents.

MRP analysis involved an iterative process with two stages: 1. building a multilevel model to estimate individual physical activity; and 2. creating a post-stratification frame of the variables used in the model to stratify the population of interest. Due to the complexity of the data, the prediction of the number of times a person had been sea angling in the last year was divided into two parts and modelled separately. These models predicted whether an individual had been sea angling in the last year (participation) and how many times had they been (avidity) (Figure 3).

The models were developed following a principled Bayesian workflow (Gelman et al., 2020), relying heavily on simulation and iteration. Bayesian statistics uses an interpretation of probability to expresses a degree of belief in an event. It incorporates prior knowledge about the event, such as the results of previous experiments or personal beliefs about the event. A Bayesian framework was used instead of a traditional frequentist approach, as it was better able to deal with multiple data sources and missing data. It also allowed the incorporation of prior information, for example, existing information on the size of the angler population in the UK. The Bayesian approach was also more robust and was able to estimate models for which frequentist maximum likelihood-based methods fail.

Bayesian models were implemented using the R package *brms* (Bürkner, 2021a), a wrapper around the probabilistic programming language *Stan* (Carpenter et al., 2017). The R package *tidymrp* (Kroese 2021b) was used for combining the model and poststratification frame.

2.2.1.1. Participation model

For predicting participation (Figure 3), a Bernoulli likelihood was used as it is appropriate for binary data (i.e., sea angler or not sea angler). The model uses a logistic link to connect the Bernoulli distribution probability parameter to the independent variables and can be referred to as a logistic regression. A range of variables were explored as potential predictors including age, proximity to the sea, and the number of tackle shops, charter boats and sea angling clubs in the region. The R package *loo* (Vehtari et al., 2020) was used to compare models using approximate leave-one-out cross-validation (LOO-CV), a statistic that is a reliable indicator of predictive accuracy for Bayesian models (Vehtari, et al., 2017).

Models with higher values of LOO-CV included variables of gender, age, NUTS 1 statistical region[9], and the number of sea angling clubs in a region. Of the region-level variables, the number of sea angling clubs had more predictive value than the number of tackle shops or charter boats. As there are only twelve regions, using more than one region level variable would lead to overfitting and so only the number of sea angling clubs was used. The model can be considered as a multi-level regression model, using the two levels of an individual and the region they live in. Both age and number of clubs were normalised to have all values between 0 and 1. The independent variables were:

- Gender as a fixed effect.
- Age normalised and as a smoothed term, using splines implemented in the R package *mgcv* (Wood, 2021).
- NUTS 1 statistical region, as a random effect.
- Number of sea angling clubs in a region normalised and as a fixed effect.

[9] https://en.wikipedia.org/wiki/NUTS_1_statistical_regions_of_England

- Year, as a random effect.

For key parameters, such as the proportion of people who are anglers and the proportion of those that are female, the priors were determined through an expert elicitation conducted according to the Sheffield Elicitation Framework (Gosling, 2018). Parameters which were harder to intuitively reason about were set using generic weakly informative priors. These generic weakly informative priors allowed the statistical computing to run effectively without a significant impact on the inference. The model was run on 8 chains for 2000 iterations, with burn-in of 1000 iterations, an adapt-delta value of 0.8, and maximum tree depth of 10.

The model fit was assessed in multiple ways. A minimal model was built that did not include any independent parameters, which gave a baseline to compare LOO-CV values against. In addition, a simulation study (Figure 4) was used to assess different approaches, with better methods generating more accurate results. Finally, posterior predictive checks (Gelman et al., 2020) were used to compare simulated datasets from the posterior predictive distribution to the actual data. A good model has simulated datasets that are representative of the data.

2.2.1.1.1. Assessing methods using simulation

Following a poststratification approach, there were different methods to get the estimates for within-stratum effort and catches (Gelman, 2007): reweighting and model-based. Hence, it was important to compare the new model-based approach with the traditional reweighting approach used to analyse the WPS data. This was done using a simulation that allowed comparison of the precision and bias of the estimates from the two methods and select the 'best' approach to use (Figure 3).

A traditional post-stratification approach has been used to reweight the sample and generate estimates of the number of UK adult sea anglers (Hyder et al., 2020b; 2021). Briefly, questionnaire responses were weighted based on the respondent location, age, sex, and social grade, and were entered into a weighting matrix. A breakdown of demographics published by the Office of National Statistics (ONS) was used to raise the weighted samples (questionnaire responses) to the entire population of the UK aged sixteen years or older. Standard errors were calculated for the activities. As the WPS did not use a simple random sampling approach, computation of a design effect was necessary to adjust the standard errors for each category of respondent. This was applied to give individual errors for each stratum and then combined to generate the weighted standard error for each activity (Hyder et al., 2020b). The weakness of the WPS reweighting approach were: the numbers of individuals in each stratum can be small; it does not make effective use of all of the available data as each individual just contributes to the stratum that they are within; and weighting analysis was focused on choosing strata to divide the population. Usually this is done by assessing which variables have the most influence on the result, and selecting strata partitioned along the lines of those variables. A unique approach was taken in analysing the data in previous years, where multiple possible divisions were tried and assessed against several metrics (Hyder et al., 2020b;

2021). The reweighting used the R packages *survey* and *srvyr* (Lumley 2021; Freedman Ellis & Schneider, 2021).

To compare the robustness of the reweighting and model-based approaches, a simulation method was used (Figure 4). As there is no registry of sea anglers in the UK, the true number of individuals that participate and their characteristics was not known and had to be estimated from surveys. This meant that comparison of the reweighting and model-based approaches had to be done using a simulation study (e.g. Downes and Carlin, 2020). In a simulation approach, a description of the 'real world' is generated with the best estimates of parameters and distributions, in this case the number of anglers and their characteristics (Frame - Figure 4). Then data were simulated following the sampling strategy employed in the WPS to recreate the act of undertaking the survey and estimates were generated using the model-based and reweighting methods. This process was repeated many times in the iterate step (Figure 4). This generated distribution of the estimates from both methods, allowing comparison of the precision and bias of each method against the known underlying parameters used to set-up the 'real-world' (Evaluate - Figure 4). This allowed the approach that generated estimates with the lowest precision and bias to be selected and provided an unbiased assessment of the most appropriate method to used (Select - Figure 4).

The most important stage of the simulation study was to generate the simulated data set (Figure 5A). A resampling approach was used taking the WPS data and weighting the respondents so that they were representative of the UK population. This was done using the weights provided in the WPS that related each respondent in the survey to the whole population. This represented the number of individuals in the UK population with the same demographic characteristics as the respondent, which were related to location, gender, age, and socio-economic status. These reflected the design of the survey and were used to generate estimates for the UK (Hyder et al., 2020b). Resampling was done from the weighted WPS proportional to the weight of the respondent, which created a larger dataset related to the UK population. However, the difference was that it was known in the resampled population if each person was a sea angler and their avidity. This simulated dataset therefore represented the best understanding of the UK population where angling population was known exactly (Figure 5A). Sampling from this UK population according to the inclusion probability (the inverse of the weight) was done to create a simulated WPS and number of anglers and avidity estimated using model-based and reweighting methods (Figure 5A). The WPS data was simulated 20 times, with the two approaches (weighting and model-based) used with each simulated WPS to estimate angling rates in the simulated population (Figure 5A). Further, the participation model was run for 200 iterations due to computational constraints. As the actual values are known, the estimates were then compared using bias, root-mean-squared-error, and mean absolute error. In addition, the error in the prediction from the actual value was also compared (Evaluate in in Figure 4). This was used to select whether the model-based or reweighting method should be used for estimation (Select in Figure 4). A schematic representation of the simulation approach can be found in Figure 5A.

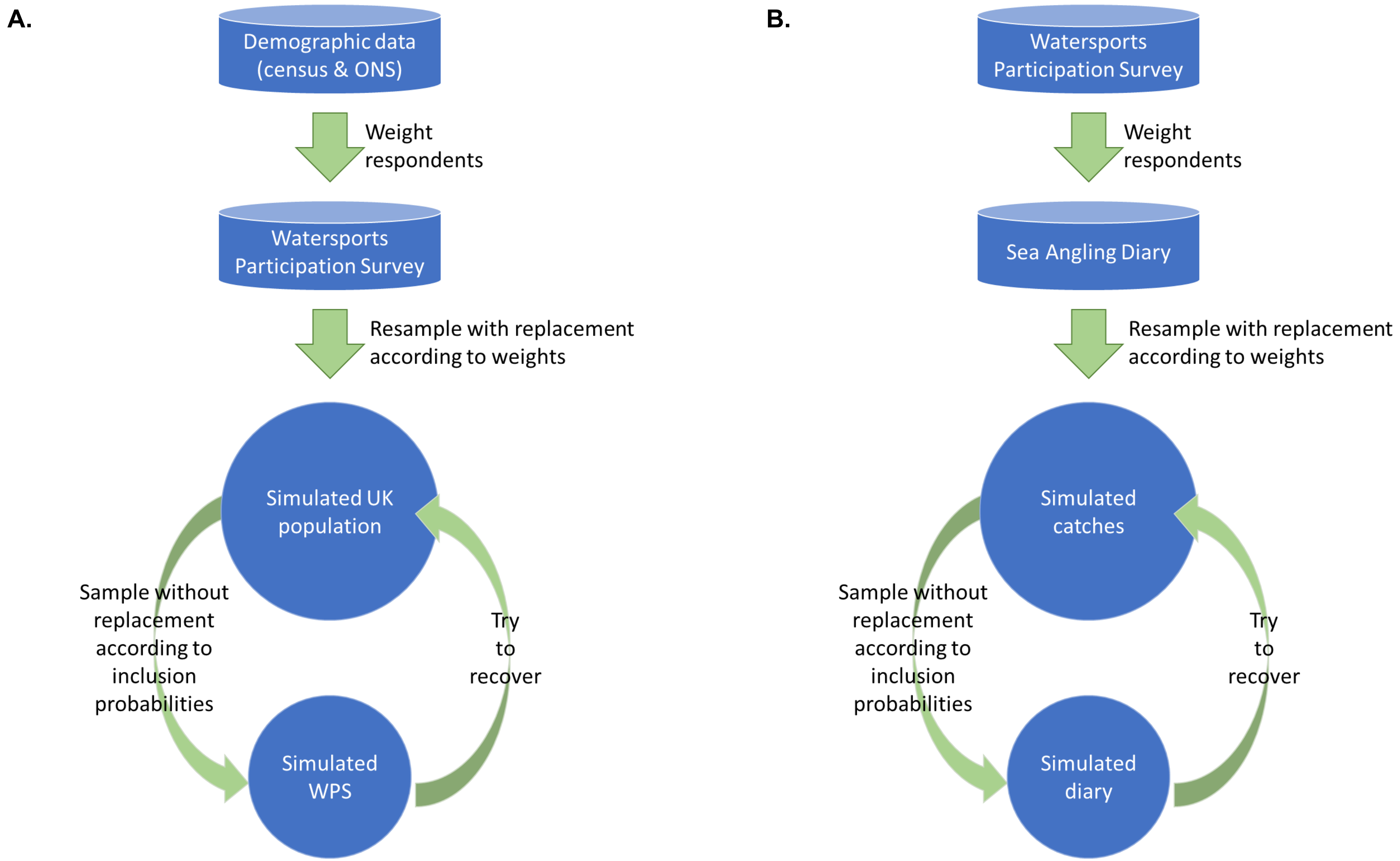


Figure 5. Schematic showing the simulation approaches to assess the robustness of the reweighting and model-based estimation methods for the effort (A) and catch (B).

2.2.1.2. Avidity model

To predict individual angler avidity, an identical modelling process to participation was used. The distribution of avidity of sea anglers was taken from the WPS. Avidity was defined to be the number of days of the preceding 12 months on which someone went angling. The WPS asked respondents to recall their avidity for the previous year. This can lead to recall biases such as misremembering the number of trips or rounding avidity estimates to numbers ending in 0 or 5 (ICES, 2010). Despite this recall bias, it was better to use the WPS stated avidities rather than the diary data where the actual avidities can be seen from the participation data. This was because the diary has a much larger possibility of selection bias in selecting anglers with different avidity patterns to the true population of anglers (see Hyder et al., 2020b; 2021). To account for overdispersion in the avidity, and to improve fits, respondents' avidity were capped to 50 days per year due to the low number of people responding to the survey fishing more than this number.

Data from sea anglers in the WPS was used to inform the avidity model. The process of iterative model building allowed identification of the subset of variables of the participation model that were most effective as gender and region. Gender was incorporated as a dummy variable, with 1 indicating a female angler. This was because there were very few female anglers so using a dummy variable improved the fit by avoiding estimating an intercept for both male and female. Region was used as a random effect. The age of respondents and the number of angling clubs in a region were included as predictors. Priors were developed in the same way as the participation model, as were the iteration approach and the assessment of model fit (Section 2.2.1.1).

2.2.1.3. Comparison with existing methods

The numbers of anglers were compared between MRP and reweighting for the whole of the UK and individual countries within the UK (i.e., England, Northern Ireland, Wales & Scotland) to assess differences between the approaches.

2.2.2. Catch per angler

Almost 5,000 sea anglers have contributed data on over 48,000 sessions and 362,000 catch records from 216,000 hours of fishing activity to the Sea Angling Diary since 2016. The Sea Angling Diary is a rich source of data for catches throughout the UK that can be used to improve understanding of sea angling. The main challenge with using the Sea Angling Diary is that it is a convenience sample (i.e. not probability-based) generated from a variety of different recruitment methods and participants are self-selected. This led to a bias in the panel profile compared to the population of UK sea anglers, with older, more experienced, and more avid individuals more likely to be part of the diary (see Hyder et al., 2020b, 2021). In addition, some species were caught rarely and some had few recorded lengths. Hence, the analysis needed to account for both the bias and the paucity of data available for some species. To address this, a similar approach was developed to model the catch per angler to participation (Section 2.2.1.1) and activity (Section 2.2.1.2).

For catch per angler (Figure 3), a model was developed to estimate the number of fish caught by a sea angler each year. It used a zero-inflated negative-binomial likelihood, as this was appropriate for the over-dispersed catch data, where most anglers catch few fish and a small number of anglers catch a lot of fish. The zero-inflation part of the likelihood reflects that a lot of anglers catch none of a given species. Poisson distributions are common for modelling non-negative count data, but struggle to account for overdispersal. Therefore, a negative-binomial or Gamma-Poisson distribution was used as it was equivalent to a Poisson distribution where the single parameter (rate), is drawn from a gamma distribution. A logit link was used on the zero-inflation part of the model and a logistic link to the negative binomial part of the model. The catch model, like the participation model (Section 2.2.1.1), was considered as a multi-level regression model, using the year, age, gender, home region location (NUTS1), and avidity. In addition, a species group variable was used in the model where species were combined into: common roundfish; elasmobranchs; flatfish; and other (other groups existed, but the species were not included in the model and so are not listed here). Avidity was capped at 40 sessions as values above this had little effect on catches. Furthermore, for use in one of the interaction terms defined below, the avidity of a diarist was grouped into three equal categories, low, medium, and high (1-4, 5-11, 12+ days fished). Grouping the avidity in this way in the interaction improved the model fits, the effective sample sizes, and reduced the run time. The capped avidity was transformed to match the link function of the different components of the model (logistic scale for the zero-inflation and log scale for the negative binomial). Avidity was included as a fixed effect in the model. To account for the impact of a small number of highly skilled diarists catching the majority of fish, the diarist ID was included as a random effect. In order to capture the complex relationships between predictors and how many fish are caught, several interaction terms were included as random effects, these included: region + species code + catch component; species group + catch component; year + species code + catch component; and finally, the avidity group + species code + catch component.

The model was run on 8 chains for 2000 iterations, with a burn-in of 1000 iterations. The catch model fit was assessed in the same multiple ways as the effort model fit. In particular, through comparing LOO-CV values to a baseline model, simulation studies and analysing posterior predictive distributions. When generating posterior distributions from the catch model for extrapolation, diarist ID was not included in the random effect formular, giving a population-level average of catch rates.

2.2.3. Weight of individual fish

Where known, sea anglers reported the length of fish kept and released as part of their data entry in the diary. This was recorded as length of fish (cm), but weights of individual fish were needed to estimate the tonnages of fish retained and released by UK sea anglers. For each species, all lengths were converted to weights using length-weight relationships, with fish weights (W_s) in grams estimated for an individual species (s) from length using the equation:

$$W_s = a_s L^{b_s} \quad (1)$$

where L is the total length (cm) and a_s, b_s are parameters defined for each species. The parameters for most species were taken from length-weight relationships derived from survey data (Silva et al., 2013). Where parameters were not available, the most closely related species with a similar body shape was used. Sea bass parameters were taken from the ICES assessment where a_s = 0.01296 and b_s = 2.969 (ICES, 2018).

A modelling approach was used to estimate the average weight of a species, differentiating between kept and returned. Given that the values are non-negative real numbers, a lognormal distribution was used. The interaction of species and 'kept or returned' component was included as a random effect for both the intercept and spread of the distribution. A predictor variable of 'midpoint weight' was also included, a value taken from (Silva et al., 2013). This report has values on the lower and upper bounds between which the equations were valid. The midpoint between those two bounds was used as it was seen to be indicative of the average weight for a species. The lengths of individual fish recorded in the diary were converted into weights (Equation 1), then were modelled using a lognormal distribution as described. This incorporated the uncertainty of the length and weight measurements into this analysis. Further, the avidity (log scaled) of the angler was included in the model under the assumption that more skilled anglers will catch larger fish. Finally, as there are a small number of diarists that catch many large fish, the diarist ID was included as a random effect in the model. As with the catch model, the effect of diarist ID was removed, giving a population level estimate, when generating posterior predictions for extrapolation.

2.2.4. Catches

The catch numbers were estimated by combining the effort model (Section 2.2.1) with the catches per angler model (Section 2.2.1.3). To do this, the effort model was used to estimate the number of anglers in each stratum, defined as the unique intersection of the three variables age, gender and region. For example, the posterior of the effort model was to get a distribution of numbers of anglers who are 34-year-old females in the East of England. The avidity model was then used to calculate the distribution of avidities of this stratum. Finally, the catch model was used to predict the distribution of catches of each species for 34-year-old female anglers in the East of England with a given avidity. Multiplying these distributions together gave a distribution of the estimated number of a species caught by 34-year-old females in the East of England. This was repeated for every stratum, producing an estimate of the number of anglers, their avidity, and their expected catch, and all the strata catch distributions were summed together to give a distribution of the estimated catch of a species for the whole of the UK. The UK catch distribution was summarised using the median and the 2.5% and 97.5% percentiles to give a best estimate and an uncertainty interval. This was done for the kept and released components for each species with sufficient data (Figure 2). To get tonnage estimates for the whole of the UK, the posterior distribution of the number of each species caught was multiplied by the posterior distribution of the weight of an individual fish of that species. This gave a posterior distribution of the total weight of a species caught in the UK which were summarised with lower and upper bounds and the median.

2.2.4.1. Assessing methods using simulation

A simulation study for total catch was used to compared MRP with a traditional reweighting approach for total number of fish caught. This followed a similar approach to the simulation study for effort (Figure 5A), with the only difference was it used the WPS and diary data as inputs (Figure 5B). The weighted sea angling diary was used, resampling from it to create a simulated dataset of every sea angling catch in the UK. Crucially, in this simulated dataset, the number of catches of every species and by which angler was known. This was sampled randomly, reflecting the Sea Angling Diary sampling process. From the simulated diary data, the goal was to recover the true values in the simulated dataset. Hence, comparisons were made between the two methods in terms of mean squared error, mean absolute error, R^2, and difference between the estimated and known values. Due to computational constraints, the model was run only for 200 iterations in the simulation study.

2.2.4.2. Model-based catch estimates

A summary of model-based catch estimates was presented including the total number and tonnage of fish kept and released each year both for the whole UK and individual countries alongside the release rates. The species or groups that are required under the Data Collection Framework to be provided to ICES were presented. In addition, model estimates of catches within ICES division were required for stock assessment purposes. However, it was not possible to include ICES division directly in the models due to the strong correlation between angler catches in an ICES division and their home location. Instead, the proportion of catches of each species that were in each ICES division were derived from the reweighting approach. To smooth out noise in the data set, the proportion across all years of the diary was used. This was applied to the model estimates for the whole of the UK, to generate estimates for each ICES division and were proportional to the estimates from the reweighting approach. To calculate errors for this, the errors on the catch proportions in the reweighting approach were needed. This was obtained through the *survey* and *srvyr* packages in R, whereby the proportion of catch within each ICES division from the reweighting approach were applied to the total model-based catch estimates to obtain the catch in by ICES division.

2.2.4.3. Comparisons with existing data

A simple comparison was made between the results from MRP and reweighting to assess differences. This was done for total numbers and tonnage of fish kept and released, release rates, catch composition, country within the UK, and DCF species. The drivers of differences between the approaches were investigated using bubble plots. This was done to identify the reasons for the differences observed between the MRP and reweighting procedures. The size of the bubble indicated the magnitude and direction of the difference. The lower category indicated that MRP generated an estimate that was 10% or lower than reweighing, with the higher category highlighting differences of 10% or higher. This was done for the total catch (tonnage, numbers) average weight of individual fish, errors expressed as relative standard error, number of anglers, and catch per angler. This provided a simple way of showing which of the factors in the estimation was driving for the difference between approaches.

2.3. Impact of COVID-19

To understand the impact of COVID-19 on UK recreational sea anglers, two approaches were used. Firstly, data from an existing survey on participation, effort and catches were compared between 2019 and 2020, to assess the impact on numbers, travel to angling locations, and catches on individual angling trips. Secondly, an online survey was conducted on a research panel of anglers participating in the UK Sea Angling Diary Project about the impact of COVID-19 on their sea angling and physical health and well-being.

2.3.1. Comparing effort, locations, and catches in 2019 and 2020

To assess the impact of COVID-19 on fishing activity, outputs from the sea angling survey in 2019 and 2020 were compared (Hyder et al., 2020b; 2021). The number of sessions reported, the number of diarists reporting fishing, fishing locations, and catches was extracted from the database each month in 2019 and 2020. Seasonal patterns were plotted for the two years for the number of sessions reported, numbers of sessions per diarist on each platform, numbers of diarists fishing, catch rates per trip, locations of trips and distances travelled. These were interpreted in the context of periods of lockdowns and restrictions that impacted access to sea angling in the UK.

2.3.2. Assessing the impacts of COVID-19 on sea angling

To understand the impact of COVID-19 on UK recreational sea anglers, an online survey was conducted on a research panel of anglers participating in the Sea Angling Diary. At the time of the research, the panel consisted of 2,129 adults (16 years of age and over) who were recreational sea anglers. Sea anglers on the panel were sent a link to the online survey through Survey Monkey[10]. They provided consent to participate before completing the survey and no identifying personal data were collected. The survey was sent on the 1 October 2020 and a reminder was sent to the same audience on the 27 October 2020 before responses were closed on the 1 November 2020.

2.3.2.1. Survey design

The survey was designed to collect a range of data about respondents, including their normal or perceived (pre-COVID-19) sea angling activity; the impact of COVID-19 on their sea angling activity; and sections to assess impacts on physical activity, well-being and sea angling-related expenditure. The survey also asked about their anticipated sea angling

[10] https://www.surveymonkey.co.uk/

activity in the near future and demographic questions to provide a profile of respondents. The survey questions are included in Appendix 1.

The first section of the survey was designed to provide information so that the sea angling profile of respondents could be compared to other data (such as that held on the Sea Angling Diary panel). This asked about the avidity of the respondent in the preceding 12 months; the platforms they usually fished from; other forms of angling they have done; their normal mode and distance of travel to sea angling; and some questions to assess the centrality of sea angling to their lifestyles, their skills, their retention of fish and the months in which they had been sea angling in 2020. Demographic questions asked about age, sex, physical and mental health disability and ethnicity (Sport England, 2021) as well as employment status and postcode.

The second section was designed to gather data about in which months (March – September 2020) the COVID-19 pandemic had prevented them from going sea angling; the most important reason that had prevented them from going sea angling (government restrictions, isolation, minimizing risk, or other reasons); which of those months they would normally have fished; whether they had fished since restrictions were lifted or partially lifted; and whether that had been at a higher or lower rate than normal for that time of year. These questions were designed to assess not only the direct effect of COVID-19 on their sea angling in 2020 but to provide counterfactual data on what they might have done if the COVID-19 pandemic had not happened.

The third section asked respondents about the effect that not being able to go sea angling had on their physical activity levels. They were provided with a series of statements about the effect of not sea angling on their physical activity and asked to rank these on the Likert five-point scale from whether they ‘strongly agreed’ to ‘strongly disagreed’. The statements provided were designed to identify causal relationships between not sea angling and lower levels of physical activity. Respondents were also given the opportunity to provide a qualitative statement about the impact of COVID-19 on their activity.

The World Health Organisation - Five Well-being Index (WHO-5) was used as a self-reported measure to determine the impact of not going sea angling on respondents’ well-being (WHO, 1998; Topp et al., 2015). Following the same format for the physical activity questions, respondents were asked to what extent they agreed or disagreed with a series of statements about their well-being, adapted from the WHO-5 well-being indicators. Following this, respondents were provided with the WHO-5 self-reported measures and asked about their well-being in the preceding two weeks, followed by a question asking them to relate their responses to their ability to go sea angling to provide some data on causal relationships between sea angling and well-being.

The final set of ‘impact’ questions asked respondents to say what their expenditure on sea angling had been in April 2020 (when no sea angling was allowed in the UK) and what they would spend in a ‘normal’ April. This allowed some analysis of the impact of not being able to go sea angling on sea angling-related economic expenditure. Following this, respondents who had been able to go sea angling since the initial lockdown in April were asked about how COVID-19 had affected their sea angling behaviour – such as whether they had travelled more or less distance, avoided crowded places or not participated on charter boats. Finally, some data suggested that the pandemic had led to more people taking up fishing: in England, the Environment Agency, which manages freshwater fishing, said that sales of licence to fish in freshwater had increased by 18% in 2020 (Environment Agency, 2020). To help assess whether the pandemic had led to more people fishing in the sea as well, respondents were asked whether they had taken people fishing who had not fished before or if they knew of people who had either fished for the first time or returned to fishing after a break in 2020.

2.3.2.2. Statistical analysis

T-tests, linear models and logistic regression models were conducted using R statistical computing environment (R Core Team, 2015) and PAST- Paleontological Statistics v4.0 (Hammer et al., 2001). A generalised linear model was used in R statistical computing environment (R Core Team, 2015) to determine predictor variables that could impact the WHO-5 score (WHO, 1998; Topp et al., 2015). To determine the impact of COVID-19 on the participation rates, effort and expenditure of sea angling a Wilcoxon t-test was used to compare the number of days fished and expenditure in 2019 versus 2020. Multinomial logistic regression was used to examine spending. Qualitative analysis was conducted using a categorical metric to determine the response.

3. Results

All results can be accessed and downloaded from the UKSAIL website.

3.1. Data collection

3.1.1. Participation and effort

The total number of people participating in sea angling each year estimate using face-to-face methods from 2016-18 was relatively consistent with a drop in participation in 2019 (Table 3; Figure 6). These were different to those presented in previous reports (Hyder et al., 2020b, 2021) as only sea anglers fishing in the UK were included. As face-to-face surveys were not possible in 2020 and 2021 due to COVID-19, an online marketing panel was used. This generated much higher estimates for all water sports, including an estimate of 3.4 million sea anglers in the UK (Table 3; Figure 6). The online approach in 2020 also showed large increases in total sea angling effort, although the days fished per angler was lower than previous years (Table 3). The numbers of freshwater anglers in England and Wales estimated from the online far exceeded the number of licences sold in the period for the year before the WPS (October 2019 – September 2020).

Table 3. Sea angler numbers, participation rates, days fished by platform, and days fished by an individual estimated through the face-to-face survey in 2016-19 and online survey in 2020-21. Please note for the reasons specified in the text that 2020-21 online results were not used in any further analysis. All data is for the residents of the UK only. 95% confidence intervals are given in brackets. These number reflect only respondents that had fished in the UK.

Measure	2016	2017	2018	2019	2020 (online)	2021 (online)
A. Numbers ('000s)						
Total sea angling UK	781 (654-908)	770 (649-893)	712 (592-832)	484 (385-584)	3446 (2901-3376)	5740 (5438-6061)
England	536 (432-639)	556 (452-660)	529 (424-633)	332 (251-413)	2847 (2631-3081)	4809 (4527-5091)
Wales	99 (52-147)	57 (25-90)	59 (25-93)	48 (16-80)	212 (161-281)	315 (243-388)
Scotland	76 (35-117)	81 (38-125)	61 (25-98)	36 (7-65)	274 (211-357)	391 (304-479)
Northern Ireland	69 (33-106)	75 (36-114)	64 (29-98)	69 (30-108)	112 (72-173)	234 (156-312)
B. Participation (%)						
Total sea angling UK	1.5	1.4	1.3	0.9	6.4	10.6
England	1.2	1.3	1.2	0.7	6.3	10.5
Wales	3.8	2.2	2.4	1.9	8.2	12.1
Scotland	1.7	1.7	1.3	0.8	6.0	8.6
Northern Ireland	4.5	4.8	4.1	4.4	7.5	15.5
C. Effort (million days)						
Total sea angling UK	7.2 (5.1-9.4)	8.0 (5.3-10.6)	6.0 (4.1-7.9)	6.5 (3.6-9.4)	21.3 (18.1-24.6)	28.0 (24.9-31.2)
Kayak	0.3 (0.0-0.6)	0.3 (0.0-0.6)	0.3 (0.1-0.6)	0.1 (0.0-0.2)	3.2 (1.9-4.4)	3.4 (2.8-4.1)
Private and rented	1.2 (0.6-1.9)	2.0 (0.8-3.2)	1.9 (0.6-3.2)	1.2 (0.6-1.9)	3.6 (2.9-4.3)	4.7 (3.9-5.6)
Charter	0.4 (0.0-0.8)	0.3 (0.2-0.5)	0.4 (0.2-0.7)	0.3 (0.1-0.5)	2.4 (2.0-2.8)	4.0 (3.4-4.6)
Shore	5.3 (3.6-7)	5.3 (3.0-7.6)	3.3 (2.1-4.5)	4.4 (1.8-7.1)	8.5 (7.0-10)	11.3 (9.4-13.1)
D. Effort (days/angler)	9.2	10.4	8.5	13.4	6.2	4.9

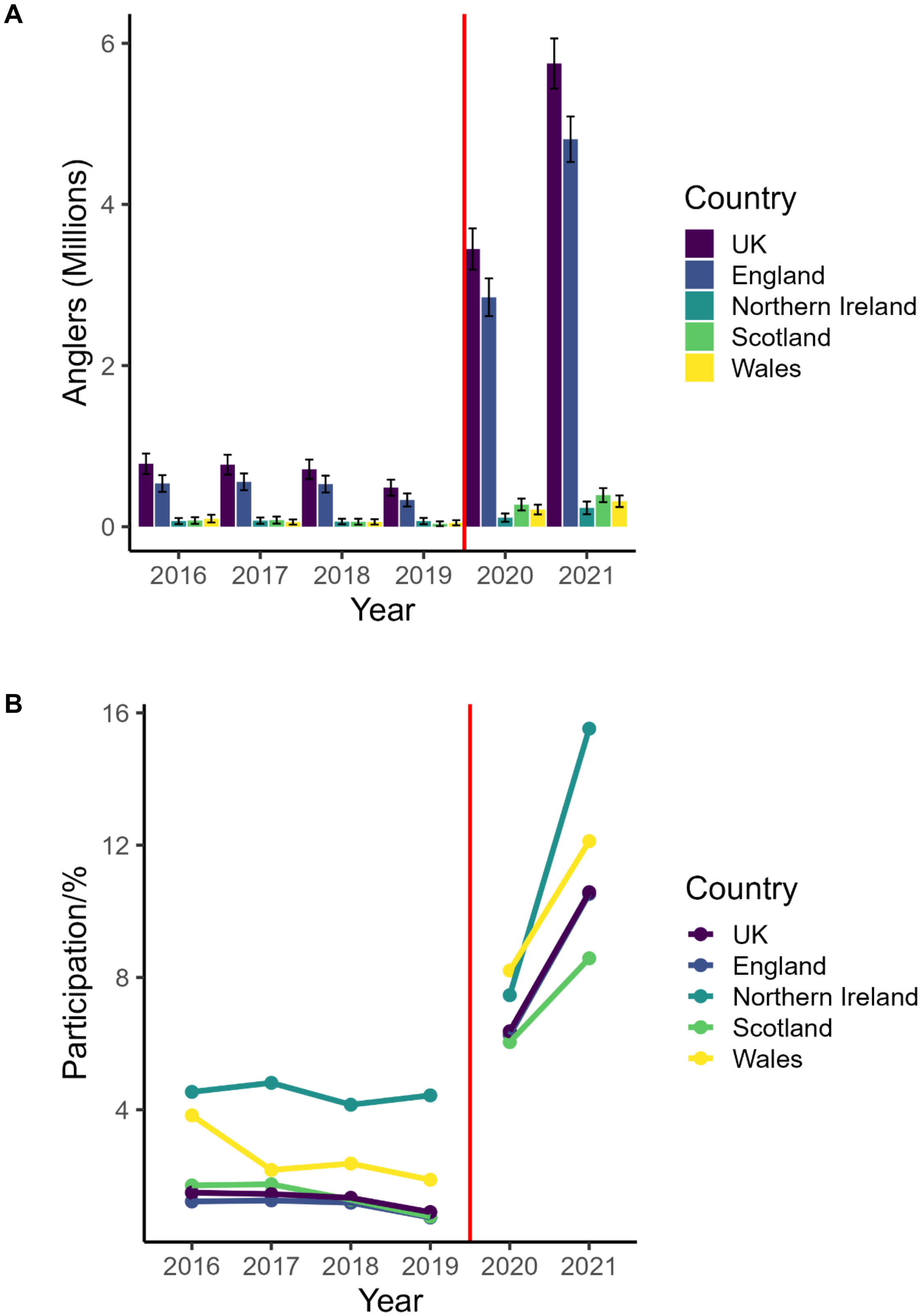


Figure 6. The total number of anglers (millions) (A) and participation rate (B) in recreational sea angling within the UK from 2016-2021. Note that 2016-19 used face-to-face methods and 2020-21 an online panel, this separation is depicted by a red vertical line on the figure. Error bars in (A) indicate 95% confidence intervals.

The differences between 2020-21 WPS and previous years was likely due to a combination of the methodological change from face-to-face to an online panel and increased sea angling participation due to COVID-19. There was an increase of nearly 20% in rod licence sales between 2019 and 2020, so it was possible that there may have been similar changes in sea angling. It was not possible to confirm if the observed increase was due to the methods or COVID-19 without a side-by-side comparison of the online and face-to-face approach. In addition, it was really important to maintain consistency in the time series of participation and catches generated in order to support decision-making. Due to the issues with the 2020 estimates and the uncertainty around the impact of the change in methods, data from 2016-19 was used to extrapolate the catch estimates in 2020 and the WPS 2020 data was excluded from any further analyses.

The majority of recreational sea anglers were male, representing an average of 83% of the total population over the timeseries. Further, the most common age range for UK sea anglers is 35-55 years old. Sea anglers were mainly working class or non-workers (social grade groups C2, D, and E), with a lower portion from the middle class (social grade groups A, B, and C1)[11]. A full description of the characteristics of sea anglers residing in the UK can be found in Hyder et al. (2021).

3.1.2. Diary panel

3.1.2.1. Recruitment

In total, 2,237 sea anglers participated in the diary panel in 2020 and 2,729 in 2021. This consisted mainly of existing diarists and some from general promotion (Table 4). Active recruitment took place from November 2019 to March 2021 for 2021 diarists and between November 2021 and March 2022 for 2022 diarists. The sign-up survey was open continuously throughout 2020 and 2021, so diarists could join at any time during the year. Due to COVID-19, face-to-face recruitment not possible in spring nor summer, with only a single event attended in February prior to the COVID-19 restrictions. Comparison with the 2019 WPS showed that the diary panel had similar regional composition (Table 5), but the diary panel had a higher proportion of older (Table 6) and more avid (Table 7) sea anglers than the general population. It is worth noting that the WPS uses a modified definition of the NUTS1 regions defined by the ONS for sampling reasons. This predominantly resulted in an underestimation of the total population residing within the East of England; 1.6 million people in the WPS compared to 5.0 million in the ONS dataset.

Table 4. The responses and numbers signed up to the diary from each type of publicity.

Mode	2020	2021
Existing diarists	1,522	1,870
Signed up from emails	447	25
General promotion	268	834
Total	2,237	2,729

[11] https://en.wikipedia.org/wiki/NRS_social_grade

Table 5. The percentage of diarists by region and country in comparison with the population of sea anglers from the 2019 Watersports Participation Survey (WPS). Percentages have been calculated for common categories to allow direct comparison with WPS.

Category	2020 Count	2020 %	2021 Count	2021 %	% 2019 WPS
East Midlands	78	3.5	81	3.0	5.8
East of England*	224	10.0	274	10.1	3.7
London	74	3.3	85	3.1	2.6
North East	132	5.9	139	5.1	4.7
North West	238	10.6	272	10.0	4.3
South East	446	19.9	516	19.0	24.4
South West	386	17.3	451	16.6	11.5
West Midlands	96	4.3	96	3.5	5.4
Yorkshire & Humber	126	5.6	141	5.2	5.5
England Total	1,800	80.5	2,055	75.7	67.9
Northern Ireland	56	2.5	87	3.2	13.4
Scotland	152	6.8	234	8.6	7.1
Wales	229	10.2	340	12.5	11.7
Prefer not to say	0	---	13	---	---
Total	2,237	100.0	2,729**	100.0	100.0

Table 6. The percentage of diarists by age in comparison with the percentage of the population of sea anglers from the 2019 Watersports Participation Survey (WPS). Percentages have been calculated for common categories to allow direct comparison with WPS.

Category	2020 Count	2020 %	2021 Count	2021 %	% 2019 WPS
16-34	287	12.8	349	12.8	27.5
35-54	773	34.6	946	34.7	44.3
55+	1,174	52.6	1,433	52.5	28.9
Prefer not to say	3	---	1	---	---
Total	2,237	100.0	2,729	100.0	100.0

Table 7. Stated avidity[12] profile of diarists compared to the percentage of the population of sea anglers from the 2019 Watersports Participation Survey (WPS). Percentages have been calculated for common categories to allow direct comparison with WPS.

Category	2020 Count	2020 %	2021 Count	2021 %	% 2019 WPS
Frequent (> 35 days)	469	23.1	552	22.6	8.9
Regular (13-35 days)	604	29.7	738	30.2	16.6
Occasional (6-12 days)	583	28.7	713	29.2	15.8
Rare - 2-5 days	312	15.4	361	14.8	37.0
Once	64	3.1	81	3.3	21.7
Not in last 12 months	182	---	251	---	---
Never	19	---	33	---	---
Prefer not to say	4	---	---	---	---
Total	2,237	100.0	2,729	100.0	100.0

[12] Stated avidity is taken at the time of sign up to the diary and asks about participation in the preceding 12 months. The time series will vary according to the date of sign up. For some diarists in 2018 and 2019 who signed up in previous years, their stated avidity will refer to their participation in 2015 and 2016. Actual avidity of diarists (as shown in the days they record fishing in the diary) tends to be significantly less frequent, meaning that the difference in actual avidity to the population may not be as great as when comparing stated avidity.

In the screening surveys for 2020 and 2021, diarists were asked about the number of years since they first went sea angling, whether there had been any significant gaps in their sea angling participation, and a self-assessment of their skill level. These questions were added in 2019 to the diary screener survey and WPS. However, as some diarists joined the project prior to 2019, this was not available for all participants. The diary panel had been fishing for longer (Table 8), had more intermediate and experienced anglers, but fewer beginners than the general sea angling population (Table 9). In comparison to the WPS, diary panel members were less likely to have had very long gaps in their fishing (Table 10).

Table 8. The number of years since diarists first went angling. Percentages have been calculated after removing blanks to allow direct comparison with 2019 WPS.

Years angling	2020 Count	2020 %	2021 Count	2021 %	% 2019 WPS
0-5	221	13.9	330	14.5	21.1
6-10	120	7.6	177	7.8	14.5
11-15	87	5.5	143	6.3	8.7
16-20	104	6.5	184	8.1	10.5
21-30	176	11.1	257	11.3	17.8
31-40	258	16.2	371	16.3	10.8
41-50	361	22.7	471	20.7	6.9
51-60	209	13.2	272	11.9	7.6
61-70	47	3.0	65	2.9	1.3
70+	6	0.4	7	0.3	0.7
Blank	648	---	452	---	---
Total	2,237	100.0	2,729	100.0	100.0

Table 9. The self-declared skill level of angling in the diary panel. Percentages have been calculated after removing blanks to allow direct comparison with 2019 WPS.

Skill level	2020 Count	2020%	2021 Count	2021 %	% 2019 WPS
I am a beginner sea angler who has been a small number of times	189	11.9	280	12.3	22.5
I am an intermediate sea angler with a reasonable amount of experience	850	53.5	1,263	55.5	42.3
I am an experienced sea angler with some specialist skills	357	22.5	484	21.3	18.4
I am a very experienced sea angler in a variety of different environments	193	12.1	250	11.0	16.8
Blank	648	---	452	---	---
Total	2,237	100.0	2,729	100.0	100.0

Table 10. The consistency of angling in the diary panel and WPS.

Consistency	2020 Count	2020 %	2021 Count	2021 %	% 2019 WPS
Yes - almost every year	566	35.6	816	35.8	40.3
Yes, but with some small gaps not fished	400	25.2	611	26.8	21.4
No, there have been some significant gaps	434	27.3	602	26.4	18.5
No, there have been some very long gaps	189	11.9	248	10.9	19.8
Blank	648		452	---	---
Total	2,237	100.0	2,729	100.0	100.0

3.1.2.2. Data entry

3.1.2.3. Activity

A total of 849 diarists reported fishing in 2020 and 946 in 2021 (Table 11). This resulted in 7,735 sessions recorded throughout the year in 2020 and 7,329 in 2021 (Table 11). The average number of sessions fished was 9.1 in 2020 and 7.7 in 2021, with an average session length of 5 hours in 2020 and 4 hours in 2021 (Table 11). Despite regular reminders, only around half of the diarists provided 6 months of data and one third provided data for the full 12 months in 2020 and 2021 (Table 12). Higher completion rates were observed for older diarists (Table 13).

Table 11. Summary of fishing activity reported by diarists in 2020 and 2021.

Item	2018	2019	2020	2021
Total diarists in study	1,706	2,188	2,237	2,729
Total diarists fishing in year	736	988	849	946
Total sessions recorded	8,755	10,016	7,735	7,329
Average number of sessions per diarist in the study	5.1	4.6	3.5	2.7
Average number of sessions per diarists who fished	11.9	10.1	9.1	7.7
Average session length	4.5	4.4	5	4.4
Total fishing hours recorded	39,413	44,086	33,746	32,096
Average number of hours per diarist in the study	23.1	20.1	15.1	11.8
Average number of hours per diarists who has fished	53.6	44.6	39.7	33.9

Table 12. Number of diarists entering some, 6 months, and 12 months of data by home region or country in 2020 and 2021.

Location	2020 % entering data	2020 % 6 months data	2020 % 12 months data	2021 % entering data	2021 % 6 months data	2021 % 12 months data
East Midlands	34.6	32.1	20.5	28.4	24.7	16.0
East of England	49.1	44.6	29.9	36.5	28.8	22.3
London	41.9	37.8	17.6	25.9	22.4	16.5
North East	35.6	31.1	20.5	32.4	28.8	19.4
North West	36.1	29.4	18.1	30.9	23.9	15.1
South East	40.8	32.3	18.8	37.0	30.6	19.0
South West	45.1	40.9	26.4	35.7	28.4	20.2
West Midlands	24.0	21.9	12.5	24.0	24.0	13.5
Yorkshire & Humber	44.4	40.5	20.6	29.8	25.5	20.6
England Total	40.9	35.4	21.7	33.6	27.6	18.8
Northern Ireland	41.1	26.8	21.4	23.0	16.1	4.6
Scotland	38.8	29.6	17.8	25.6	20.5	9.4
Wales	47.6	35.8	19.7	30.9	22.4	12.9
Total	41.4	34.9	21.2	32.1	25.9	16.7

Table 13. Age profile of the diarists signed up and percentage entering data.

Age	2020 % entering data	2020 % 6 months data	2020 % 12 months data	2021 % entering data	2021 % 6 months data	2021 % 12 months data
16-34	33.1	17.8	7	20.3	9.7	2.9
35-54	40.2	31.6	16.8	30.4	22.2	12.8
55+	44.7	41.8	27.9	36.4	32.4	22.8
Prefer not to say	0.0	0.0	0.0	0.0	0.0	0.0
Total	41.7	35.1	21.3	32.2	25.9	16.8

3.1.2.4. Catch records

In 2020 a total of 57,281 fish across almost 100 different species were recorded by diarists in the UK and 50,416 fish were recorded in 2021. Release rates were high, with 76% of all fish recorded by diarists released in both years, which was similar to previous years. Despite the diversity of fish caught, 80% were attributed to ten species in 2020 and 78% in 2021. The top 5 species caught by diarists in 2020 by number were whiting, mackerel, lesser spotted dogfish, sea bass, and cod, with mackerel, whiting, lesser spotted dogfish, sea bass and black sea bream for 2021 (Figure 7).

For the European Union Data Collection Framework (DCF) species, the most caught in 2020 were sharks and dogfish, followed by sea bass and Atlantic cod (Table 14). This was the same in 2021. The most common group of fish caught were common roundfish (Table 15), and most records were for the North Sea, English Channel, and Irish Sea (Table 14). Release rates were high across all species and areas (Table 14 - Table 16).

Table 14. The numbers of DCF species retained and released reported by diarists, and release rates in 2020 and 2021.

DCF species	2020 Kept	2020 Released	2020 Released (%)	2021 Kept	2021 Released	2021 Released (%)
European sea bass	427	3,821	89.9	407	3,170	88.6
Cod	884	1,832	67.4	425	1,033	70.9
Sharks and dogfish	149	5,890	97.5	238	7,187	96.8
Skates and rays	123	1,365	91.7	122	1,183	90.7
Freshwater eel	0	236	100.0	0	191	100.0
Salmon	1	7	87.5	1,192	12,764	91.5

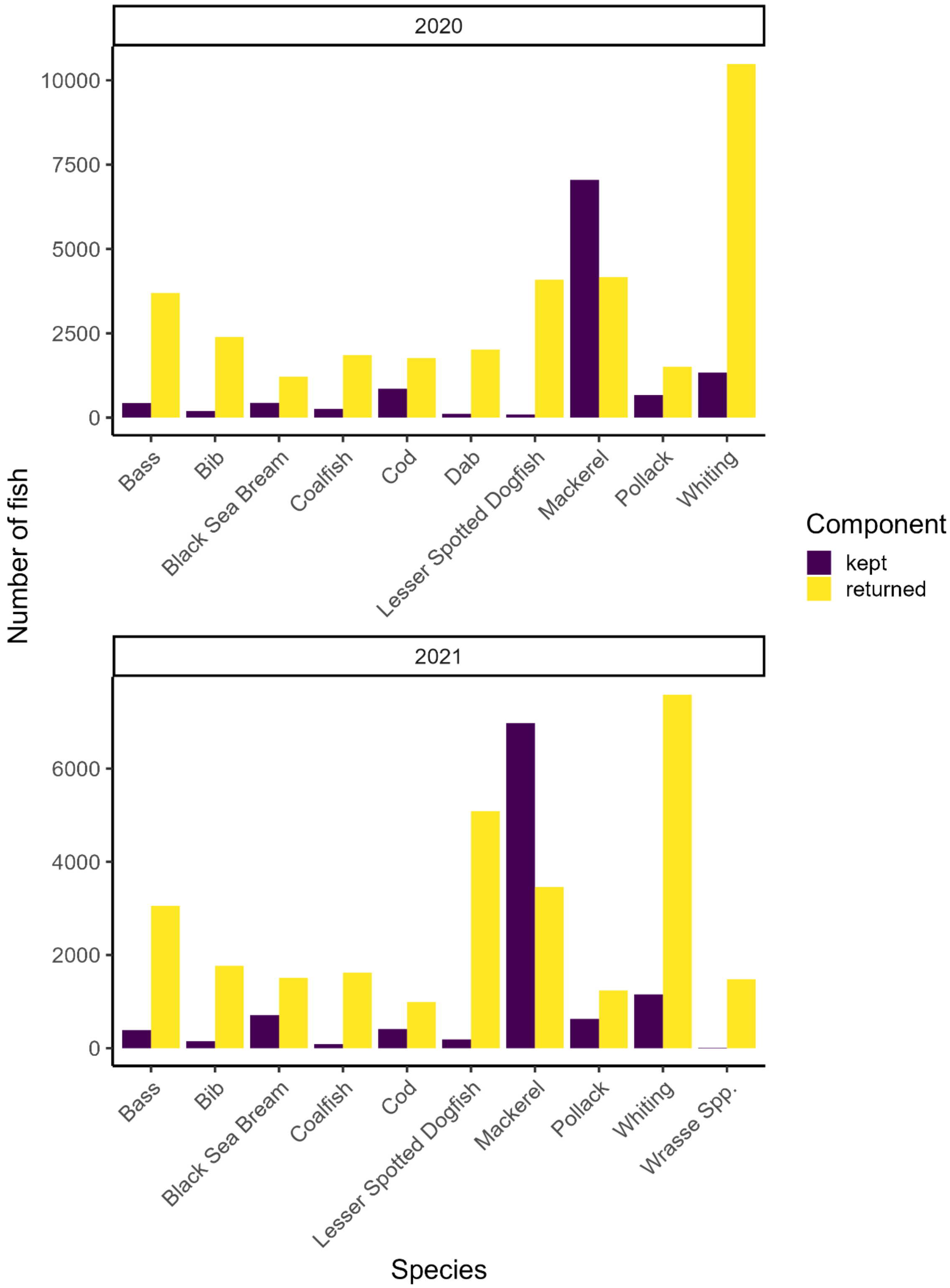


Figure 7. Top ten species reported by diarists in terms of number of fish in 2020 and 2021.

Table 15. The fish kept and released by diarists for each fish group in 2020 and 2021.

Groups	2020 Kept	2020 Released	2020 Released (%)	2021 Kept	2021 Released	2021 Released (%)
Common round fish	11,216	27,413	71.0	9,982	21,150	67.9
Dogfish & shark species	149	5,890	97.5	238	7,187	96.8
Flatfish	619	4,198	87.1	438	3,614	89.2
Other	8	140	94.6	34	107	75.9
Other fish species	972	2,124	68.6	483	1,840	79.2
Wrasse	5	1,040	99.5	16	1,402	98.9
Seabreams & Mullets	467	1,503	76.3	743	1,838	71.2
Skates & Rays	123	1,365	91.7	122	1,183	90.7
Rare & Unusual Species	3	6	66.7	1	3	75.0
Tuna	0	1	100.0	0	3	100.0
Crabs and lobsters	11	28	71.8	3	29	90.6
Total	13,573	43,708	76.3	12,060	38,356	76.1

Table 16. The fish kept and released by diarists for different ICES divisions in 2020 and 2021.

Division	2020 Kept	2020 Released	2020 Released (%)	2021 Kept	2021 Released	2021 Released (%)
4.a Northern North Sea	653	105	13.9	20	119	85.6
4.b Central North Sea	2,222	5,131	69.8	1,792	4,114	69.7
4.c Southern North Sea	934	8,925	90.5	513	4,610	90.0
6.a West of Scotland and Northern Ireland	358	1,903	84.2	392	1,872	82.7
7.a Irish Sea	2,189	5,612	71.9	2,630	6,122	69.9
7.d Eastern English Channel	1,307	6,513	83.3	1,895	6,779	78.2
7.e Western English Channel	5,280	11,095	67.8	4,208	10,064	70.5
7.f Bristol Channel	457	3,803	89.3	471	3,850	89.1
7.g Celtic Sea North	112	498	81.6	52	507	90.7
7.h Celtic Sea South	61	123	66.8	26	96	78.7
Total	13,573	43,708	76.3	12,060	38,356	76.1

3.2. Catches by UK sea anglers

3.2.1. Effort

3.2.1.1. Participation

For participation, a Bayesian multi-level regression model was fitted to the WPS data that included gender, age, region, number of angling clubs, and year. The parameter values of the fitted participation model showed that there was a large difference between males and females, with far fewer females (Figure 8). The relationship between age and participation was not linear as the confidence limit included zero, with a more complex non-linear relationship identified (Figure 8). Sea angling clubs and region were also important in predicting participation, but the effect of year was limited suggesting that participation did not vary much between years (Figure 8). The posterior predictive checks showed a strong fit of the model to the data for percentage of anglers (Figure 9), gender (Figure 10), region (Figure 11), and year (Figure 12). MRP estimated that the total number of sea anglers in the UK was between 568,188 to 753,165, depending on the year (Figure 13). Most sea anglers were resident in England, with similar numbers of sea anglers found in Scotland, Wales and Northern Ireland (Figure 13).

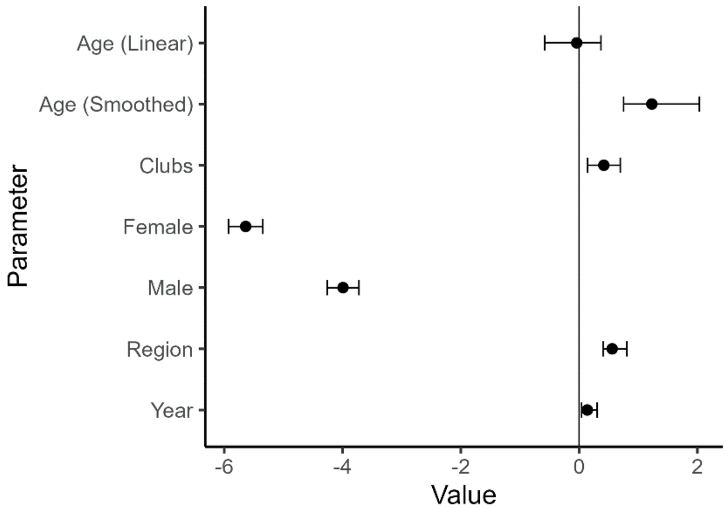


Figure 8. Parameter values of the fitted angler participation model. Errors show the 95% credible intervals.

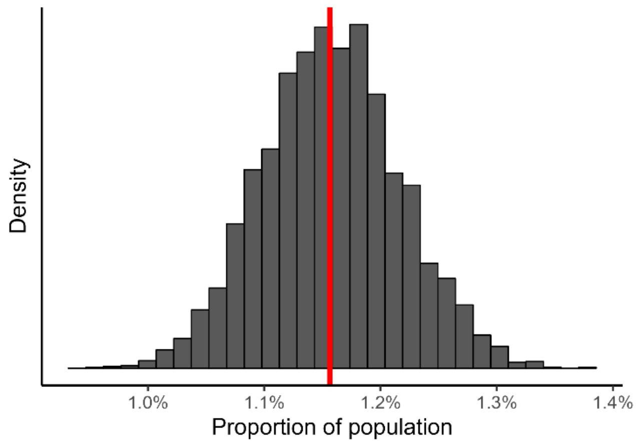


Figure 9. A posterior predictive check of the percentage of anglers. The bars show the proportion of each value from the posterior distribution of the fitted Bayesian model and the red line shows the estimate from the data.

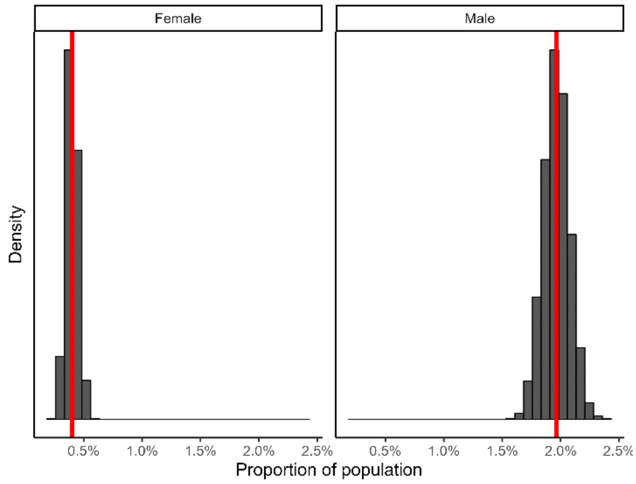


Figure 10. A posterior predictive check of the proportion of anglers, grouped by gender. The bars show the proportion of each value from the posterior distribution of the fitted Bayesian model and the red line shows the estimate from the data.

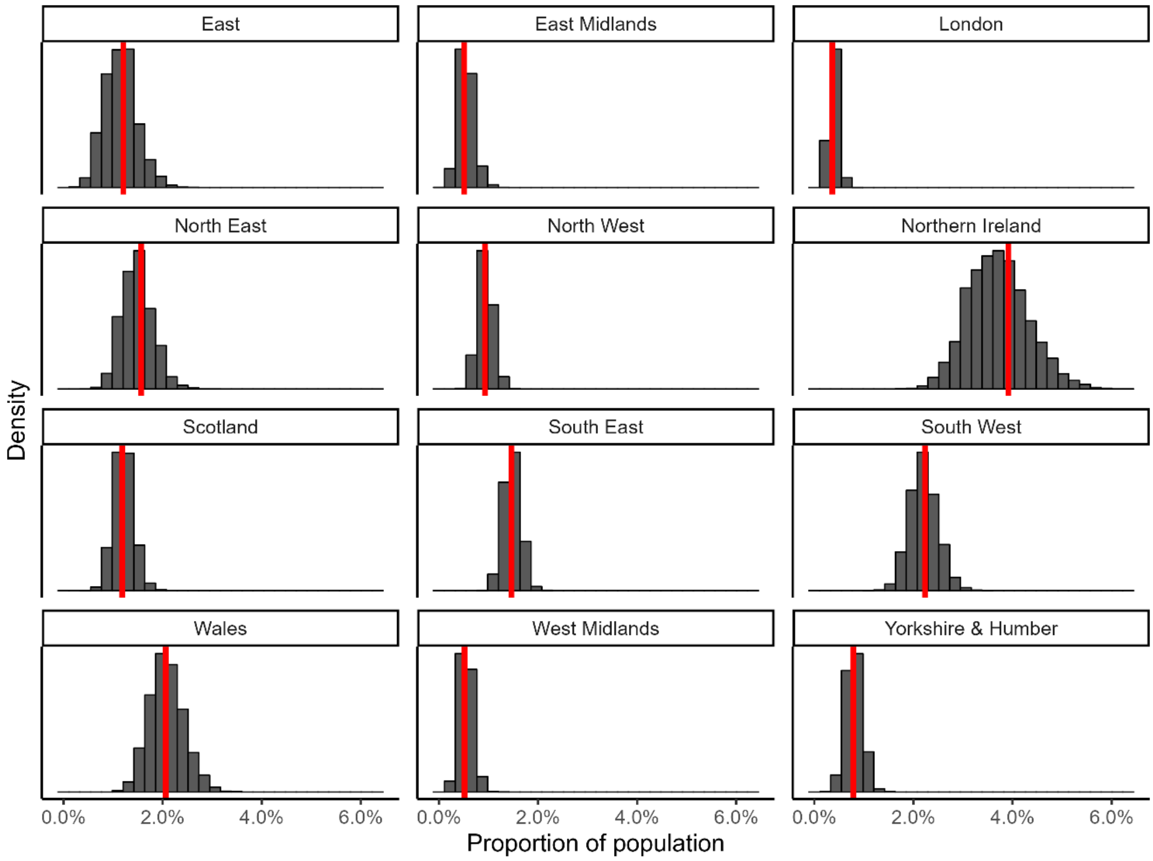


Figure 11. A posterior predictive check of the proportion of anglers, grouped by region. The bars show the proportion of each value from the posterior distribution of the fitted Bayesian model and the red line shows the estimate from the data.

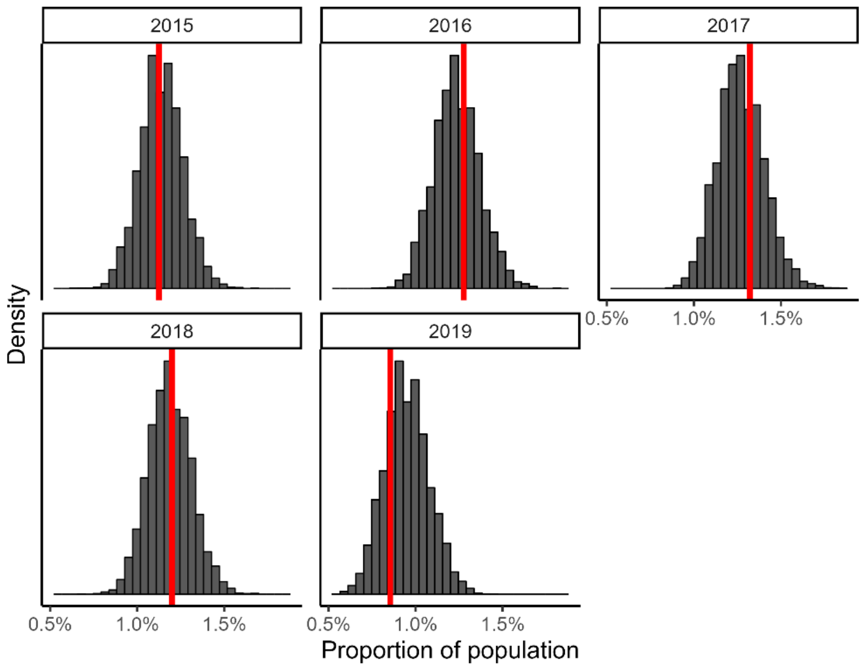


Figure 12. A posterior predictive check of the proportion of anglers, grouped by year. The bars show the proportion of each value from the posterior distribution of the fitted Bayesian model and the red line shows the estimate from the data.

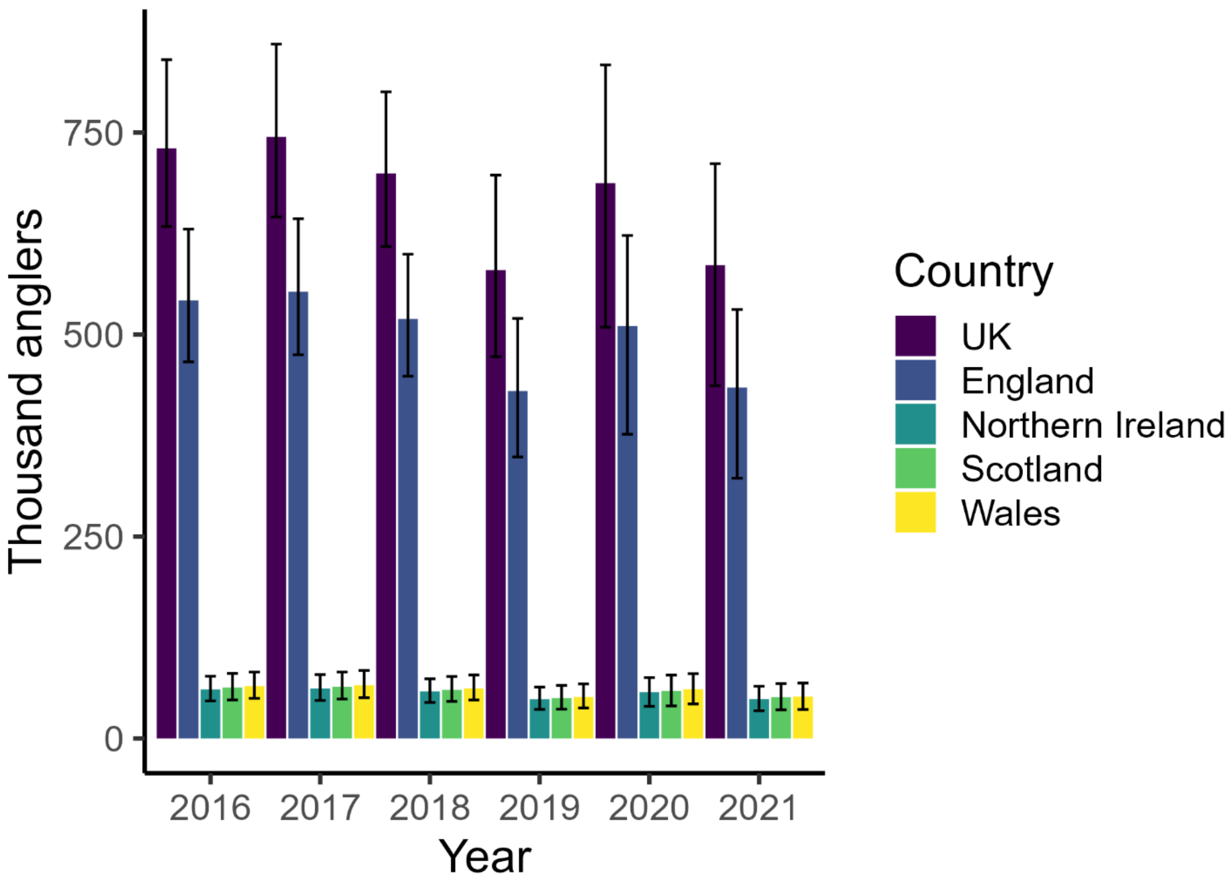


Figure 13. The total number of anglers (thousands) within the UK and each of the countries within the UK estimated by Multi-level Regression and Post-stratification (MRP). Error bars represent 95% credible intervals.

3.2.1.1.1. Assessing methods using simulation

A simulation approach was used to assess the robustness of MRP against a traditional reweighting approach. This showed that MRP outperformed reweighting on all key metrics. The mean squared error for MRP was consistently lower than the reweighting method (Figure 14). This pattern was reflected in the mean absolute error (Figure 15). Similarly, the R^2 value for the model was consistently higher than the weighting method (Figure 16). When using the methods to estimate the total number of anglers, the MRP estimate made a notable improvement on the estimates, moving from an average absolute difference of 43,670 for the reweighting method to 26,373 with the modelling method, an improvement of 40% (Figure 17). This showed that the modelling approach generated both more accurate and precise estimates and should be used for future analysis.

3.2.1.2. Avidity

A Bayesian lognormal mixture model was used for avidity that included gender, age, angling clubs, and region. The parameter estimates show that female anglers tend to go fishing less often than males, and that older anglers go fishing more often (Figure 18). The posterior predictive checks of the avidity model revealed an acceptable fit to the data (Figure 19), and a good ability to smooth through the rounding bias in the raw data. Furthermore, the posterior predictions showed good fits were found for overall (Figure 20), gender (Figure 21), and regional (Figure 22) avidities. MRP estimated the total number of days fished by UK sea anglers to be between 5.1 – 6.8 million (Figure 23). The majority of the trips were by sea anglers in England, with similar number of trips in Scotland, Northern Ireland and Wales (Figure 23).

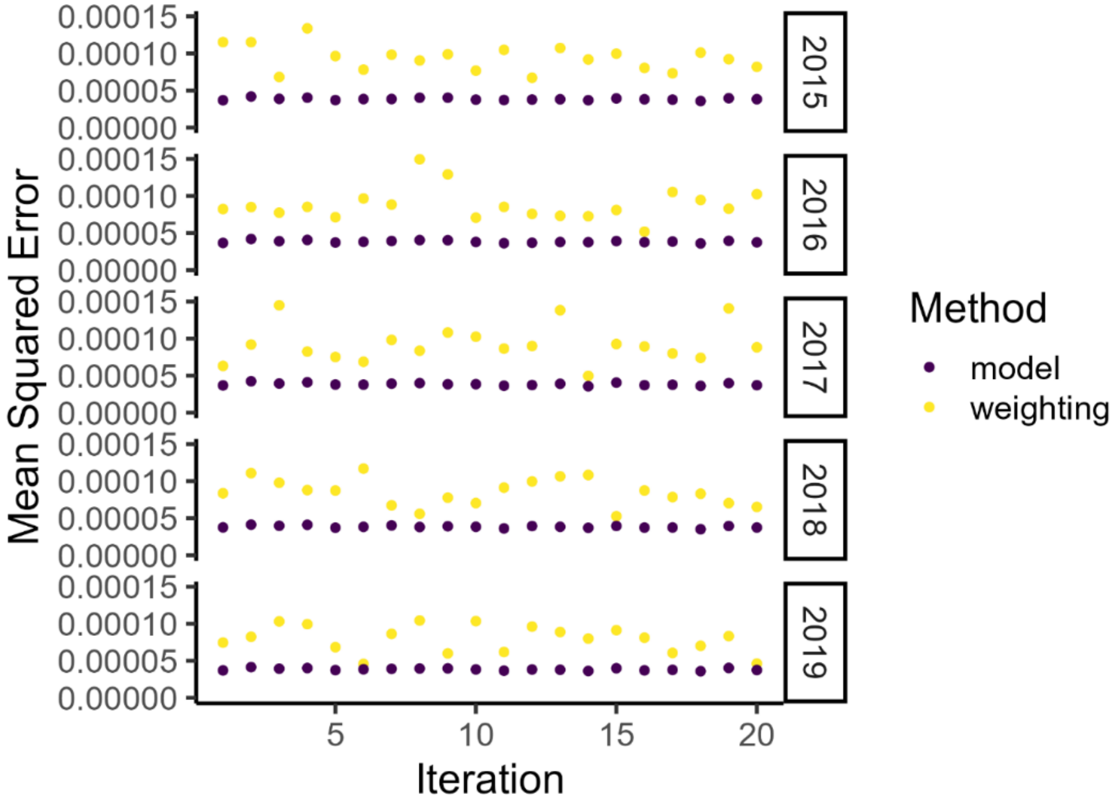


Figure 14. The mean squared error of the two methods in the simulation study. Values closer to zero indicate a better method.

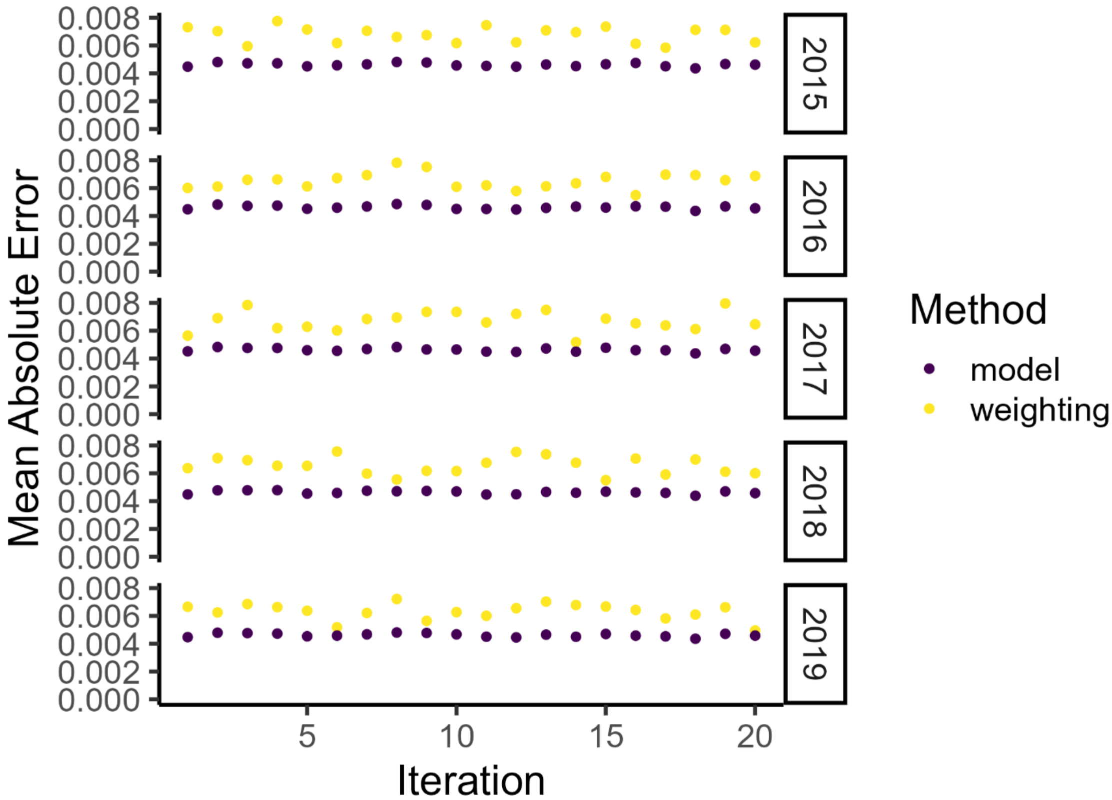


Figure 15. The mean absolute error of the two methods in the simulation study. Values closer to zero indicate a better method.

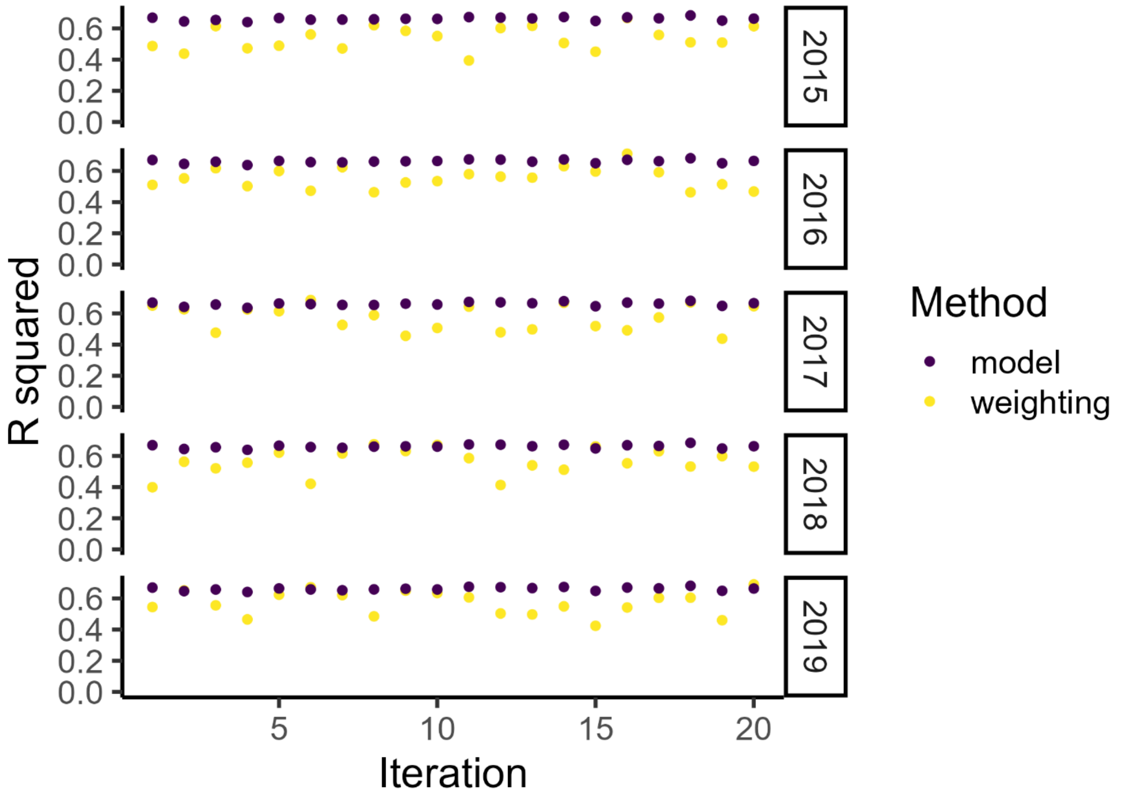


Figure 16. The R^2 value of the two methods in the simulation study. Higher values indicate a better method.

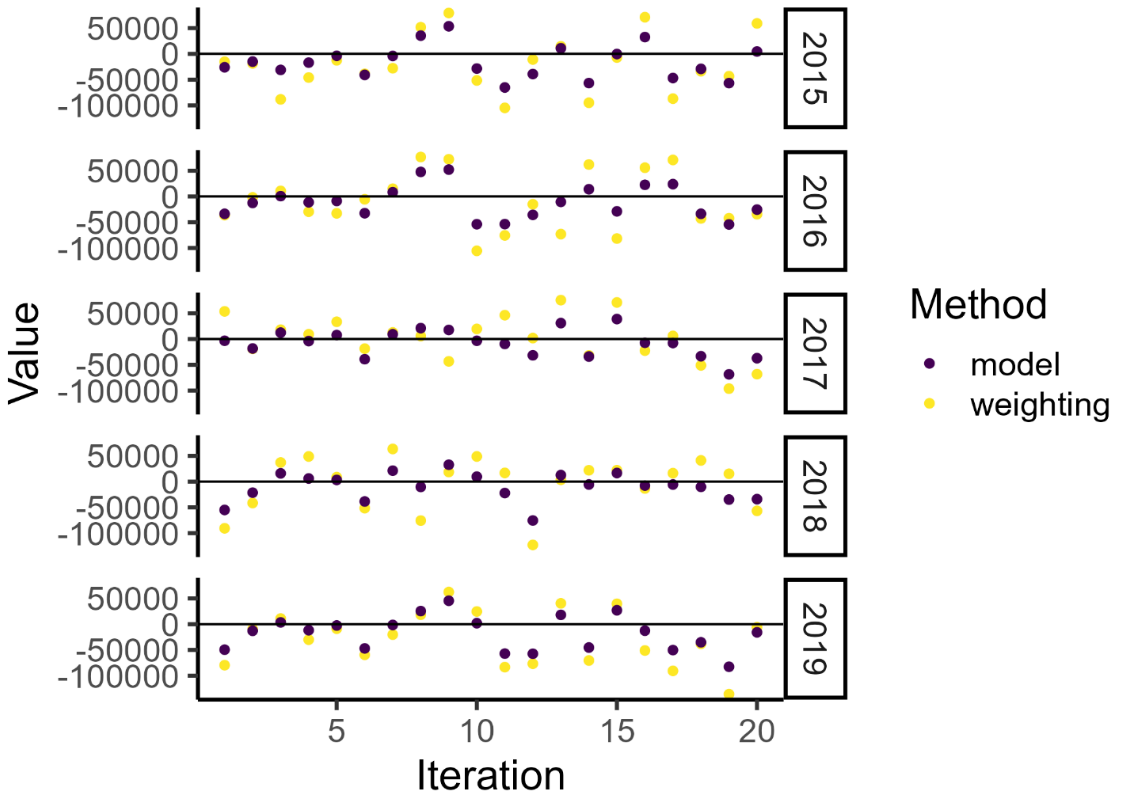


Figure 17. The difference between the predicted and actual number of anglers. Values closer to zero indicate a better method.

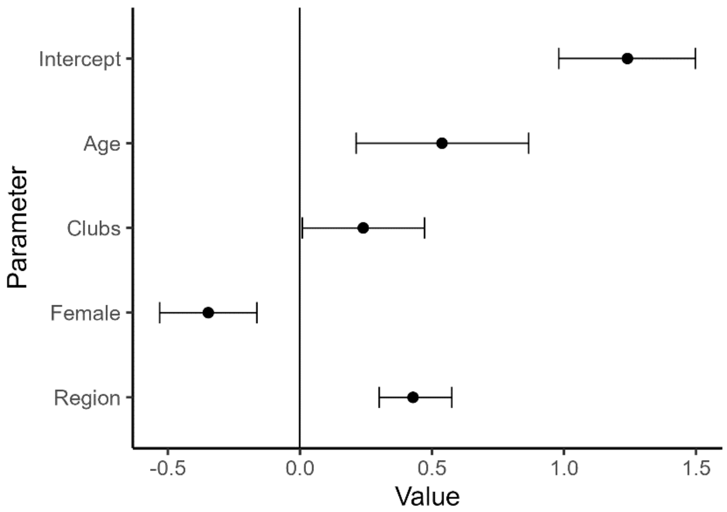


Figure 18. Parameter values of the fitted angler avidity model. Errors show the 95% credible intervals.

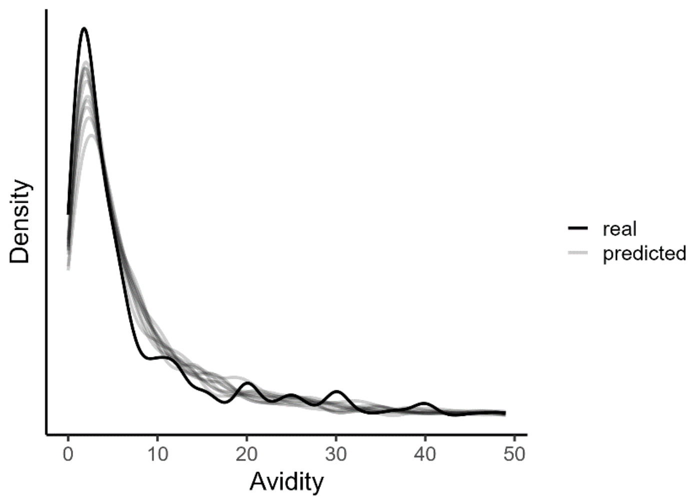


Figure 19. Posterior predictive check of the avidity model. The dark line shows a smoothed line of the avidities in the actual data and the faint blue lines show avidities simulated using the model.

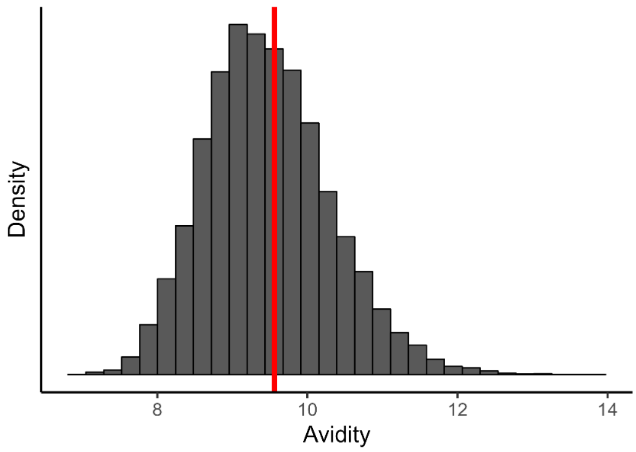


Figure 20. A posterior predictive check of the number of days fished (avidity) by UK sea anglers. The bars show the proportion of each value from the posterior distribution of the fitted Bayesian model and the red line shows the estimate from the data.

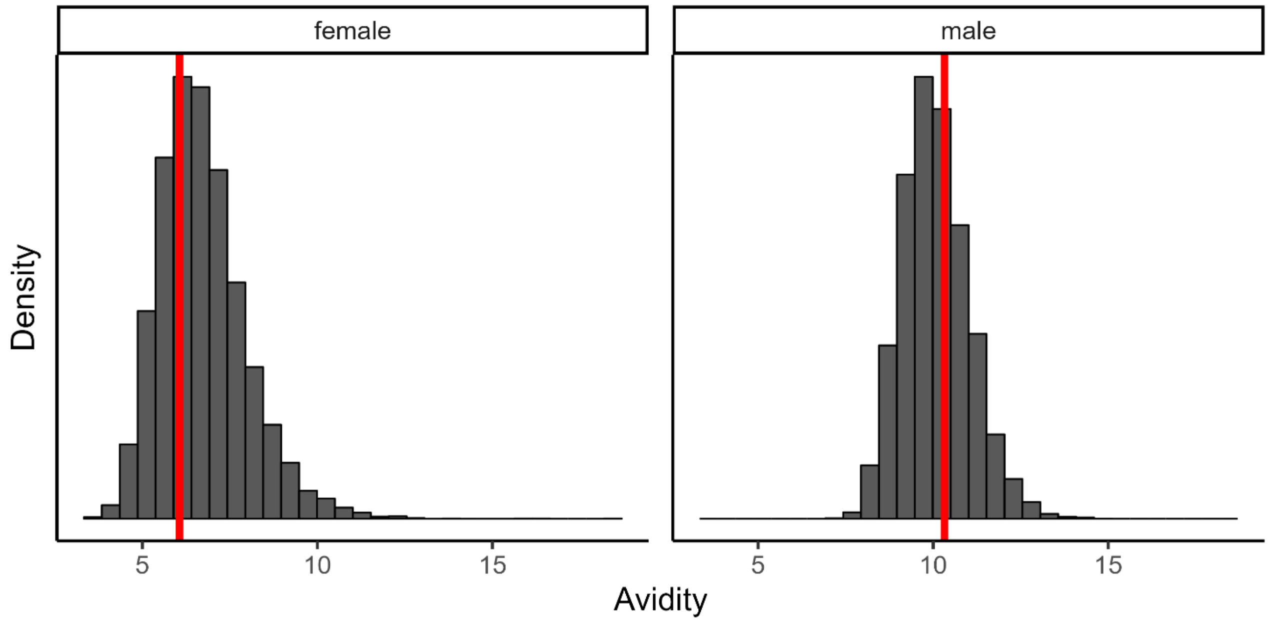


Figure 21. A posterior predictive check of the number of days fished (avidity) by male and female UK sea anglers. The bars show the proportion of each value from the posterior distribution of the fitted Bayesian model and the red line shows the estimate from the data.

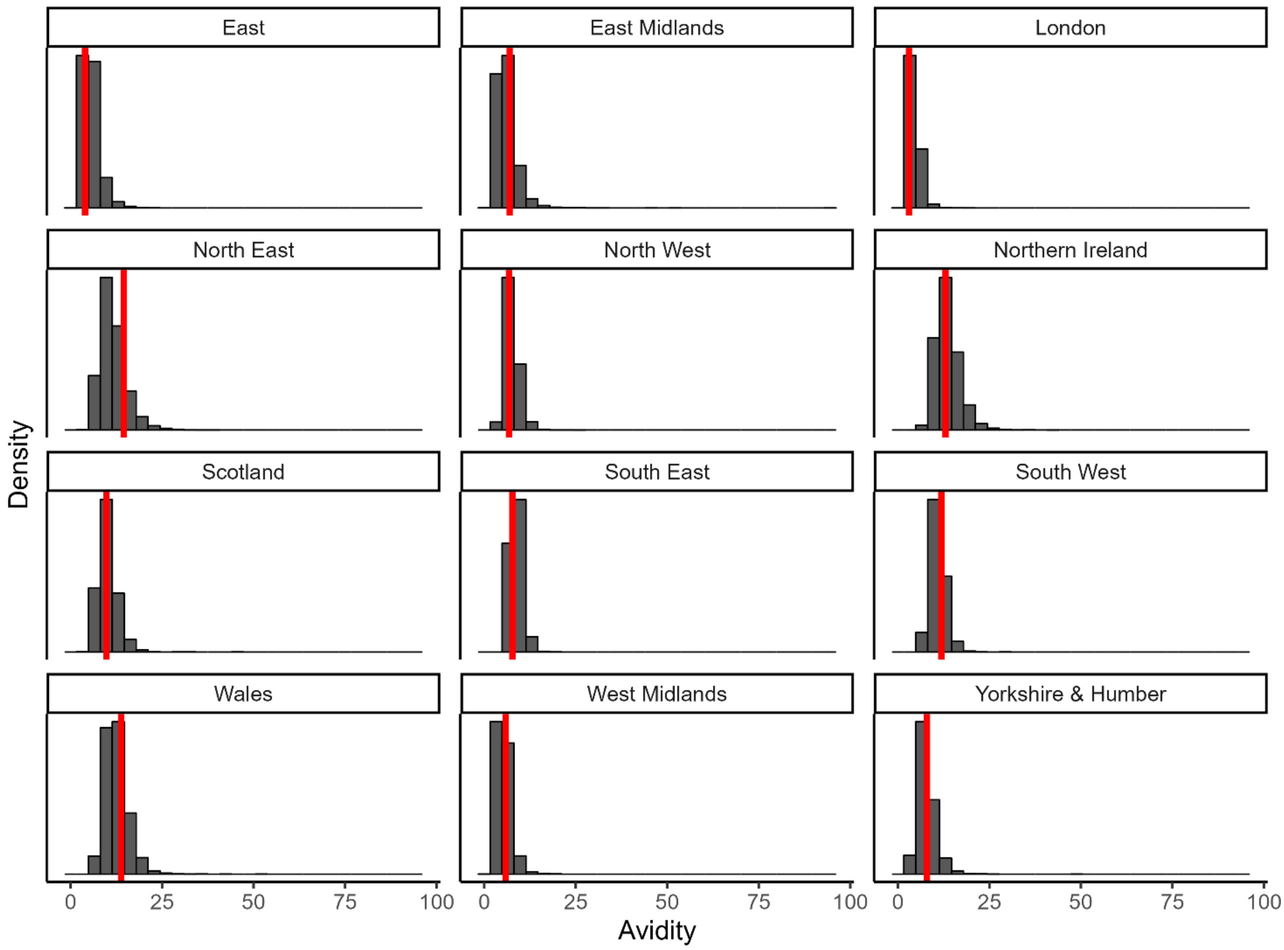


Figure 22. A posterior predictive check of the number of days fished (avidity) by sea anglers within each NUTS1 region of the UK. The bars show the proportion of each value from the posterior distribution of the fitted Bayesian model and the red line shows the estimate from the data.

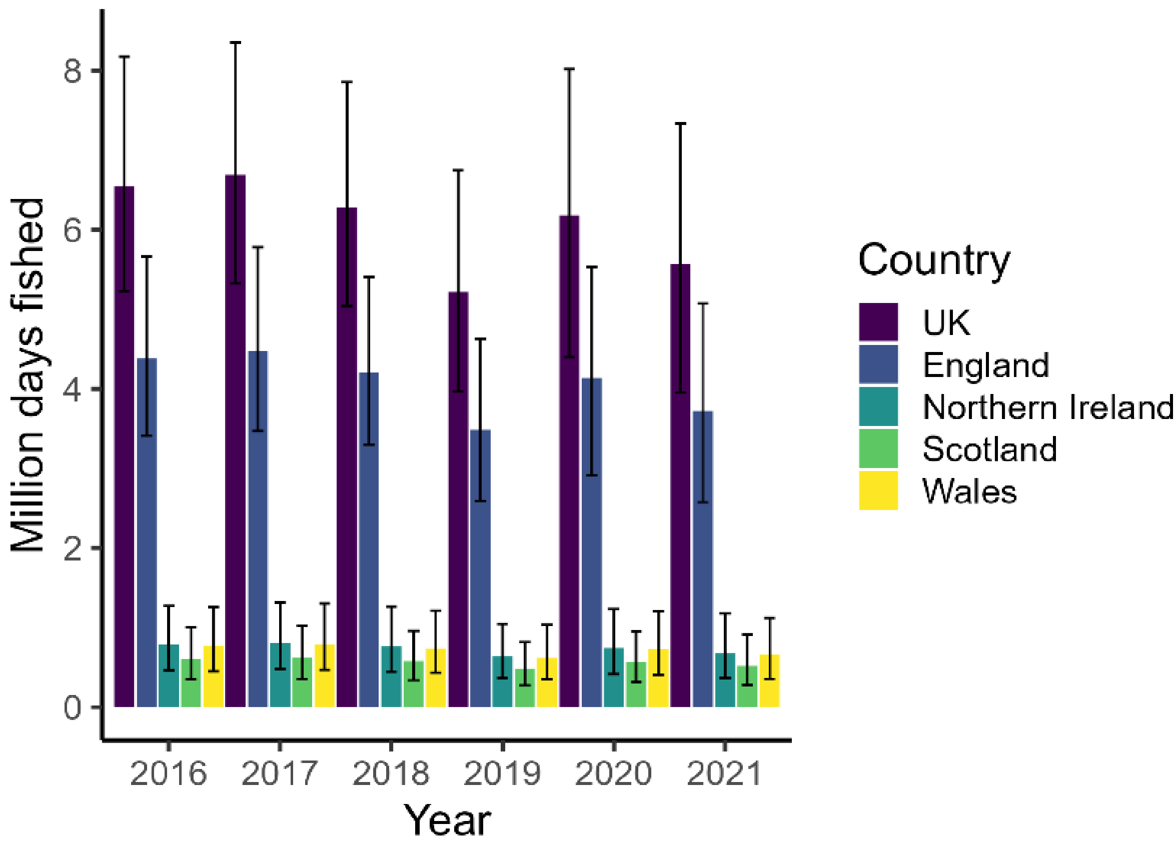


Figure 23. The total number of days fished (millions) ± 95% credible intervals for the UK and each of the countries within the UK estimated by Multi-level Regression and Post-stratification (MRP).

3.2.1.3. Comparison with existing methods

Comparing the total number of sea anglers in the UK estimated by MRP and reweighting procedure showed similar estimates of total anglers (Figure 24), with slightly lower estimates of error. Whilst both reweighting and MRP estimate a decrease in the number of fishers between 2017-19, this reduction was less severe using MRP. Furthermore, MRP estimates an increase in the number of fishers in 2020. As the face-to-face survey could not be conducted in 2020 and the replacement online survey produced results that were not in-line with previous estimates the 2019 reweighting estimates were used as a proxy for 2020 and 2021.

Although estimates of the number of sea anglers in each country of the UK in MRP appeared to differ in several years, the difference was usually within the estimates of error (Figure 25). However, the reduction in the error surrounding the estimates of angers within each country within the UK was lower when using MRP compared to reweighting.

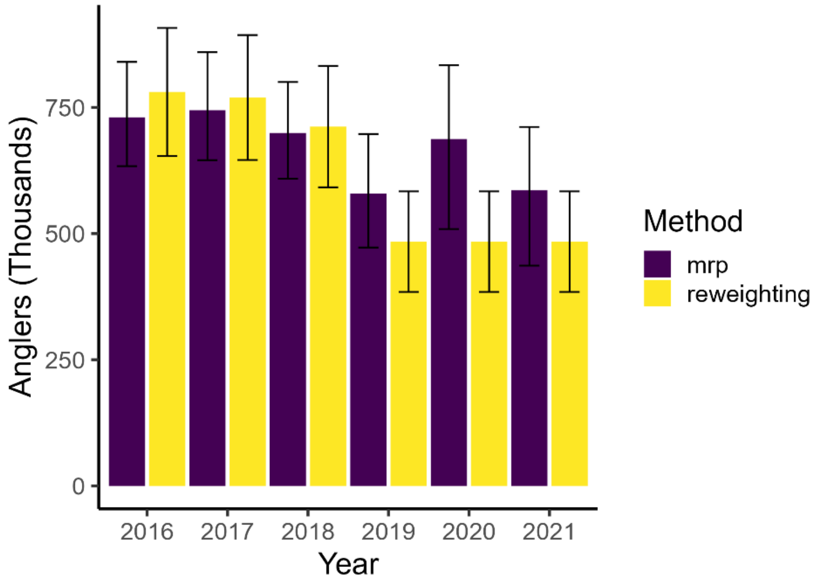


Figure 24. The total number of sea anglers in the UK estimated by multi-level regression and post stratification (MRP) and reweighting methods. Watersports Participation Survey results from the online survey in 2020 could not be used, so the reweighting results for 2019 were used as a proxy for 2020. Errors represent the 95% CI.

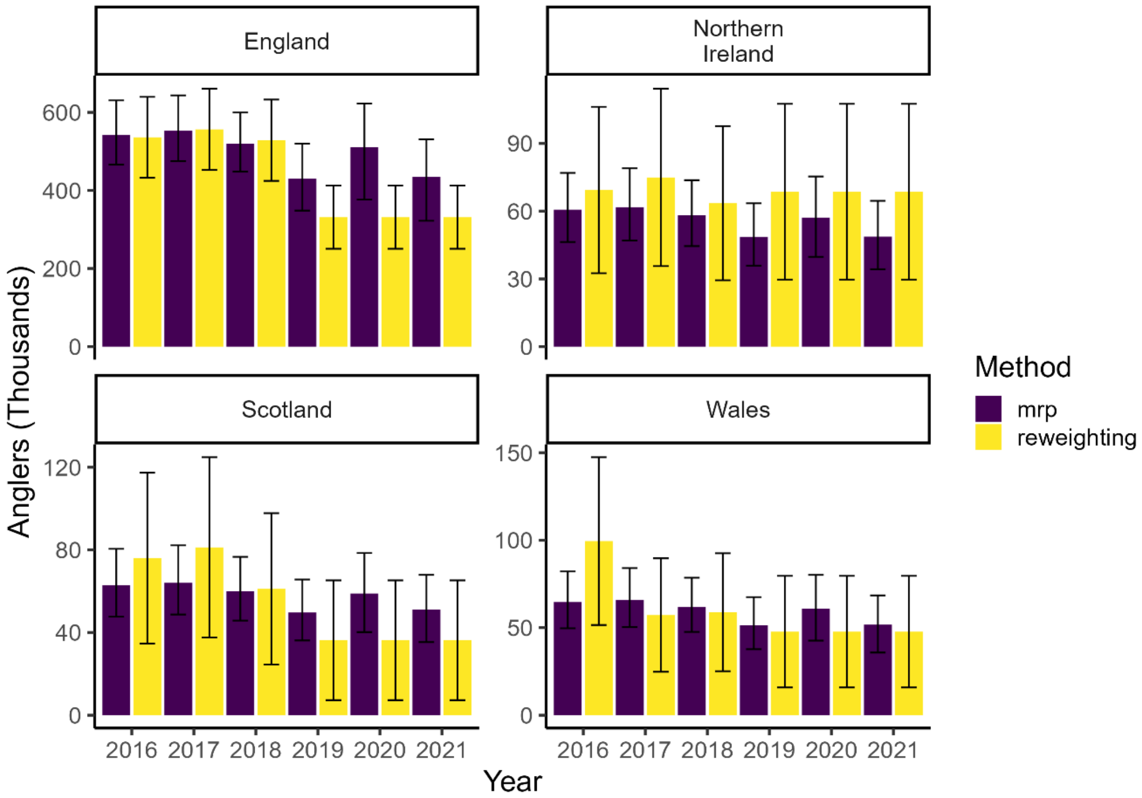


Figure 25. The total number of sea anglers in each of the countries within the UK estimated by multi-level regression and post stratification (MRP) and reweighting methods Watersports Participation Survey results from the online survey in 2020 could not be used, so the reweighting results for 2019 were used as a proxy for 2020. Errors represent the 95% CI.

3.2.2. Catch per angler

Some fish were caught rarely, so there was insufficient data to estimate catches. Thresholds were imposed on the number of fish recorded as kept or released (150), sessions (15), or diarists (15), with catches only estimated for species that exceeded these thresholds. This resulted in catches for 46 species that could not be estimated (Table 17).

Table 17. Species excluded from the analysis due to there being fewer than 150 caught (negligeable catch), 15 sessions where catches were caught, or 15 diarists reporting catch.

Name	Name
Anchovy	Megrim (Cornish sole, whiffy)
Atlantic saury	Northern squid
Black-mouthed dogfish	Norway pout
Blue-fin tuna	Other
Blue whiting	Pandora sea bream
Brill	Pogge
Brown crab	Porbeagle shark
Butterfish	Red band fish (ribbonfish)
Comber	Red mullet (striped mullet)
Connemara sucker (clingfish)	Red sea bream
Couch's sea bream	Salmon (north Atlantic salmon)
Cuckoo ray	Sand sole
Dragonet (common)	Solenette
European squid	Spanish mackerel
Greater pipefish	Sprat (skipper)
Greater weever fish	Starry ray (thorny skate)
Hake	Stingray (common stingray)
Halibut (Atlantic halibut)	Sunfish
Imperial scaldfish	Topknot
John dory	Triggerfish
Lemon sole	White sea bream
Lesser forkbeard (tadpole fish)	White skate (bottle-nose ray, spear nosed skate)
Lobster (common lobster)	Shad spp.

A zero-inflated Bayesian negative binomial model that included avidity, region, and year was fitted to the kept and release components for each species with sufficient data. In both the zero-inflation and catch parts of the model, year interaction with species and catch component had little impact as the parameter was close to zero (Figure 26). Avidity in its raw form was an important predictor for overall catch, with high avidity resulting in lower zero inflation and higher catch overall (Figure 26). The avidity group interaction with species and catch component was another strong predictor in the catch and zero-inflation portion of the model indicating some species were encountered and kept/returned at different rates by anglers that go fishing more often. Similarly, the diarists home region interaction with species and component was a good predictor suggesting that species are encountered and caught more in some regions compared to others. In both the zero-inflation and catch portion of the model the value for the species group interaction with catch component was the largest, but also had the highest error, suggesting high variation in return rates within species groups. Finally, the diarist ID was another key predictor in the model suggesting the probability of catching a fish and catch rates in the diary were highly variable between diarists.

It was not possible to present the predictions for all species, so instead the examples presented below relate to the number of sea bass caught per person. The raw data show an average of 0.43 seabass kept and 6.4 returned per person. The posterior predictions where the diarist ID was included when generating the predictions (Figure 27A) showed a close fit for the kept component of the catch with a median catch rate of 0.44, and a small overestimate for the returned component of the catch with a median catch rate of 6.94. When generating the same predictions with the effect of diarist ID removed (Figure 27B), providing an average estimate per person in the population, the model predictions are reduced to 0.34 seabass kept and 5.33 returned per person.

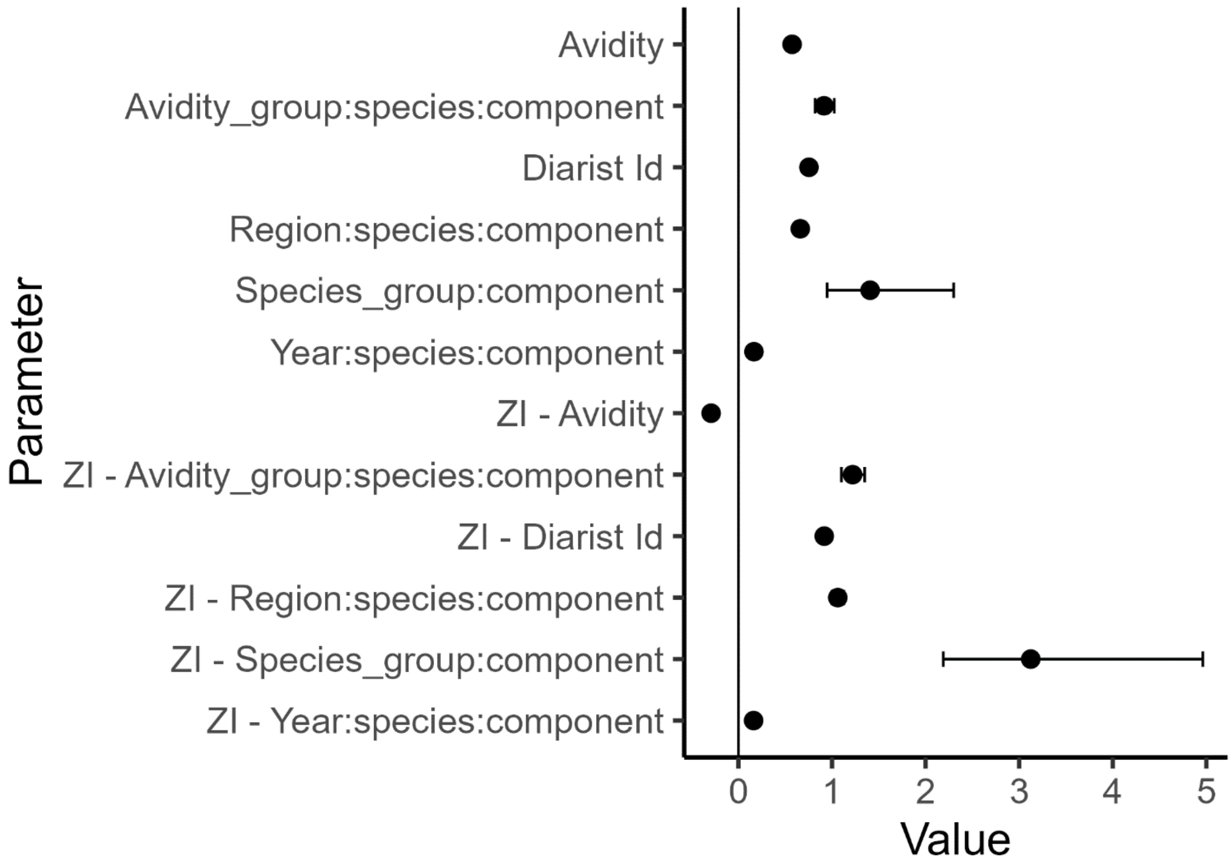


Figure 26. Parameter values of the catch per angler model. ZI indicates the value for the zero-inflation parameter. : indicates a model interaction term.

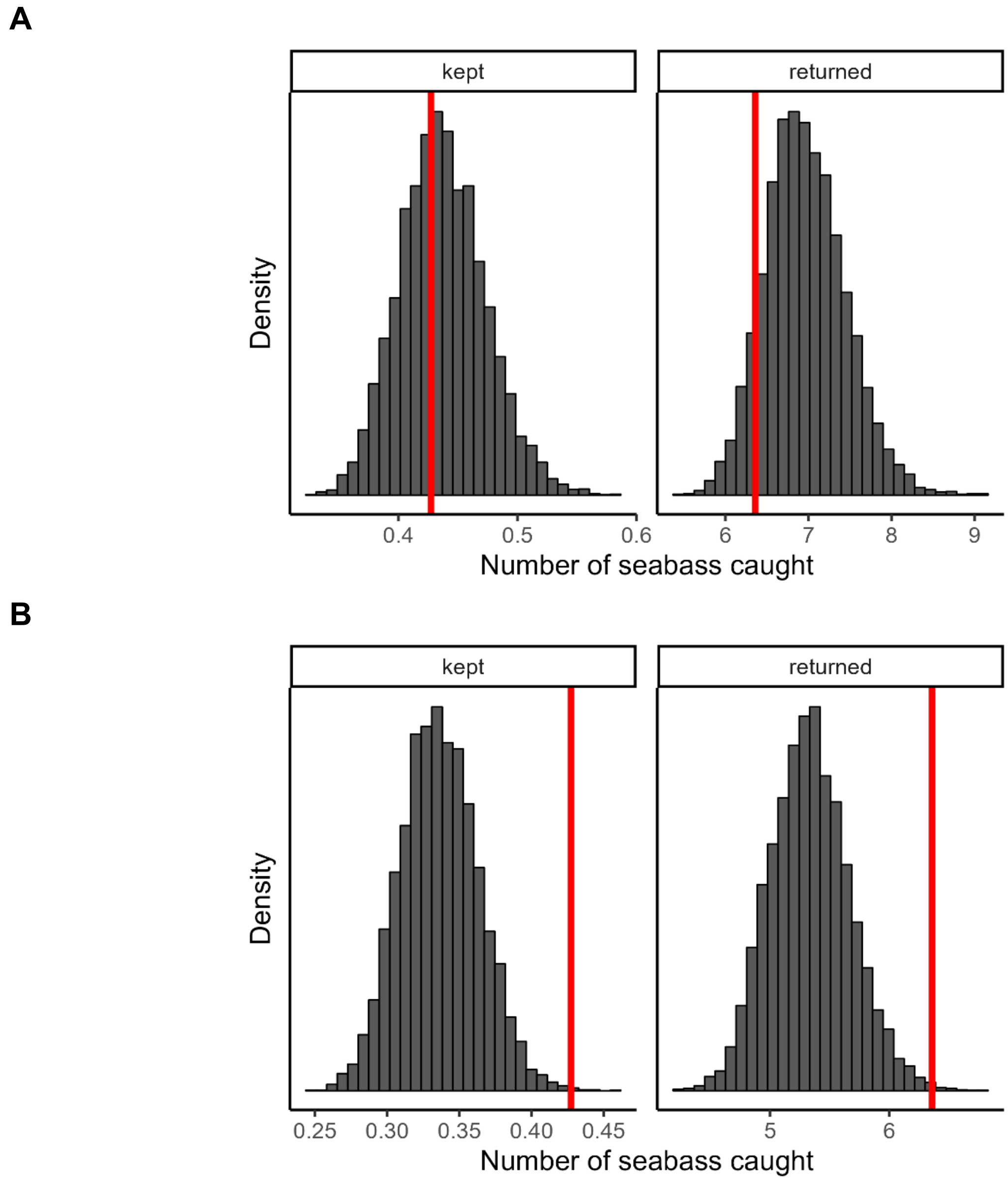


Figure 27. Posterior predictions for the mean number of sea bass caught where the diarist ID effect was included (A) and excluded (B), giving a population-level estimate that is used for extrapolation.

3.2.3. Weight of individual fish

A Bayesian lognormal model was fitted to individual fish weights for kept and released components variable (Figure 28). As expected, weight varies between species and kept and released fish. Angler avidity had a small but notable impact on the average weight of a fish caught with higher avidity angler catching larger fish on average. Finally, the diarist ID had a large effect on the predictions indicating there was large variation between the weight of fish caught by diarists.

Examining the posterior predictions from the model for sea bass caught revealed a 41% overestimate of the kept weight with the model predicting a median value of 2.36kg compared to the raw data average of 1.56kg (Figure 29A). However, the model showed a good fit for the returned data with a median prediction of 0.67kg compared to the raw average of 0.66kg. When removing the effect of diarist ID the median weight of a seabass caught predicted by the model reduced to 1.48kg for the kept component and 0.51kg for the returned component (Figure 29B). This suggested that there were a small number of anglers catching a lot of large fish, inflating the average weights in the model. For extrapolation, the predictions were generated by removing diarist ID from the random effect formula, resulting in a less biased population-level average.

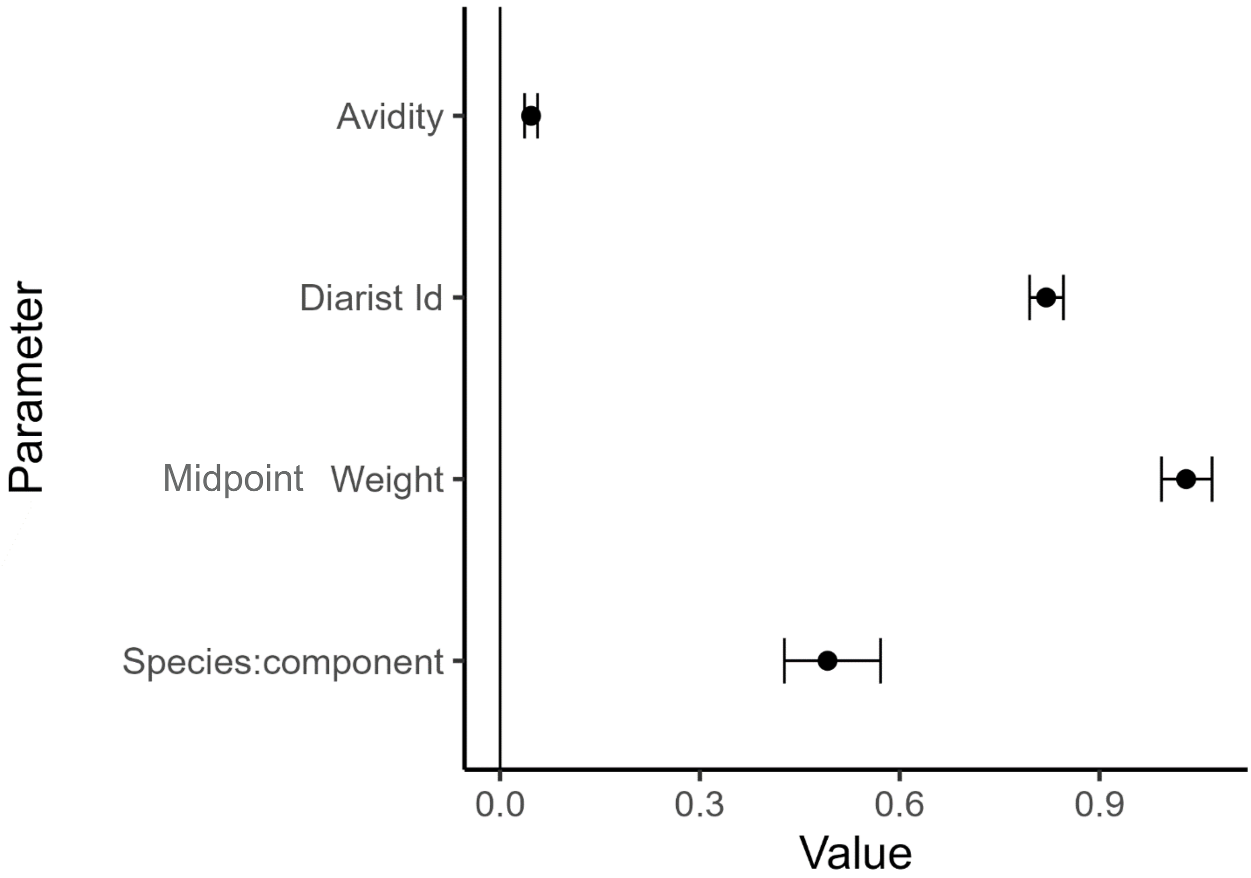


Figure 28. Parameter values of the weight model of all species and components.

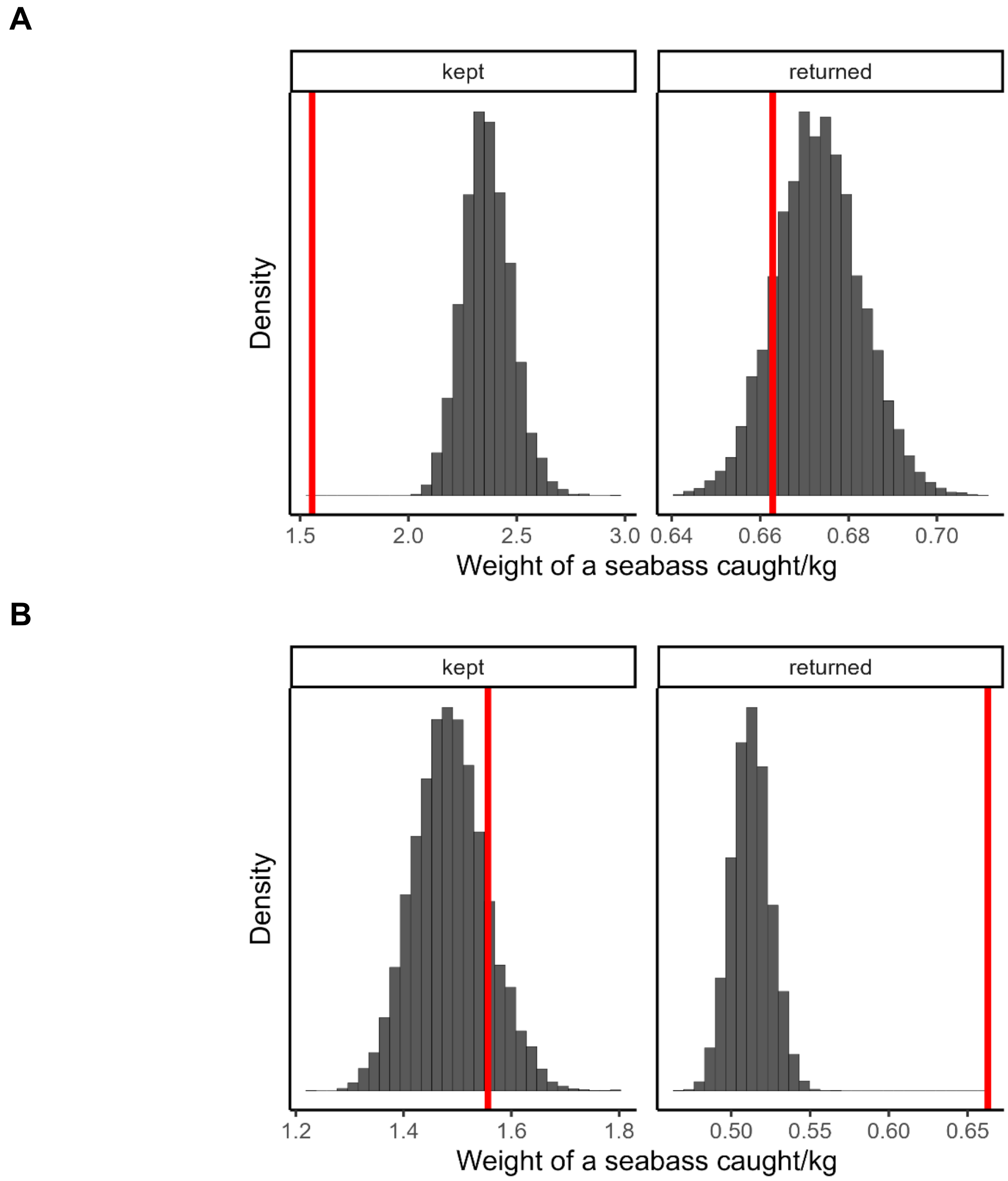


Figure 29. Posterior predictions for the mean weight of a seabass caught where the diarist ID effect was included (A) and excluded (B), giving a population-level estimate that is used for extrapolation.

3.2.4. Catches

Total catch was estimated by combining the effort and the catch per angler models, accounting for differences in avidity, age, gender, and region. A simulation approach was used to assess the robustness of MRP against a traditional reweighting approach. Total catch was estimated by combining the posterior distributions of the total catch and the weight models of kept and released fish for each species. Results of the modelled approach were assessed and compared with a traditional reweighting approach, with the drivers of differences investigated.

3.2.4.1. Assessing MRP & reweighting methods using simulation

The simulation study of the MRP and reweighting approaches for estimating total number of fish caught showed that MRP outperforms weighting on all key metrics. The mean squared error for MRP was consistently lower than the reweighting method (Figure 30), as was the mean absolute error (Figure 31). The R^2 value for the model was consistently higher than the reweighting method (Figure 32). When using the methods to estimate the sea bass catches, the MRP estimate generated an improvement of 58% compared to reweighting for the kept component, and a 61% improvement for the returned component (Figure 33).

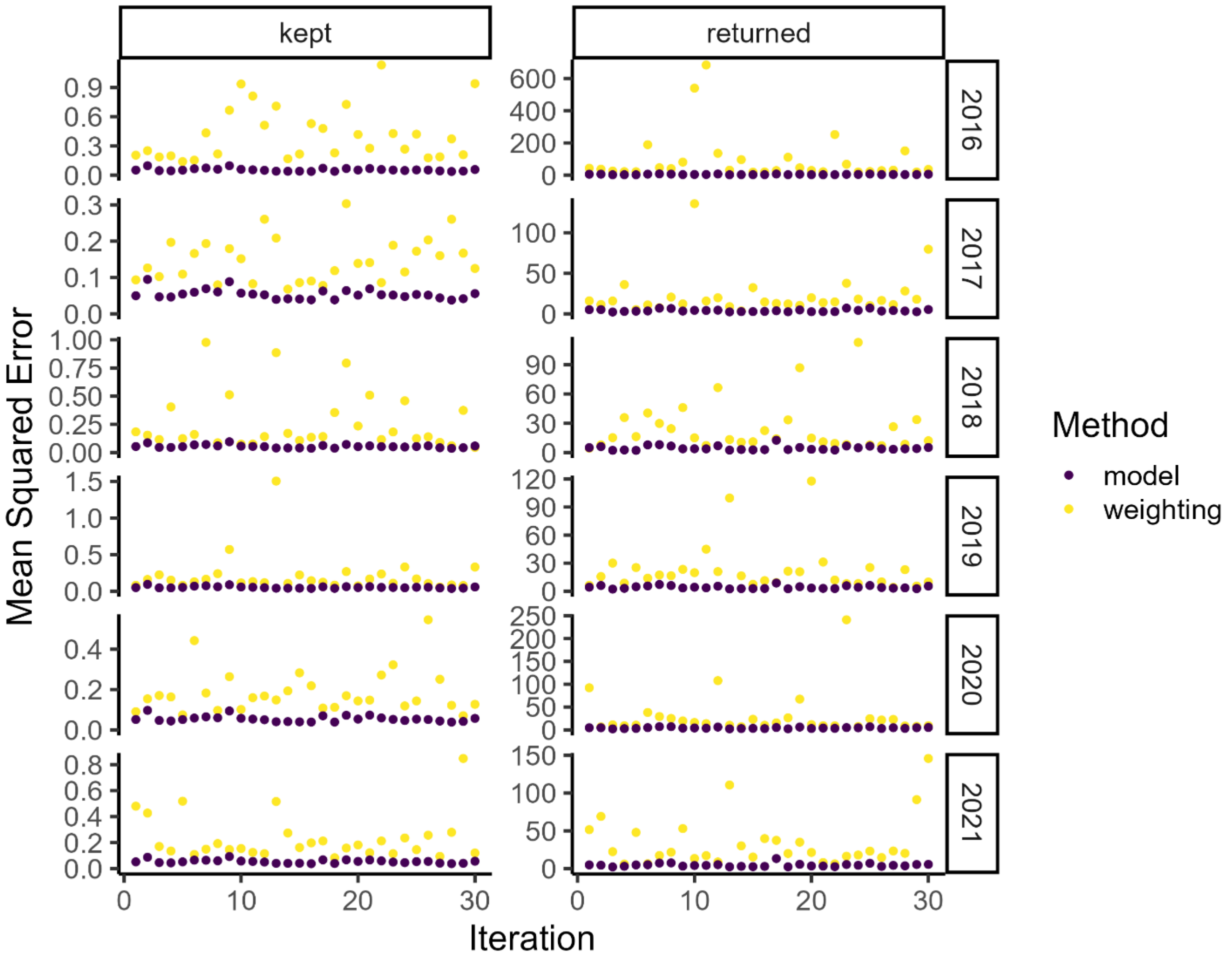


Figure 30. The mean squared error for both the model and reweighting based estimates of kept and returned catches of sea bass compared to simulated values. Values closer to zero are better.

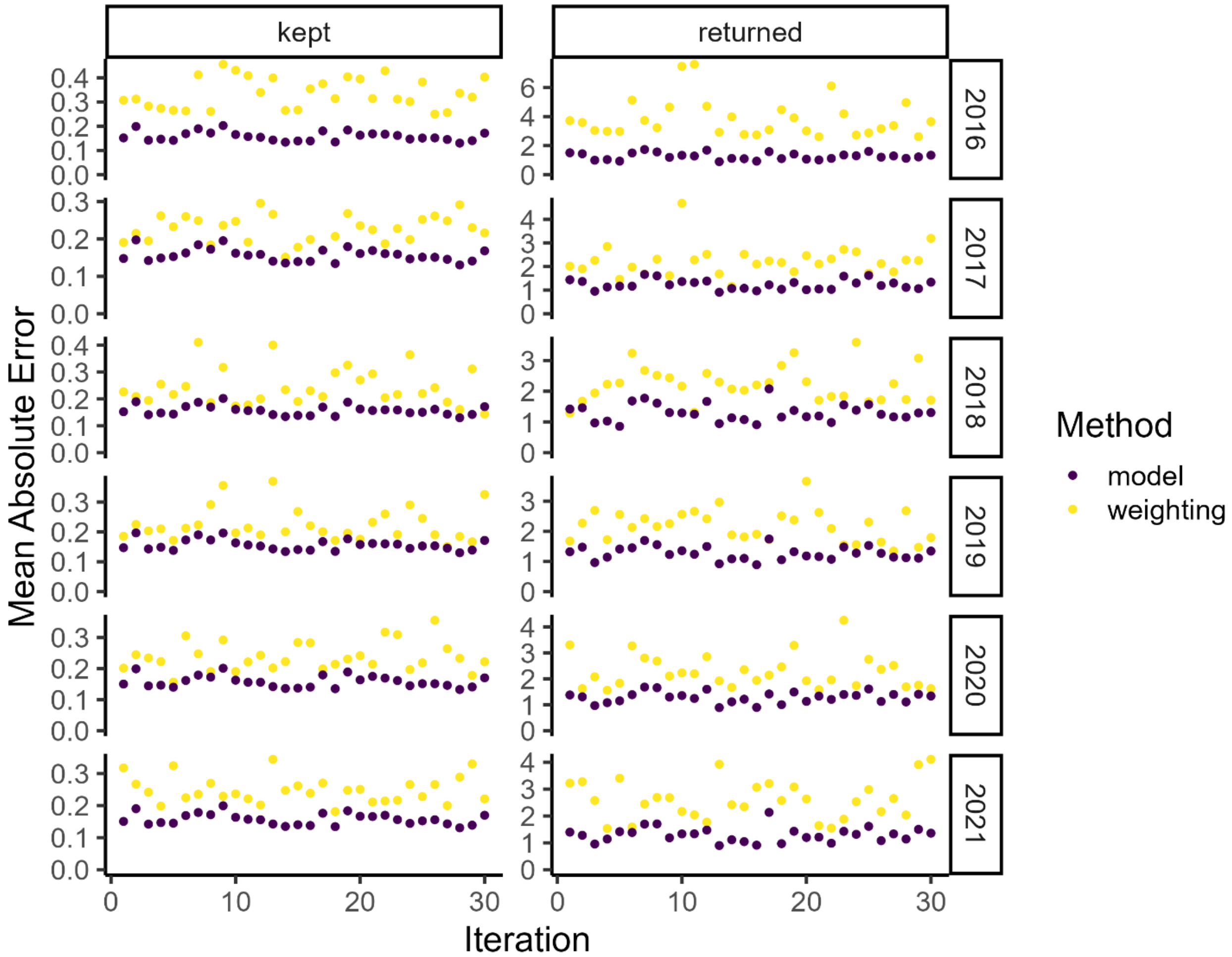


Figure 31. The mean absolute error for both the model and reweighting based estimates of kept and returned catches of sea bass compared to simulated values. Values closer to zero indicate a better fit.

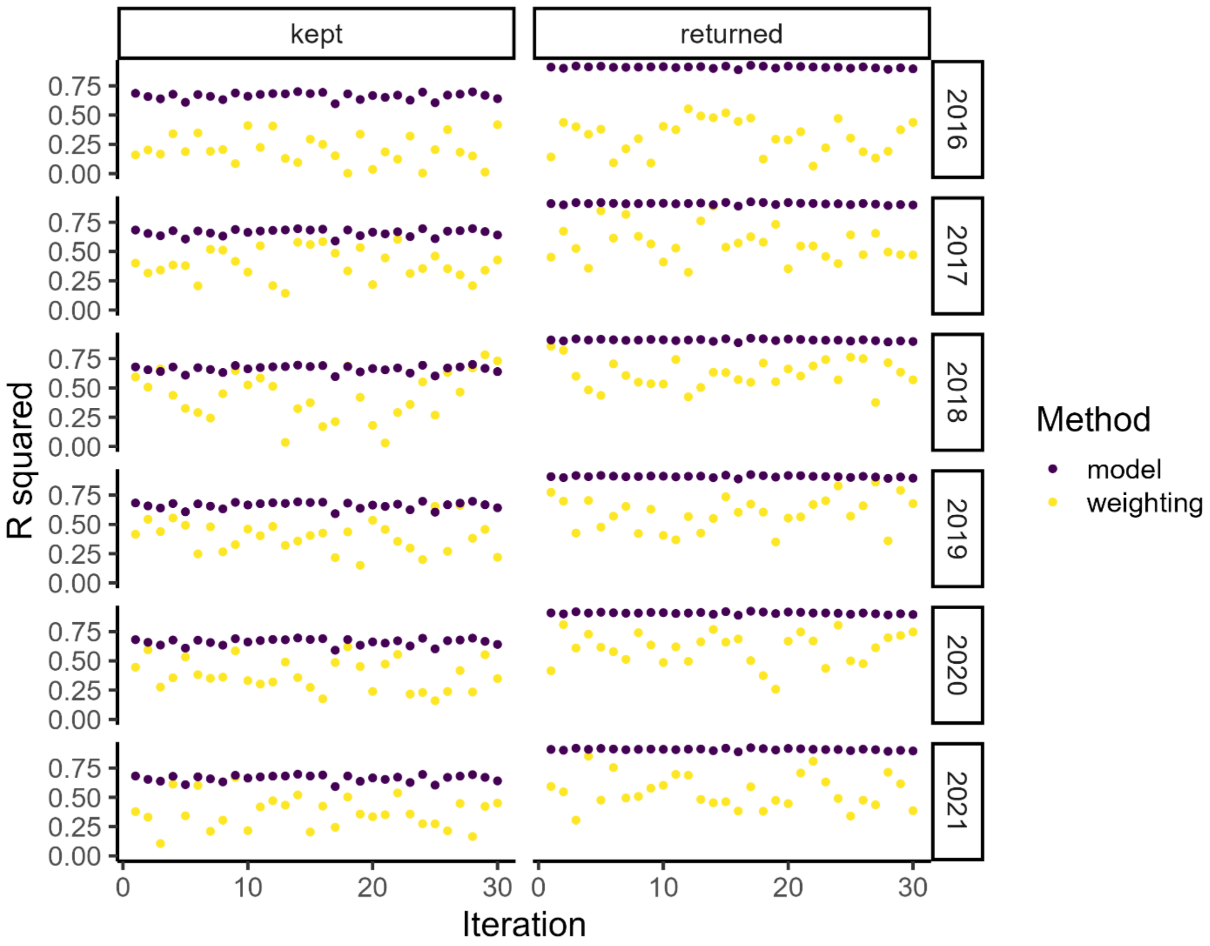


Figure 32. The R^2 for both the model and reweighting based estimates of kept and returned catches of sea bass compared to simulated values. Higher values are better.

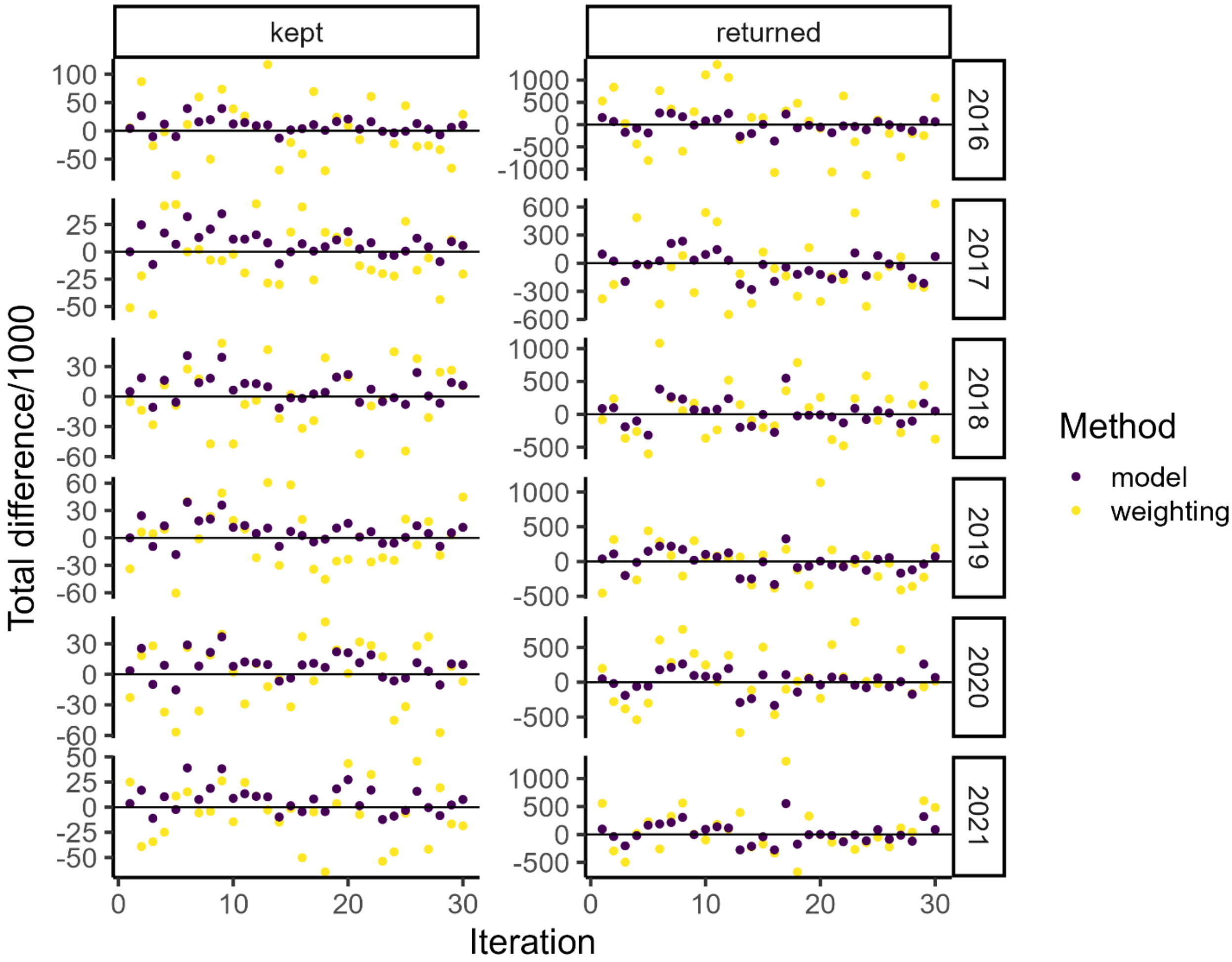


Figure 33. The total difference in catches of sea bass between the weighting and model methods compared to simulated totals Values closer to zero indicate a better fit.

3.2.4.2. MRP model-based catch estimates

For some species, despite there being sufficient data to model the catches, the RSE associated with the result was above the 50% threshold meaning the estimates were too uncertain to be presented (Table 18). Excluding these species resulted in 48 species where either the kept or returned catches were reported, 47 species where the returned catches were reported, and 35 (34 in 2016 due to a high RSE for blonde ray) where the kept catches were reported (Table 19).

Table 18. Estimates excluded from reporting due to the relative standard error (RSE) being above 50%. Values in the columns are the percentage RSE's relating to the species, component, and year. Where '---' occurs the RSE was below 50% and so was included in the reporting.

Species	Component	2016	2017	2018	2019	2020	2021
Blenny spp.	kept	75	73	73	76	73	72
Blonde ray	kept	50	---	---	---	---	---
Blue shark	kept	105	104	99	104	101	102
Spurdog	kept	63	62	63	61	60	61
European eel	kept	74	71	73	71	71	74
Tope	kept	65	62	62	64	62	65
Goby spp.	kept	91	91	89	92	93	90
Pilchard	returned	55	54	54	53	55	53
Rockling spp.	kept	59	58	60	57	61	59
Sea scorpion spp.	kept	112	111	110	110	111	109
Common skate	kept	76	73	71	76	74	76
Smelt spp.	kept	90	88	88	89	92	87
Sea trout	kept	59	57	58	58	56	56
Undulate ray	kept	60	60	60	59	60	60
Lesser weever	kept	111	112	110	113	112	111

The MRP modelling approach estimated that between 29.7 and 42.6 million fish were caught between 2016-21, with around 80% of these being released each year (Figure 34A&B). This equated to between ~3,000-4,400 tonnes of fish kept and between ~10,200-13,400 tonnes of fish returned (Figure 35). Most of the catches were reported in England, with the magnitude of catches reported within the countries of the UK similar (Figure 34C&D; Figure 36).

The EU Data Collection Framework species, sea bass, cod, pollack, and elasmobranchs (sharks, skates, and rays) catch totals were mostly similar across years (Figure 37A&B). However, the number and weight of cod returned decreased in 2020 (Figure 37A&B). Furthermore, the weight of sea bass kept increased in 2019 and 2020 (Figure 37B). Splitting the catches of cod and sea bass to an ICES division level (Figure 38) revealed that most sea bass was caught within the ICES divisions located in the southwest (ICES divisions starting with 7). However, cod is mostly caught within the North Sea (ICES divisions starting with 4). Estimates of error at an ICES division level were not taken from MRP due to current limitations of the model, instead, the error in catches were generated using a reweighting approach. Consequently, the credible intervals presented for ICES division level estimates were likely to be overestimates. Further work is required to develop the model to generate model-based catches at an ICEs division level.

Table 19. The species that were reported for the 2016-21 survey based of sufficient raw data, and less than 50% relative standard error (RSE) in the estimate. * indicates where the species & component were not reported in all years due to a high RSE.

Kept	Returned
Bib (pouting, pout, pout-whiting)	Bib (pouting, pout, pout-whiting)
Black sea bream	Black sea bream
Blonde ray*	Blenny spp.
Cod (Atlantic cod)	Blonde ray
Conger eel	Blue shark
Dab (common dab)	Cod (Atlantic cod)
Bull huss (greater spotted dogfish, nursehound)	Conger eel
Bass (seabass)	Dab (common dab)
Flounder (European flounder, fluke)	Bull huss (greater spotted dogfish, nursehound)
Garfish (needlefish, garpike, sea pike)	Spurdog
Grey mullet spp.	Freshwater eel (common eel, silver eel)
Grey gurnard	Bass (seabass)
Red gurnard	Flounder (European flounder, fluke)
Haddock	Tope
Herring	Garfish (needlefish, garpike, sea pike)
Scad (horse mackerel)	Goby spp.
Ling (common ling, white ling)	Grey mullet spp.
Lesser spotted dogfish (lsd)	Grey gurnard
Mackerel	Red gurnard
Pilchard	Haddock
Plaice	Herring
Poor cod	Scad (horse mackerel)
Coalfish (saithe, coley)	Ling (common ling, white ling)
Pollack (lythe)	Lesser spotted dogfish (lsd)
Small-eyed ray (painted ray)	Mackerel
Sandeel spp.	Plaice
Gilthead sea bream	Poor cod
Spotted ray	Coalfish (saithe, coley)
Smoothound	Pollack (lythe)
Dover sole (common sole, black sole)	Small-eyed ray (painted ray)
Thornback ray (roker)	Rockling spp.
Tub gurnard (yellow gurnard, tubfish)	Sandeel spp.
Turbot	Gilthead sea bream
Whiting	Spotted ray
Wrasse spp.	Smoothound
	Sea scorpion spp.
	Common skate
	Smelt spp.
	Dover sole (common sole, black sole)
	Thornback ray (roker)
	Sea trout (brown trout)
	Tub gurnard (yellow gurnard, tubfish)
	Turbot
	Undulate ray
	Lesser weever
	Whiting
	Wrasse spp.

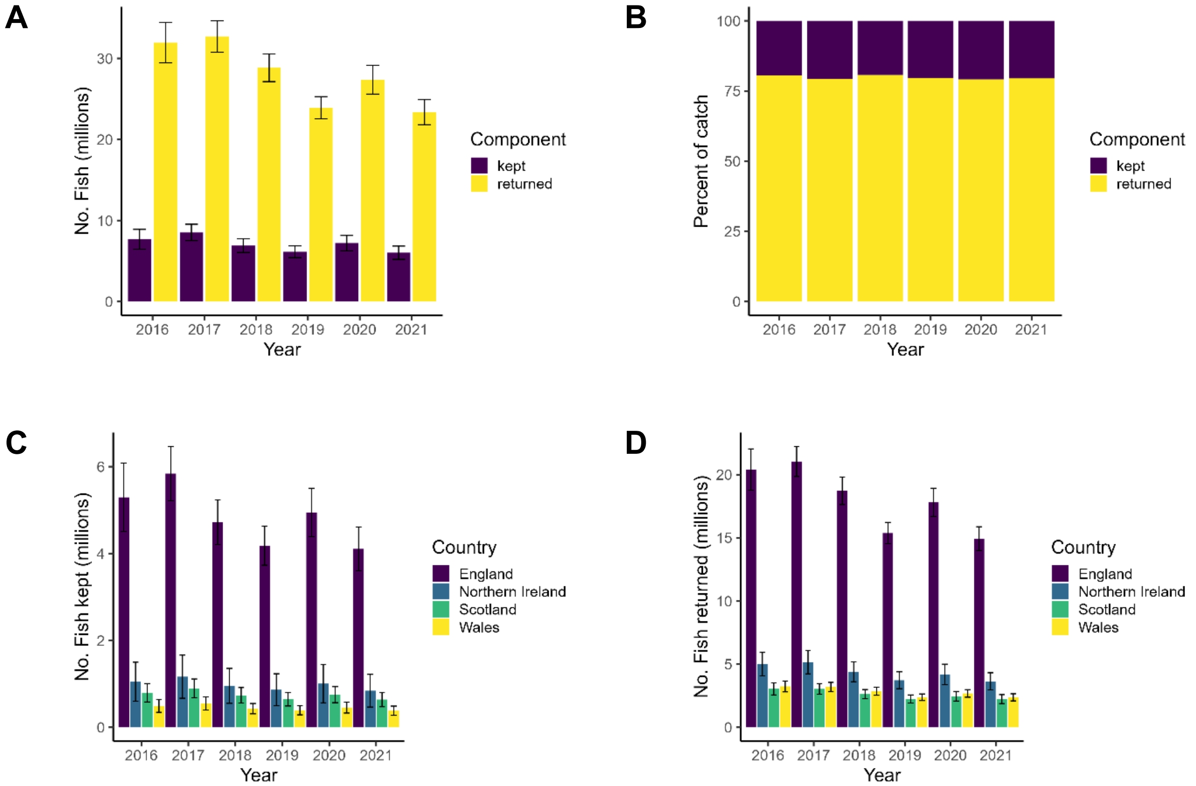


Figure 34. Numbers of fish kept and released (A), release proportions (B), and numbers of fish kept (C) and released (D) for individual countries within the UK between 2016-21. The error bars represent the 95% credible interval.

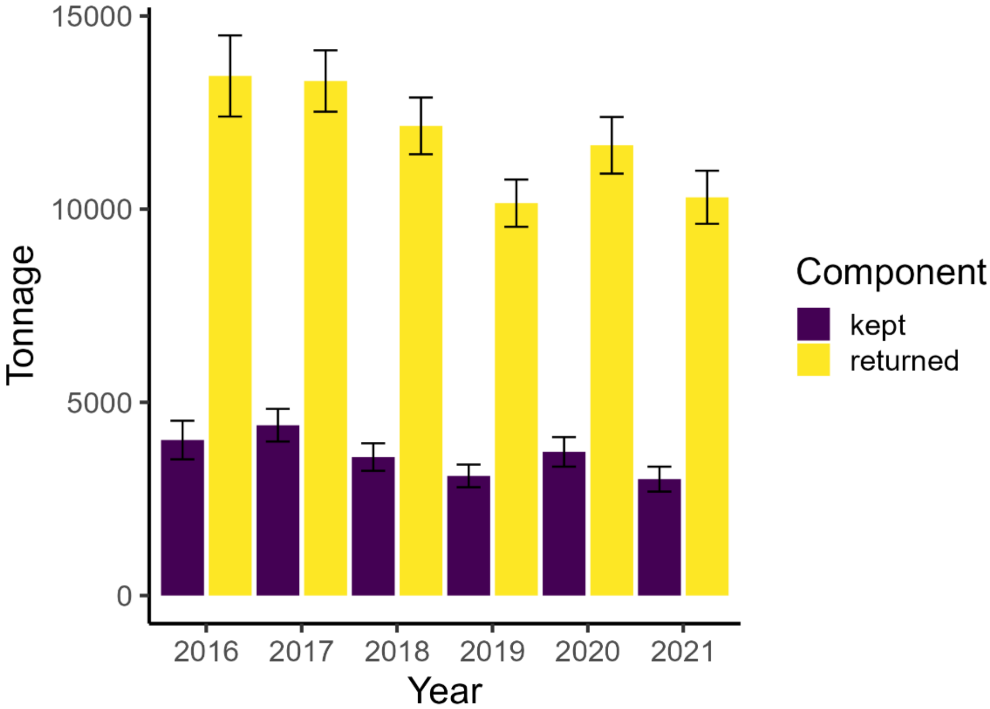


Figure 35. The tonnage of fish kept and returned in the UK between 2016-20. The error bars represent the 95% credible interval.

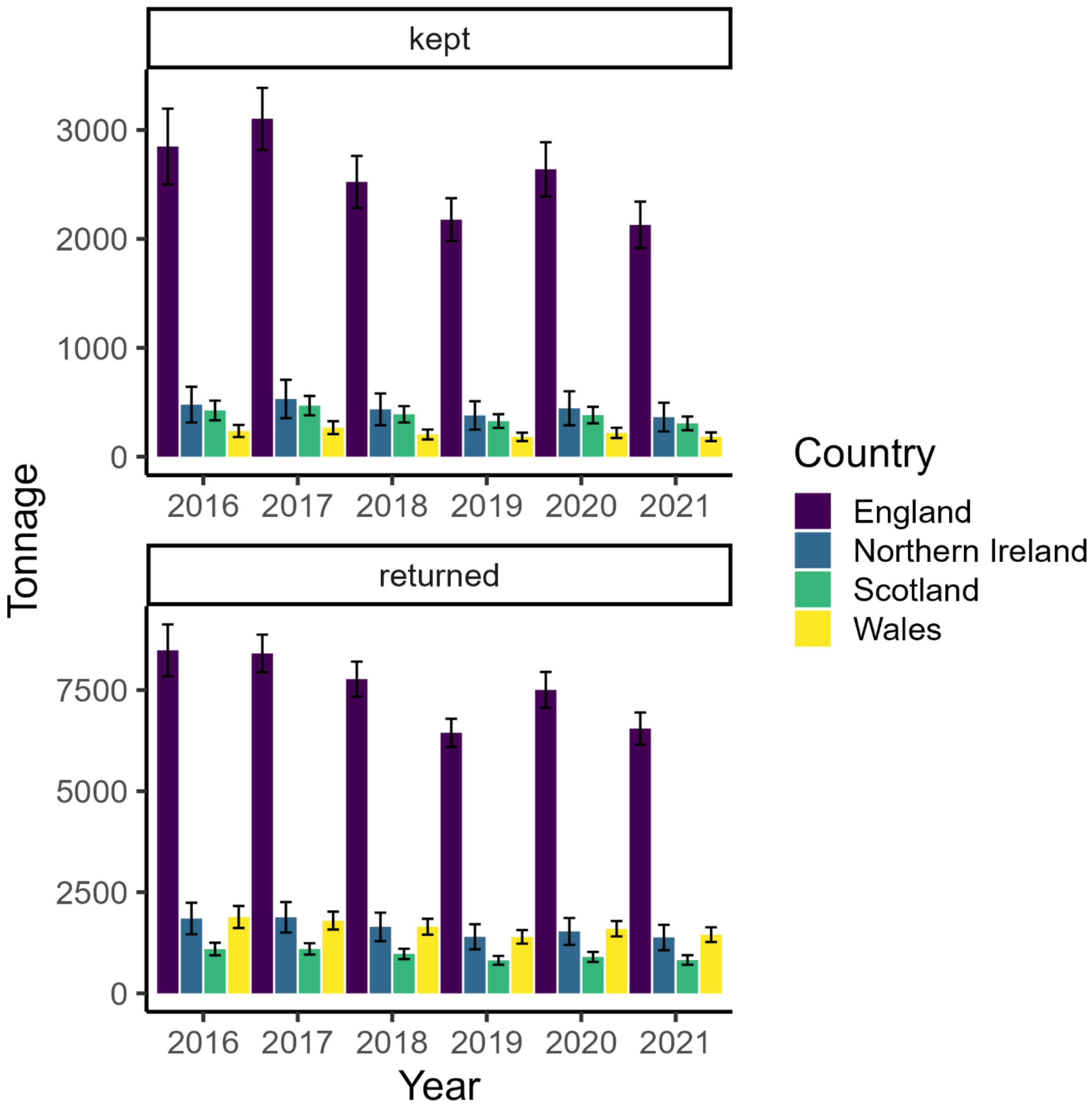


Figure 36. Tonnage of fish kept (top) and returned (bottom) for individual countries within the UK between 2016-21. The error bars represent the 95% credible interval.

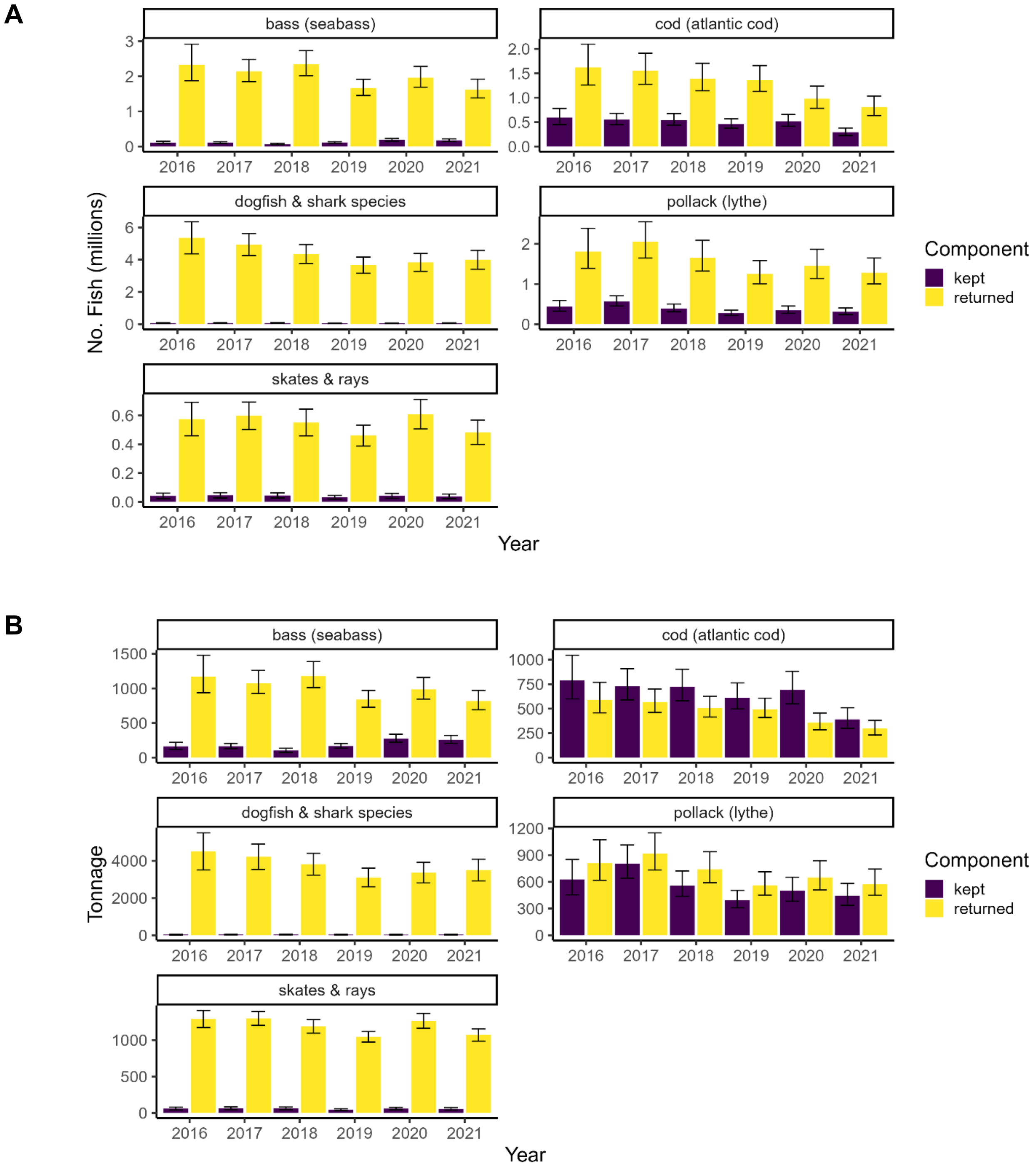


Figure 37. Numbers (A) and tonnage (B) of Data Collection Framework species kept and released by sea anglers resident the UK in 2016-21. Error bar are 95% credible intervals.

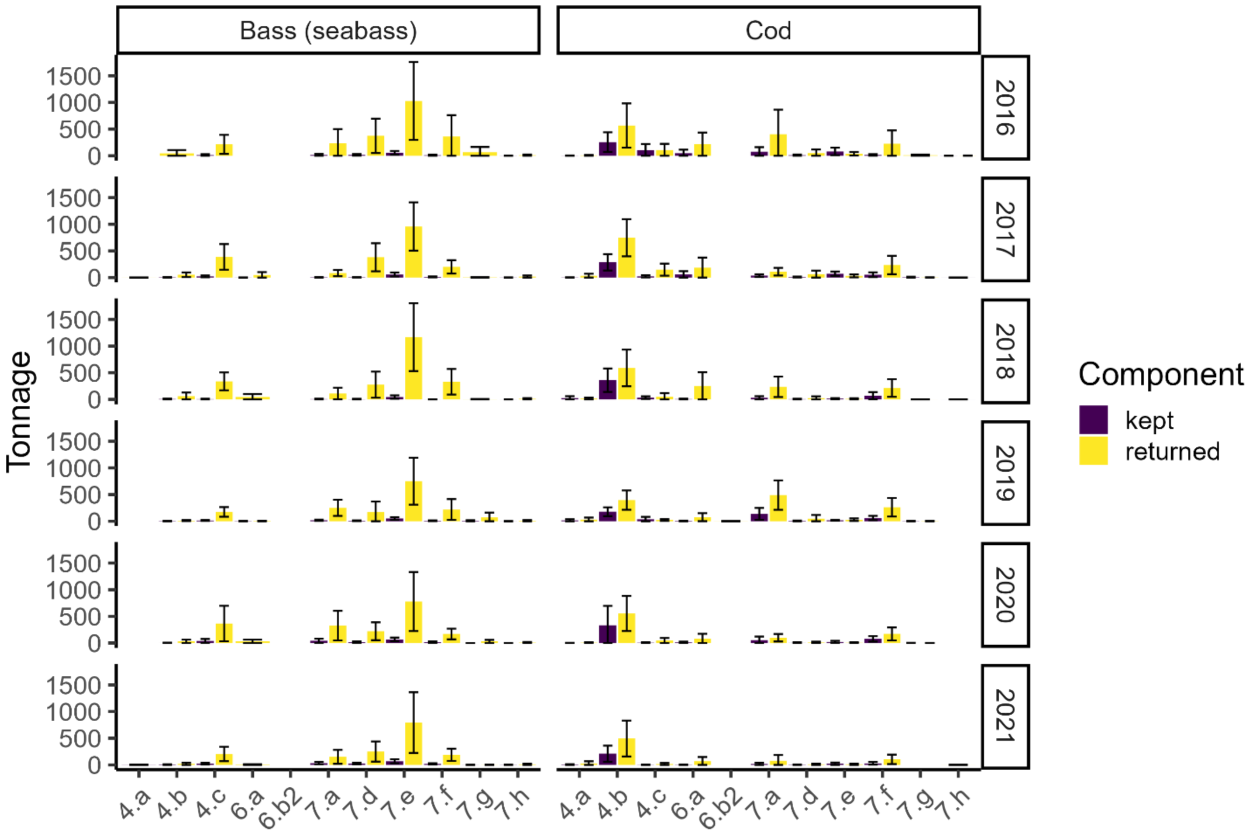


Figure 38. Tonnages of cod and sea bass kept and released for ICES divisions by sea anglers resident in the UK in 2016-20. Error bars represent 95% credible intervals (CI). Note, the CI's represent the CI within the ICES division taken from all years of the reweighting approach due to current limitations of the catch model.

3.2.4.3. Comparisons of catch estimates from MRP with reweighting

When compared to reweighting, MRP estimated lower numbers of fish caught between 2016-19 for the kept and returned component of the catch (Figure 39A). Whilst the numbers of fish kept and returned in 2020-21 were larger using MRP, the difference are relatively small ranging from 13-19% and are within 95% confidence intervals (Figure 39A). Furthermore, the tonnage of fish caught estimated by MRP was lower than reweighting for all components and years (Figure 39B). In addition to producing lower mean estimates, the interannual variation between catches as well as the RSEs were lower when using MRP for both the number and weight of fish caught (Figure 40; Figure 41). The method used did not impact on the proportion of fish kept and released (Figure 42). The majority of the top ten species caught in 2021 identified were the same for both methods, but there were differences in order with whiting higher using reweighting and black sea bream absent from MRP (Figure 43A&B). The main drivers for lower catch estimates from 2016-19 using MRP than reweighting were reduced catches per angler and fish weights, and higher MRP estimates were related to increased numbers of anglers in 2020-21 (Figure 44).

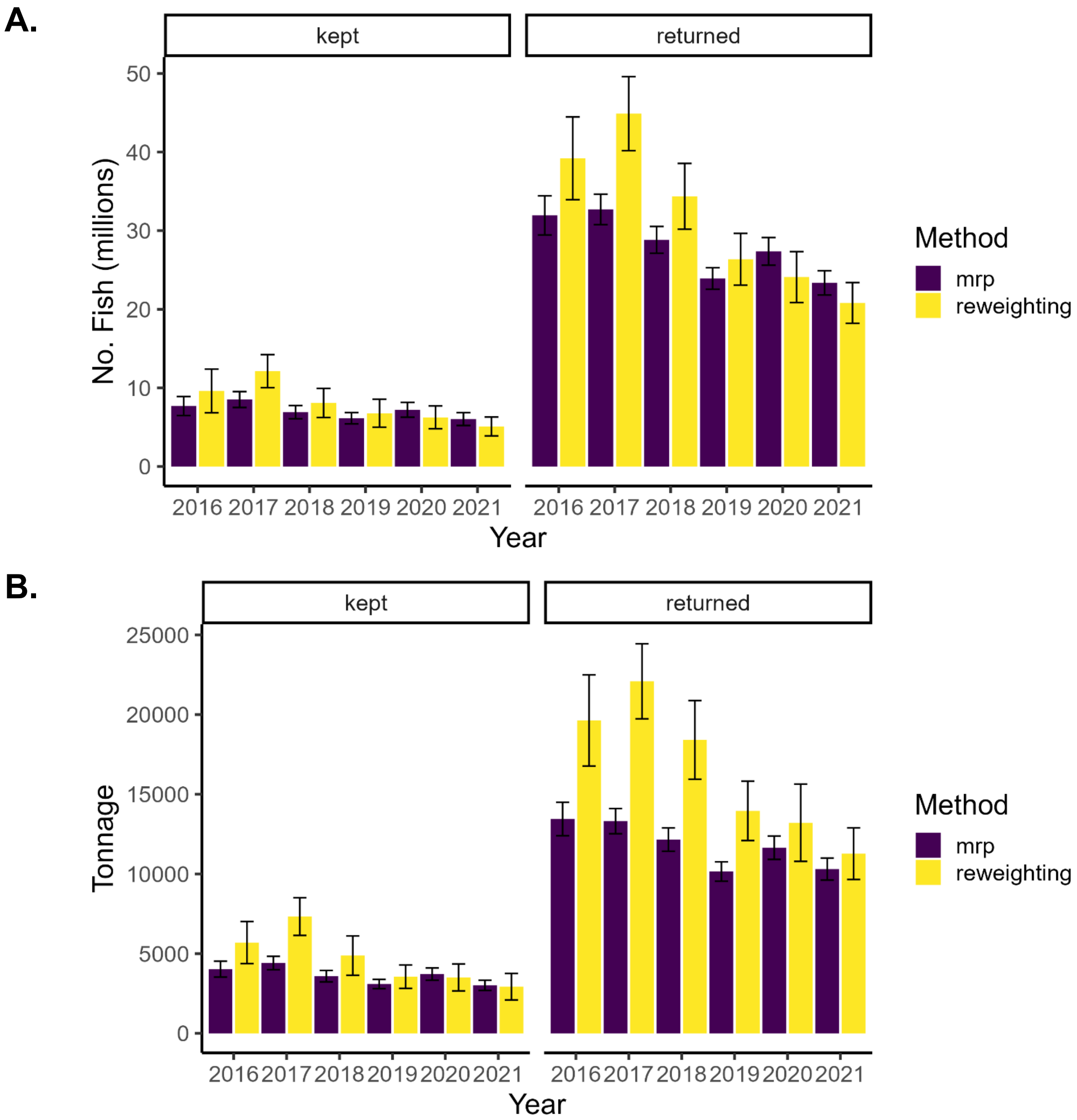


Figure 39. The number (A) and weight (B) of fish caught, as calculated by the reweighting and multilevel regression and poststratification (MRP) approaches. Errors are 95% CI.

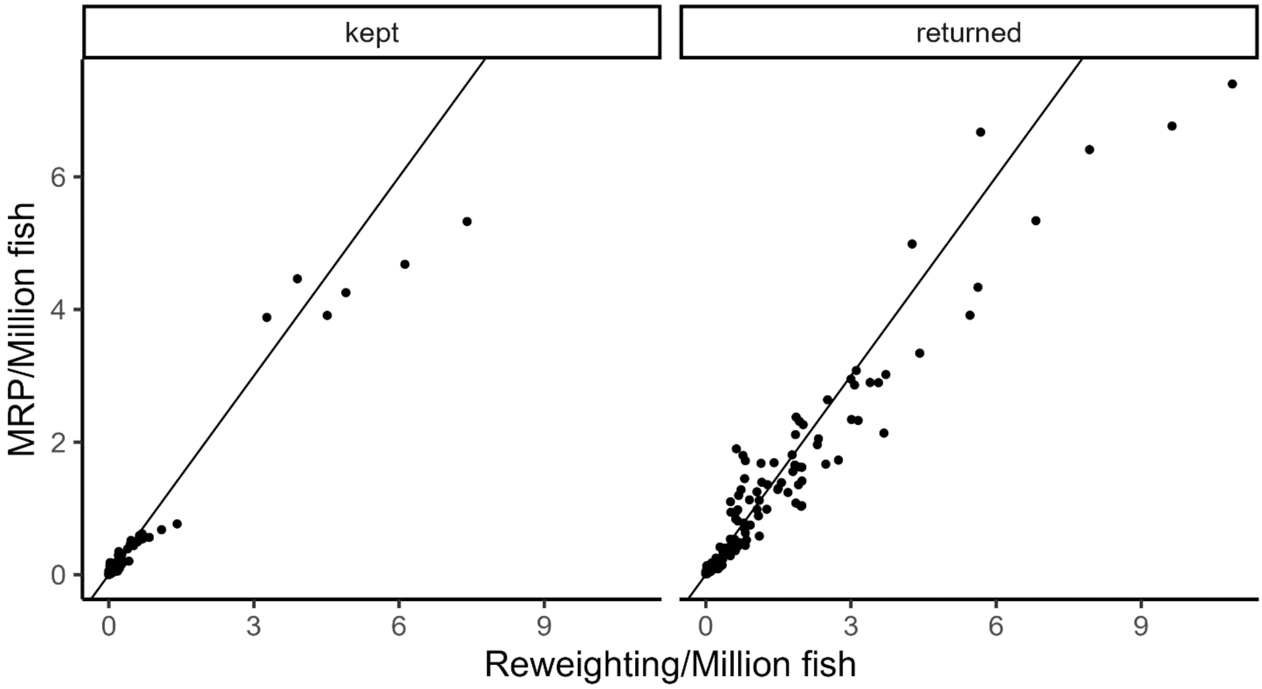


Figure 40. The number of fish caught (millions), as calculated by the reweighting and multilevel regression and poststratification (MRP) approaches. The diagonal line represents the value if the RSE in both approaches is equal. Each point represents a species catch within a year.

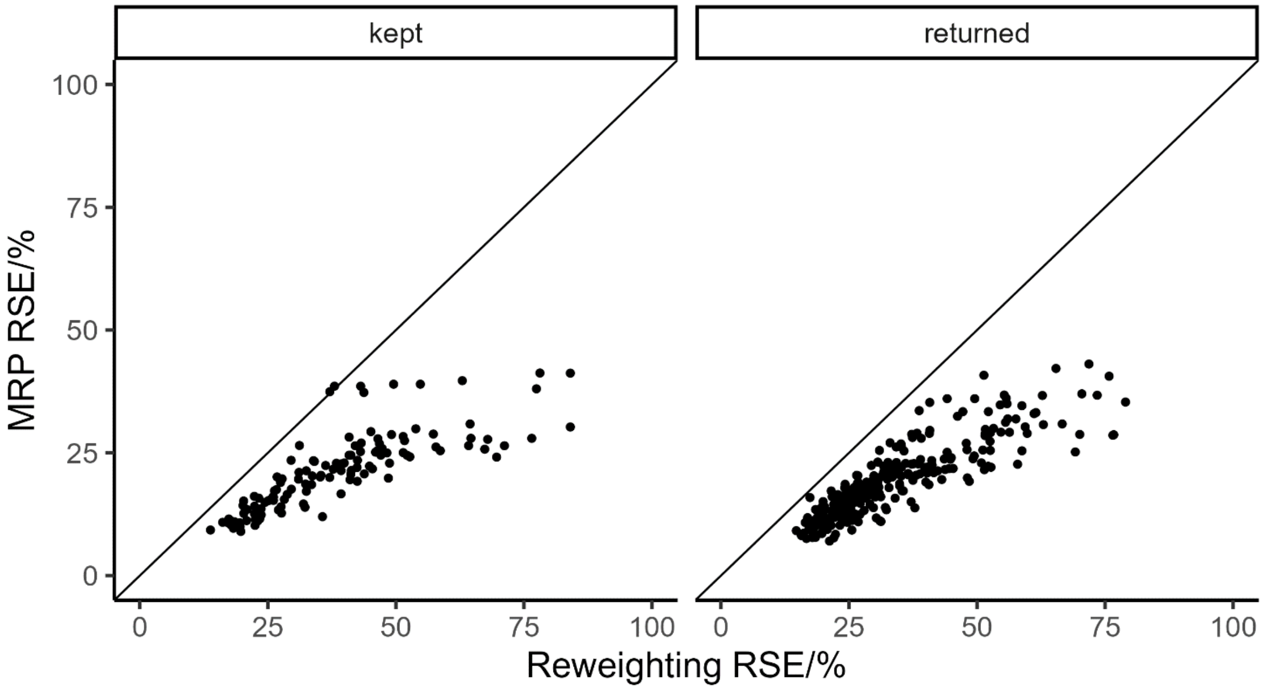


Figure 41. The relative standard error (standard error divided by the total catch; RSE) in the total number of fish caught, as calculated by the reweighting and multilevel regression and poststratification (MRP) approaches. The diagonal line represents the value if the RSE in both approaches is equal. Each point represents a species catch within a year.

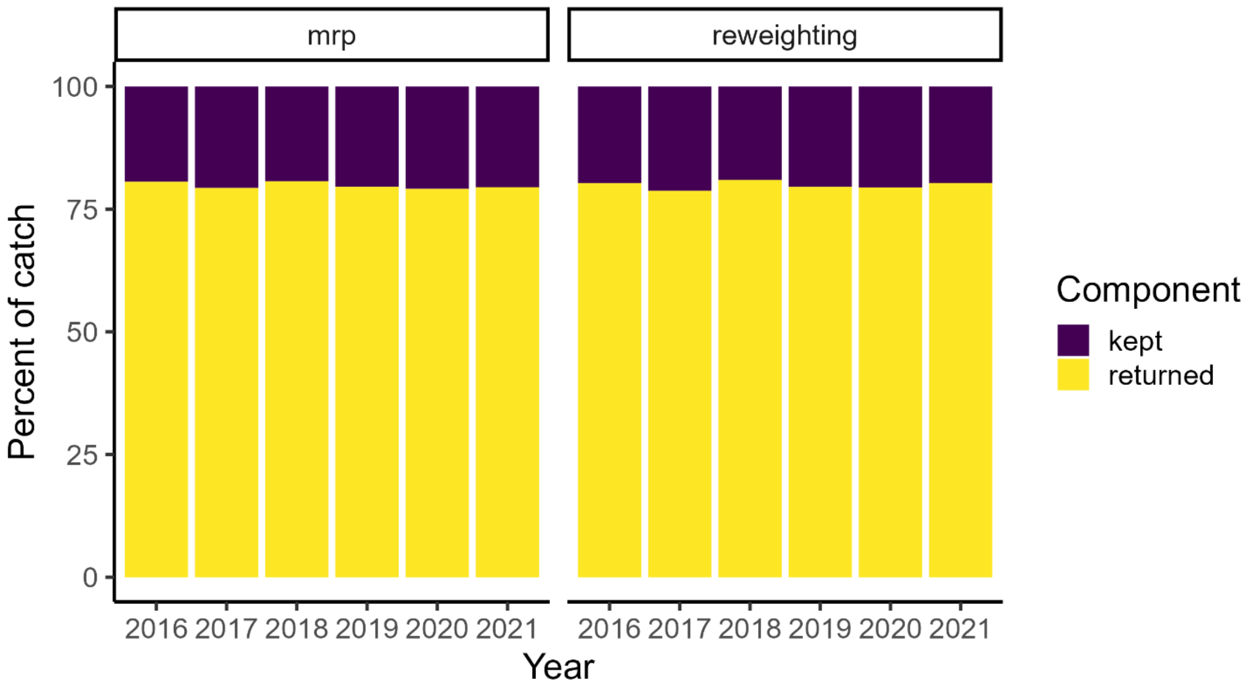


Figure 42. The percent of the total catch kept and returned in both the reweighting and multilevel regression and poststratification (MRP) approaches.

Partitioning the total number and weight of the caught estimated using MRP and reweighting among the individual countries of the UK further demonstrated the higher consistency and lower error for estimates produced using MRP (Figure 45A&B). For England, the results followed the overall trend observed for the whole of the UK where estimates were lower in 2016-19 and slightly larger in 2020-21 (Figure 45A&B). Identifying a pattern for the other countries within the UK was difficult due to the high variability (Figure 45A&B). In general, MRP produced similar or lower estimates compared to reweighting and had much smaller errors (Figure 46A&B). The bubble plots for each of the countries within the UK showed varying reasons for the differences in total catches (Figure 47). For England, the differences in totals were the same as the UK (Figure 47). Increases in MRP-based catch estimates in Northern Ireland was mainly caused by larger catch rates despite the numbers of anglers being lower (Figure 47). Where differences for Scotland occurred, reductions in overall catch were due to lower catch rates and numbers of anglers. In 2020-21 increased Scottish catches in MRP compared to reweighing were due to higher catch rates and some increases in average weights (Figure 47). Finally, a pattern for Wales was difficult to identify due to each year having a different combination of factors driving catch rates (Figure 47).

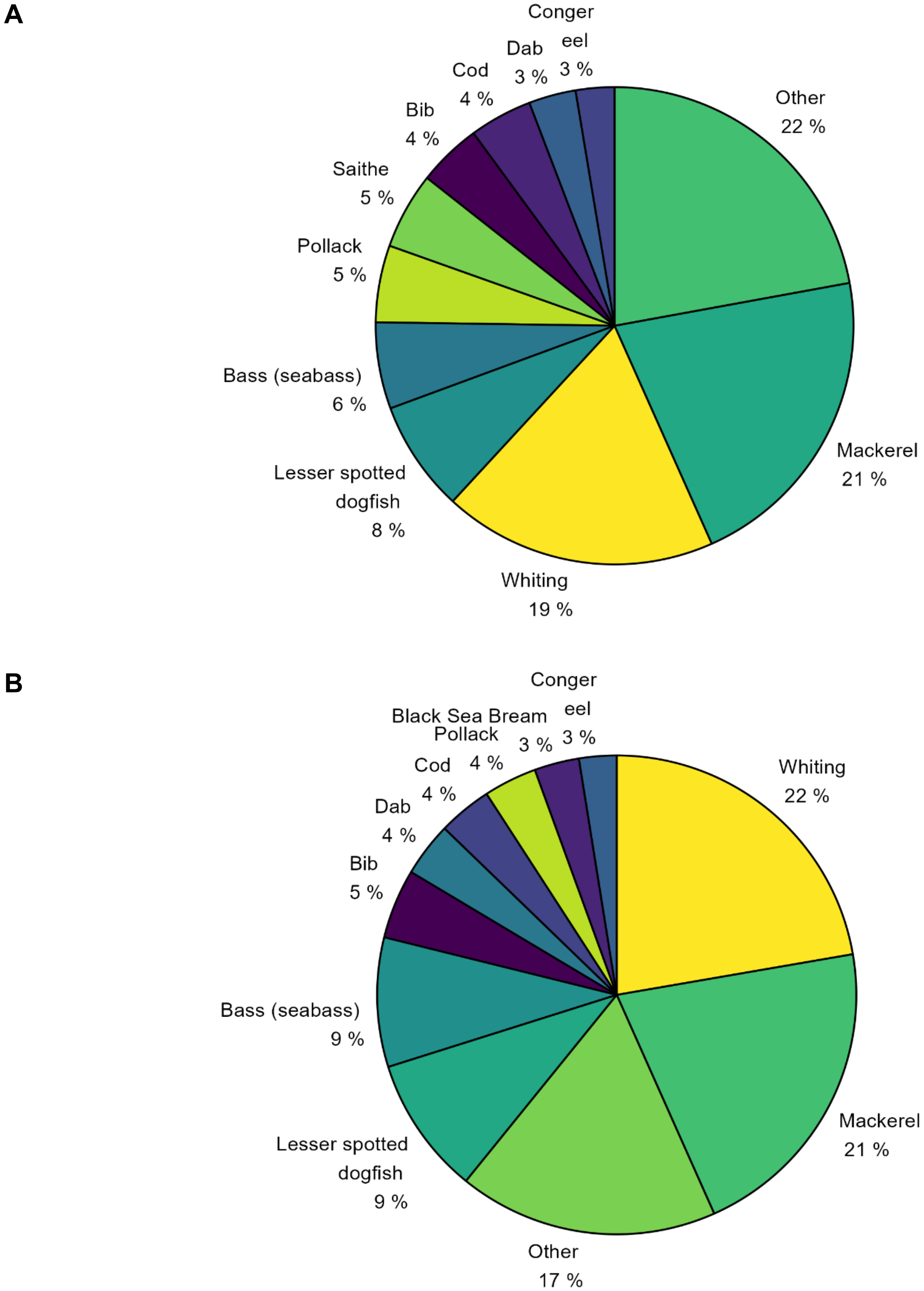


Figure 43. Catch composition by number for the UK in 2021 for multilevel regression and poststratification (MRP) (A) and reweighting (B) with the top 10 most commonly caught fish displayed.

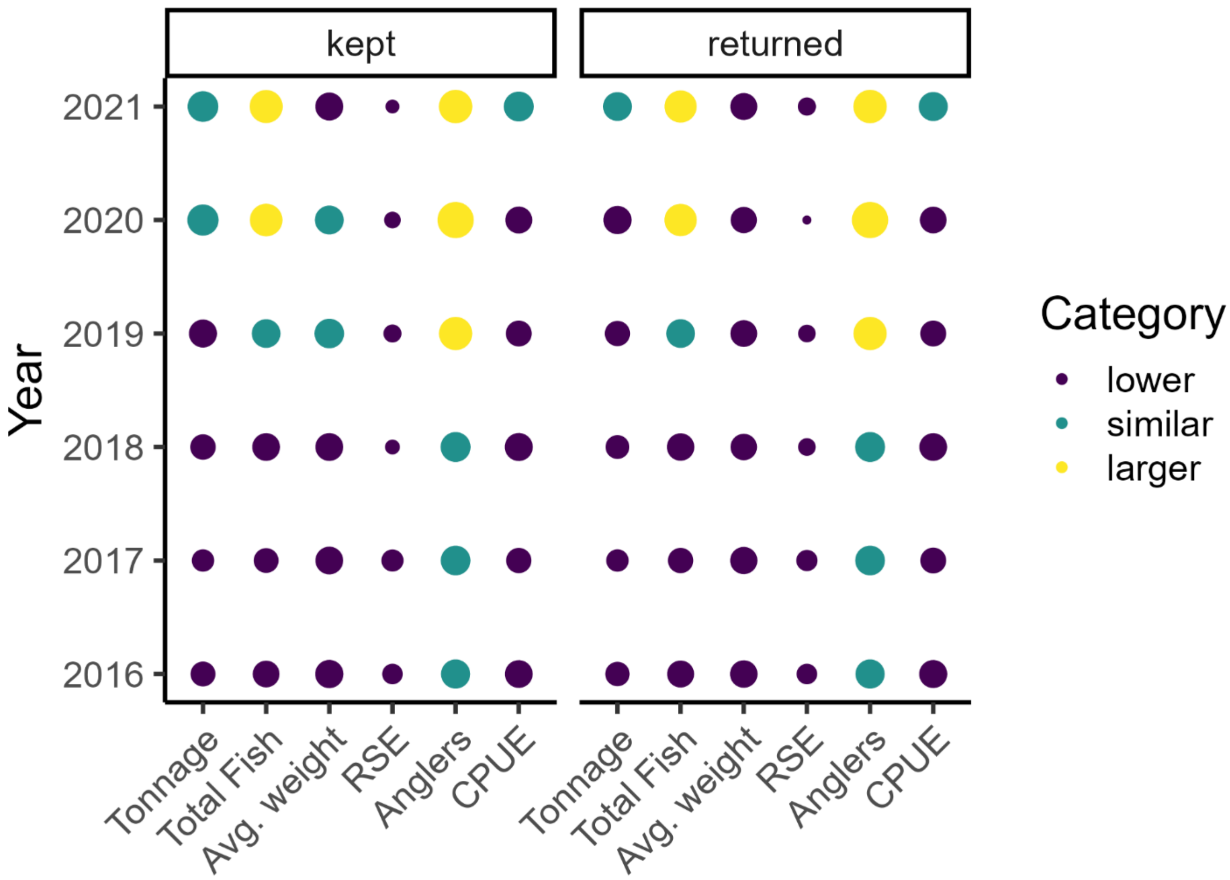
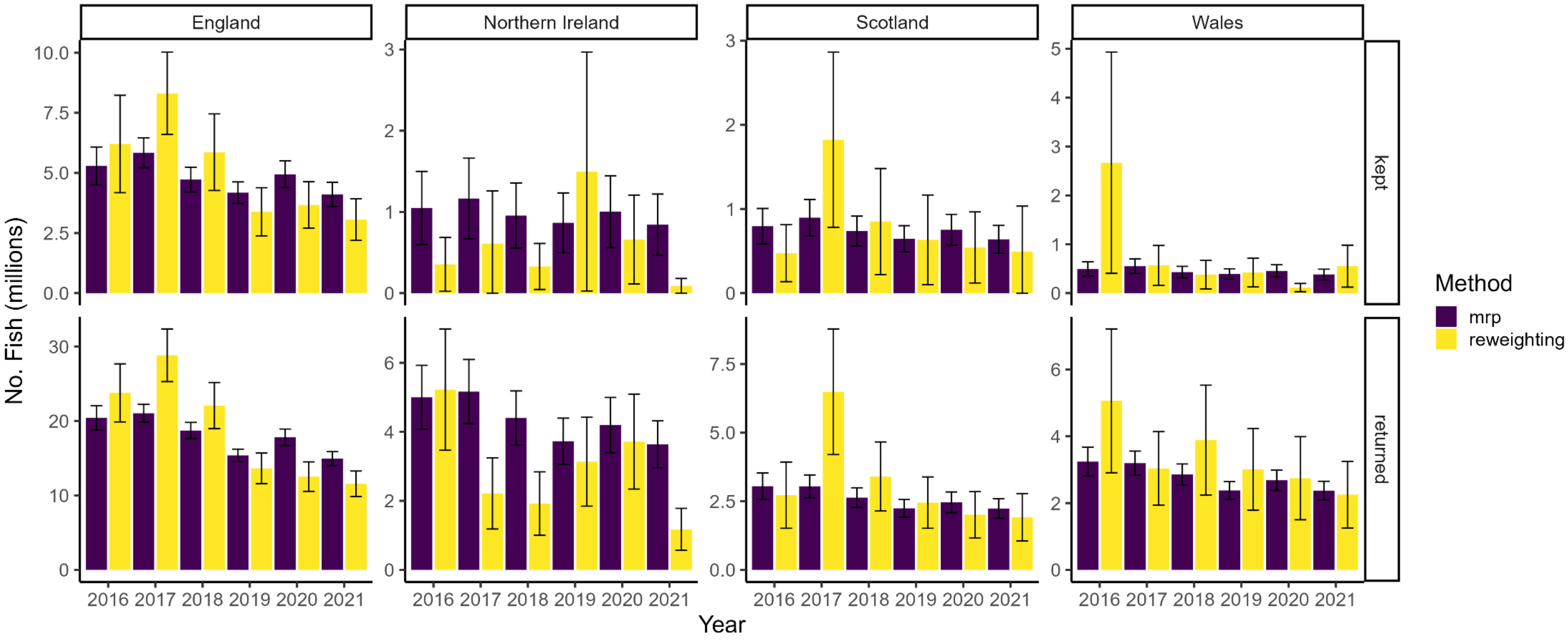


Figure 44. A 'bubble plot' to identify the reasons for the differences observed between the multilevel regression and post-stratification and reweighting raising procedures. The size of the bubble indicates the size and direction of the difference, where a smaller bubble indicates lower values for MRP. The lower category indicates that MRP as a 10% or lower estimate than reweighing, similar indicates the value is ±10% of reweighting and larger indicates that MRP has a 10% or larger estimate than reweighting. Tonnage is the total weight of fish caught, total fish is the total number of fish caught, avg. weight is the average weight of all fish caught (i.e., total tonnage divided by total number of fish), RSE is the relative standard error (i.e., standard error divided by the estimate) in the total number of fish caught, anglers is the number of people fishing within the year, and the cpue is the number of fish caught by each fisher.

A


England
Northern Ireland
Scotland
Wales
kept
returned
No. Fish (millions)
Year
2016 2017 2018 2019 2020 2021
Method
mrp
reweighting

B

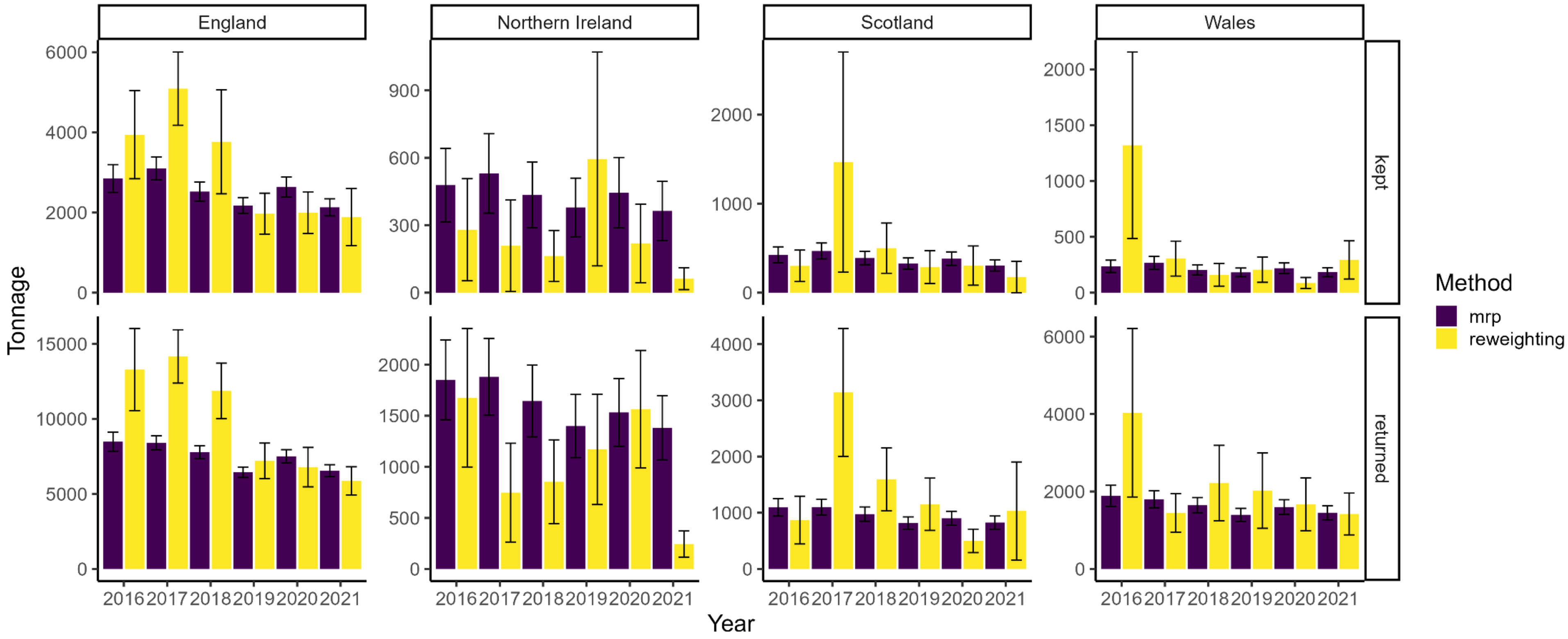
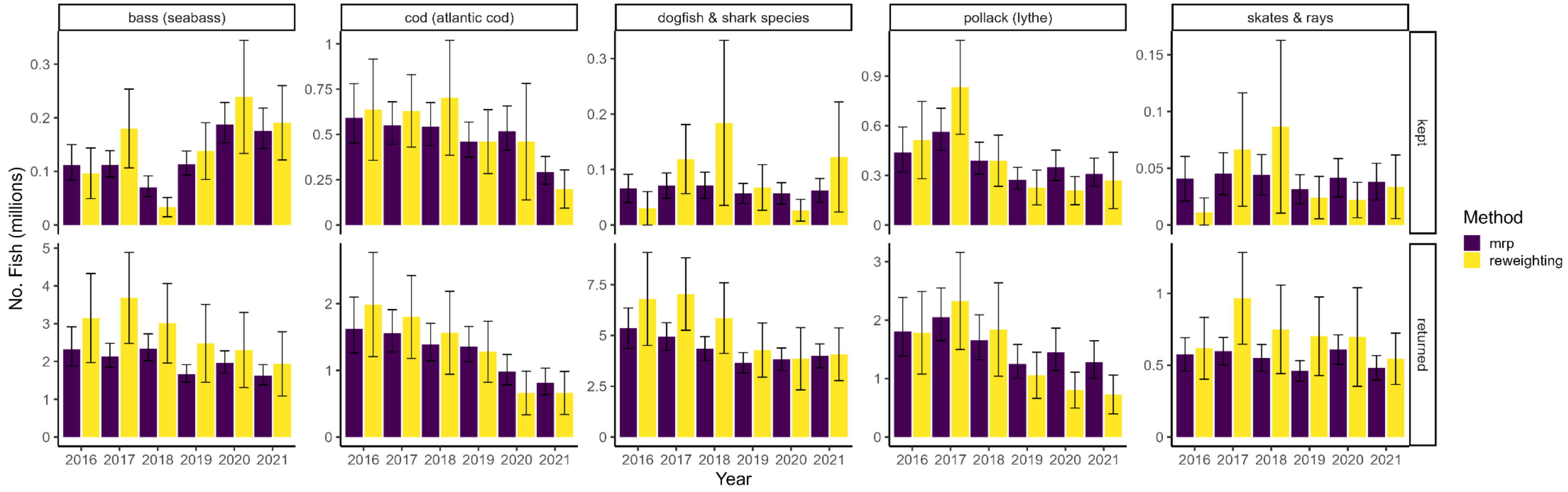


Figure 45. The number (A) and weight (B) of fish caught by people fishing in each country within the UK, as calculated by the reweighting and multilevel regression and poststratification (MRP) approaches. Errors are 95% CI.

A



bass (seabass)
cod (atlantic cod)
dogfish & shark species
pollack (lythe)
skates & rays
kept
returned
No. Fish (millions)
Year
Method
mrp
reweighting

B

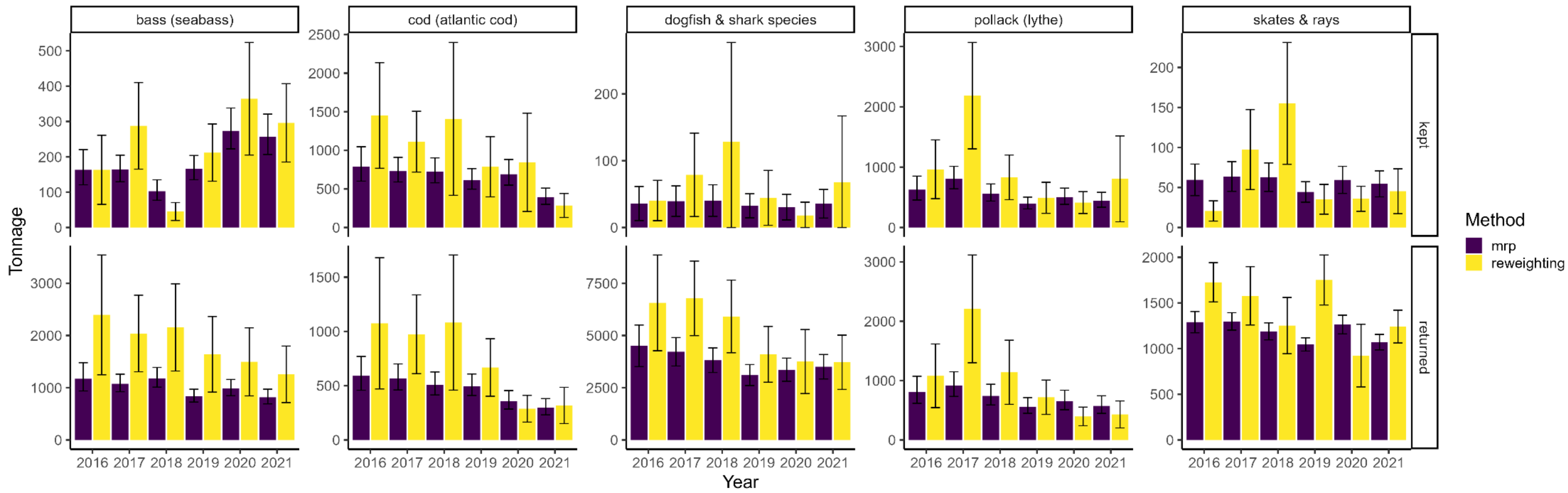


Figure 46. Numbers (A) and tonnage (B) of data collection framework species kept and released by sea anglers resident the England using the reweighting and multilevel regression and poststratification (MRP) raising approaches between 2016-20. Error bar are 95% CI.

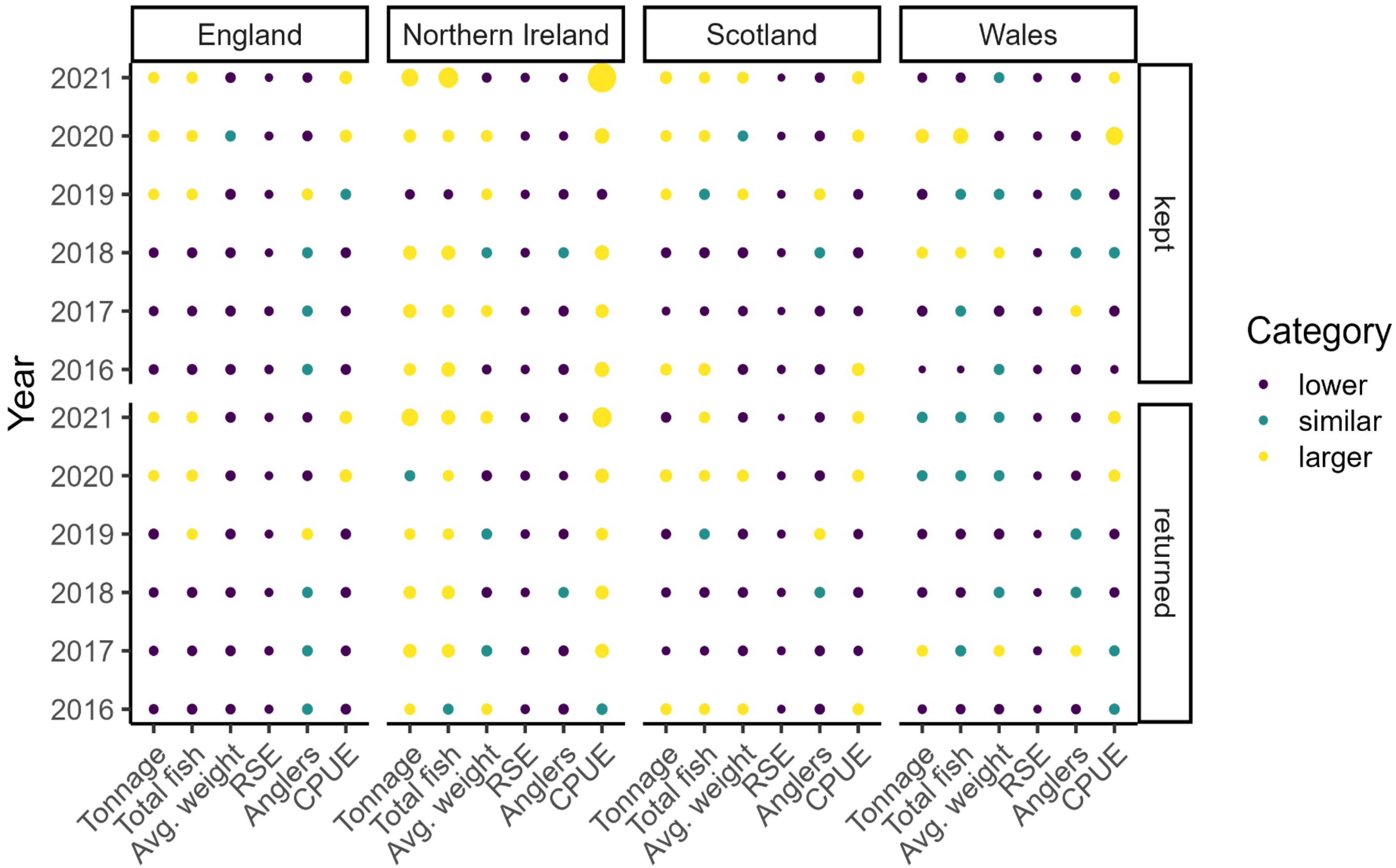


Figure 47. A ‘bubble plot’ to identify the reasons for the differences observed between the multilevel regression and post-stratification and reweighting raising procedures within each country within the UK. The size of the bubble indicates the size and direction of the difference, where a smaller bubble indicates lower values for MRP. The lower category indicates that MRP as a 10% or lower value than reweighing, similar indicates the value is ±10% of reweighting and larger indicates that MRP has a 10% or larger estimate than reweighting. Tonnage is the total weight of fish caught, total fish is the total number of fish caught, avg. weight is the average weight of all fish caught (i.e., the total tonnage divided by the total number of fish), RSE is the relative standard error (standard error divided by the estimate) in the total number of fish caught, anglers is the number of people fishing within the year, and the cpue is the number of fish caught by each fisher.

3.3. Impact of COVID-19

3.3.1. Comparing sea angling effort, locations, and catches in 2019 and 2020

The number of sessions reported by anglers in 2020 decreased significantly from February with almost no sessions reported in April 2020. The total number of sessions per month recovered to 2019 levels in July, August, and September, but were below reported 2019 numbers in the autumn and winter months (Figure 48a). The average number of sessions per angler exceeded 2019 figures in July-September 2020, and matched 2019 later in the year (Figure 48b). The number of anglers fishing in 2020 followed a similar pattern to the number of sessions reported, with a significant decrease in comparison to 2019 levels with some recovery from July onwards (Figure 48). Catches reported in 2020 remained lower than those reported in 2020, with April reporting the largest difference and numbers recovering in the summer months (Figure 48d). The total distance travelled by anglers from their home to their session site was significantly lower in April 2020 compared with the same month in 2019 (Figure 48e). Distances did not recover to pre-COVID-19 levels until August and then followed a similar pattern in the autumn and winter months compared with 2019.

3.3.2. Assessing the impacts of COVID-19 on sea angling

3.3.2.1. Respondent profile

In total, 635 responses to the survey were received, of which 559 respondents completed the whole survey. There was a bias in age, as seen in the Sea Angling Diary panel, where respondents were generally older in comparison to the estimated UK sea angler profile (Table 20). As expected, the location of the respondents matched the Sea Angling Diary panel location profile, which is also somewhat different to the UK sea angler location profile (Table 20). The bias in the Sea Angling Diary panel, and therefore our responses to this survey in comparison to the UK sea angling population as estimated by the national survey has been defined and analysed in Hyder et al. (2020b).

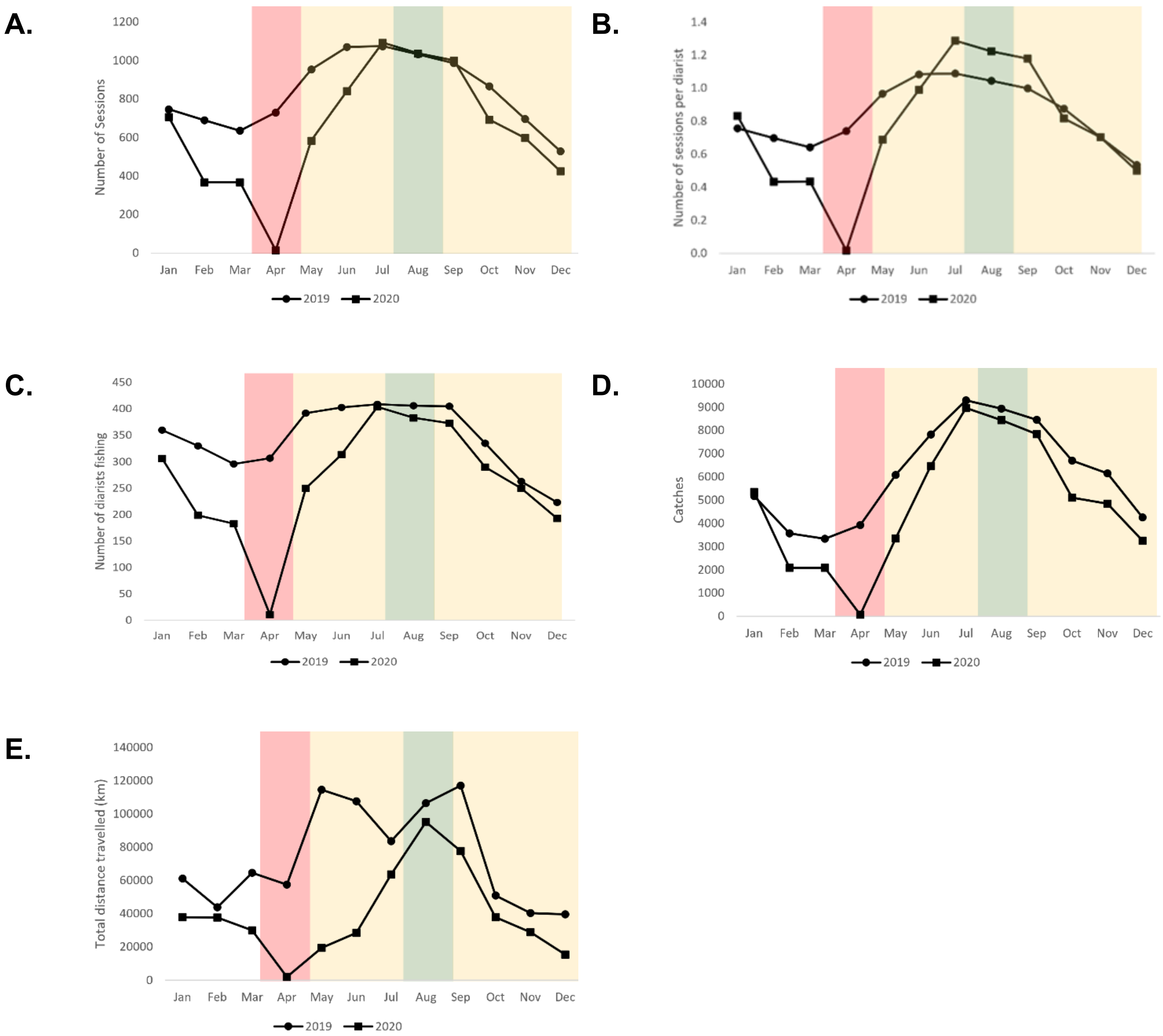


Figure 48. Seasonal patterns of angling activity and catches in 2019 and 2020, generated from the UK Sea Angling Diary. a. The total number of sessions reported per month; b. the average number of sessions per diarist per month; c. the total number of diarists fishing per month; d. the total number of catches per month; and e. the total distance travelled per month. Red represents the full lockdown, yellow is a partial lockdown, green is when the lightest restrictions were in place, no colour is prior to COVID-19 pandemic lockdowns.

Table 20. Characteristics of the respondents to survey in comparison with the whole Sea Angling Diary panel and the UK population of sea anglers in 2019. 'Number' is the number in each group, while all 'Age' and 'Location' are presented as a percentage (%).

Measure	Respondents*	Sea Angling Diary Panel	UK sea anglers in 2019**
Number	531-559	2,129	551,000
Age* (%)			
• **16-34**	1.6	12.8	27.5
• **35-54**	22.9	34.9	44.3
• **55+**	74.1	52.2	28.9
• **Prefer not to say**	1.4	0.1	---
Location * (%)**			
• **East**	10.4	10.8	3.7
• **East Midlands**	2.7	3.5	5.8
• **London**	2.8	2.7	2.6
• **North East**	6.5	5.5	4.7
• **North West**	10.8	10.9	4.3
• **Northern Ireland**	1.9	2.2	13.4
• **Scotland**	5.7	6.9	7.1
• **South East**	20.5	19.5	24.4
• **South West**	18.0	18.9	11.5
• **Wales**	10.6	9.5	11.7
• **West Midlands**	4.0	3.9	5.4
• **Yorkshire and Humber**	6.1	5.7	5.5

*The number of respondents that completed demographic questions ranged from 531-559.
**Percentages have been calculated for common categories allow comparisons with the WPS 2019. The credible intervals for the total number of UK sea anglers is 370,000 – 726,000. Note these are slightly different to the numbers in this report as the model was not complete at the time of publication, but have been used for consistency with Hook et al. (2022).
***Survey respondents (n=4, 0.8%) and panel members (n=16, 0.8%) living in the region 'Other' have been excluded from this table to allow for comparison with the WPS 2019.

3.3.2.2. Effort and participation

Anglers were significantly less likely to fish in each month from March to September in 2020 than in a typical year (Wilcoxon $p < 0.001$). April represented the largest change between a typical year and 2020, where 57% of individuals who would have typically been sea angling did not do so (Figure 49a, Figure 50). For individuals who were not able to go sea fishing in particular months, the single most important reason was that there were government lockdowns or restrictions on travel/activities (54%), followed by their own decision to minimise risk (21%). The main reason for not fishing in March and April was due to government lockdown or restrictions on travel/activities (67%) (Figure 49b). In August and September, 18% of individuals reported they made their own decision not to fish to reduce risk, whilst 57% of individuals reported that they were not restricted and therefore this did not prevent them from fishing (Figure 49b).

The survey found that 45% of anglers had chosen to fish in places where they can avoid other people, more than they would usually (Figure 51). Cited reasons in the qualitative responses included crowding at their regular fishing spots (either public use of the beach or increased numbers of other anglers): "*When lockdown ceased the coast was swamped with people so I couldn't/didn't want to fish in amongst the crowds*"; and "*Far more anglers on the beach than pre-pandemic*. *Many people, non-anglers, on the beach and in the sea,* *therefore, could not guarantee fishing safety for all nor able to ensure social distancing.*” The majority of anglers (58%) reported that they did not know other people who had not fished before who have done so since the COVID-19 crisis began (Figure 52).

3.3.2.3. Expenditure

There was a significant difference in people’s sea angling expenditure when comparing spending in a ‘typical April’ to spending in April 2020 (Wilcoxon test: $p < 0.001$). In total, 363 (63%) people had spent less, 161 (28%) reported no change in their spending and 51 (9%) people has spent more in April 2020 than they typically would on sea angling.

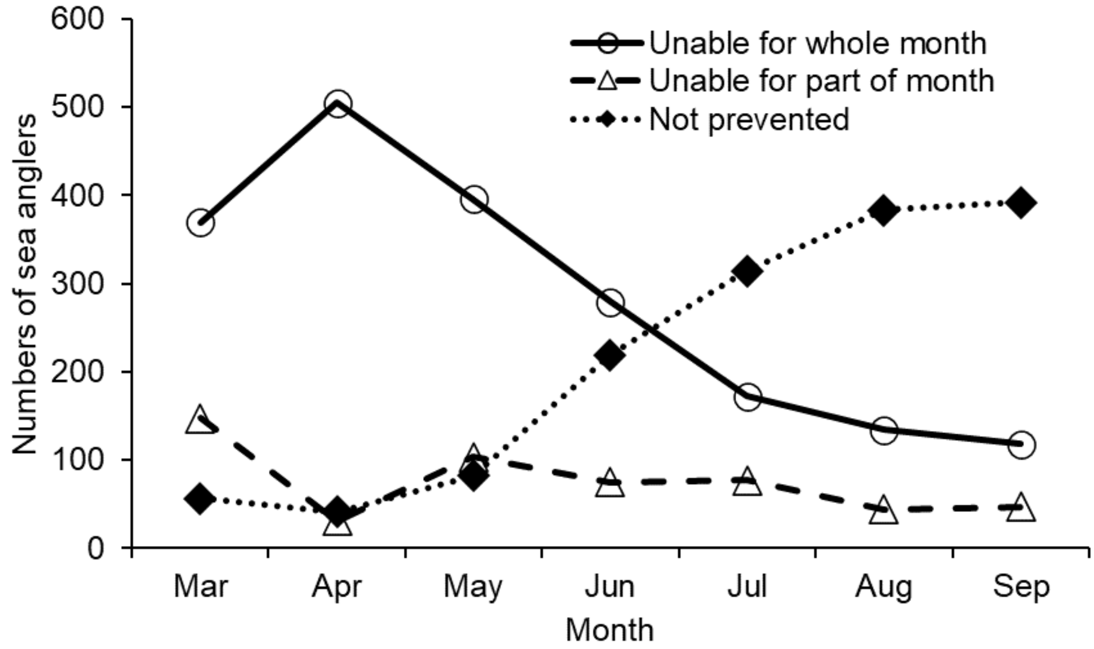
The difference between the nominal values of individual usual spends during a ‘typical April’, and spending in April 2020 were taken, and respondents were placed into one of three categories: no change; spent less; or spent more. A multinominal regression model was conducted as the data were not normally distributed.

Changes in the AIC and probability values were reviewed to determine that whether individuals fished in 2020, fished in April, fished in June, how central recreational angling was to the respondent's life, their stated avidity and their mental health and well-being score (WHO-5) were all variables which affect whether an individual was more like to spend more, spend less, or have no change in their spending activities.

3.3.2.4. Physical activity

During COVID-19, 45% of respondents felt that they were less active because they could not go sea angling, while 21% agreed that they were less active for other reasons (Figure 53a). Individuals who had either or both a mental and physical health concern (66%) were more likely to be less active because they could not go sea angling when compared to individuals who had neither health concern (38%). Unemployed individuals were more likely to agree or strongly agree that they had been less active because they could not go sea angling (77%) compared to individuals employed (41%), furloughed (40%), or retired (44%). Comparisons based on gender were not possible due to the very low number of female respondents (n=6).

A.



B.

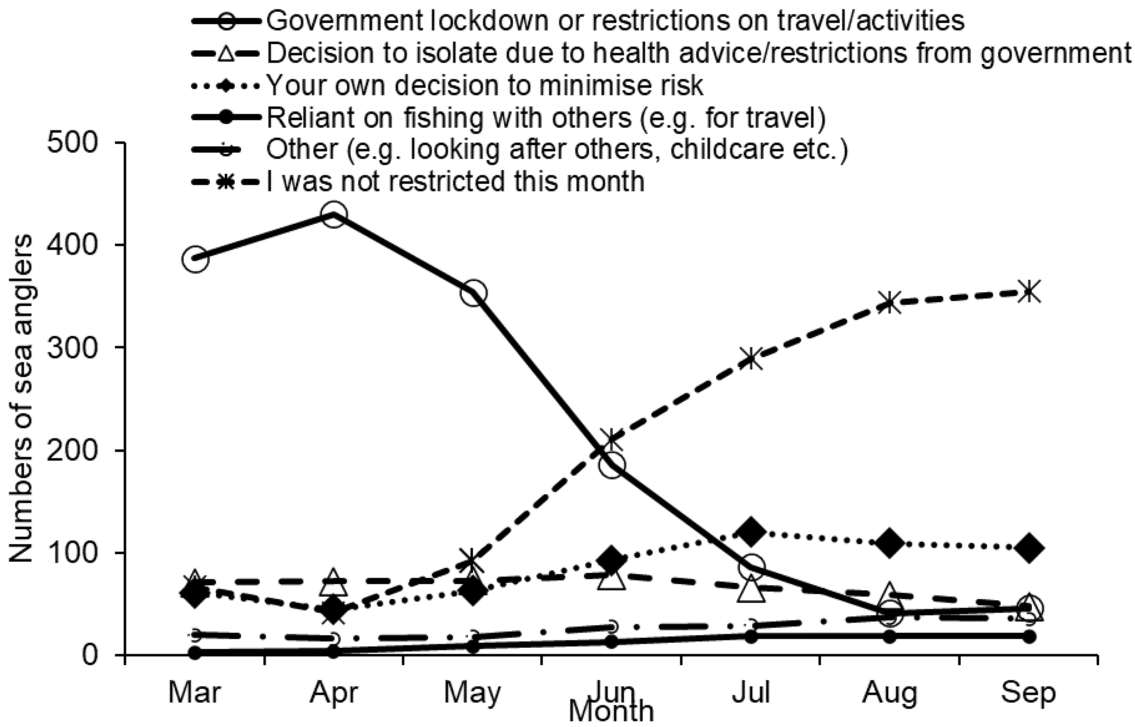


Figure 49. A. Impact of covid on the ability of the respondents to access sea angling. B. Reasons for not fishing during COVID-19 across respondents to the survey. As lockdown rules varied across the UK and people were shielding, this is not simply related to the periods of nationwide lockdown.

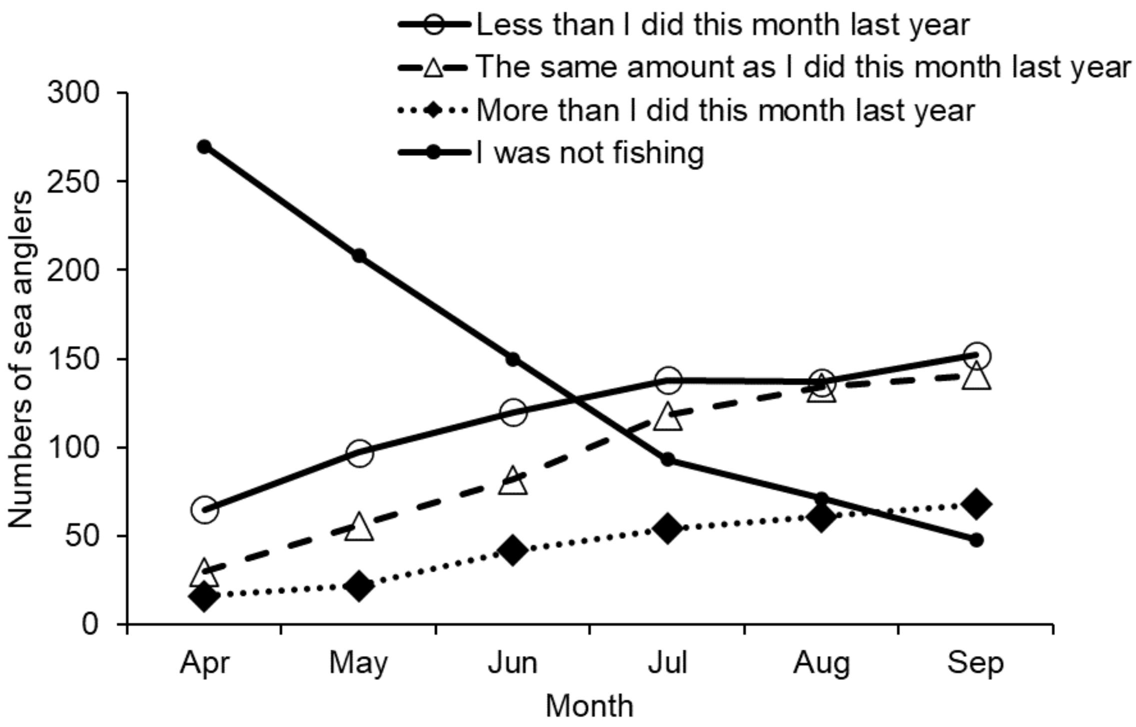


Figure 50: Effect of COVID-19 on the frequency of fish trips.

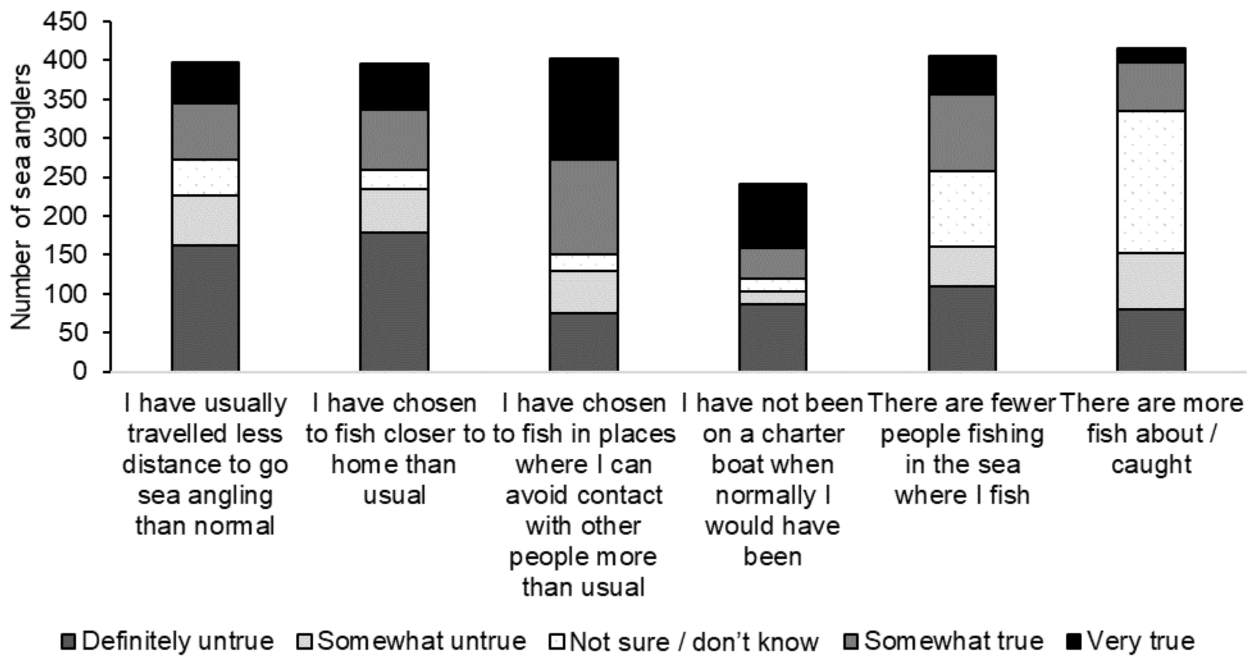


Figure 51. Impact of COVID-19 on angling experience.

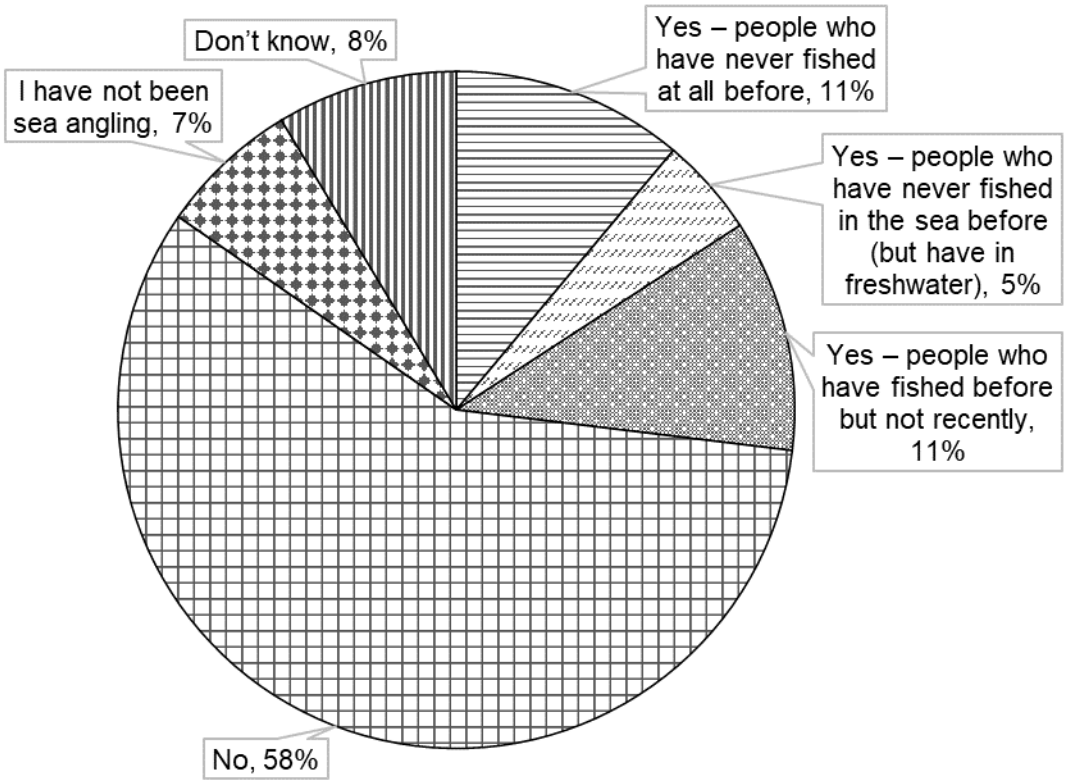


Figure 52. Changes in participation in sea angling during covid. Responses to the question: Do you know of other people who have not fished before who have done so since the COVID-19 crisis began?

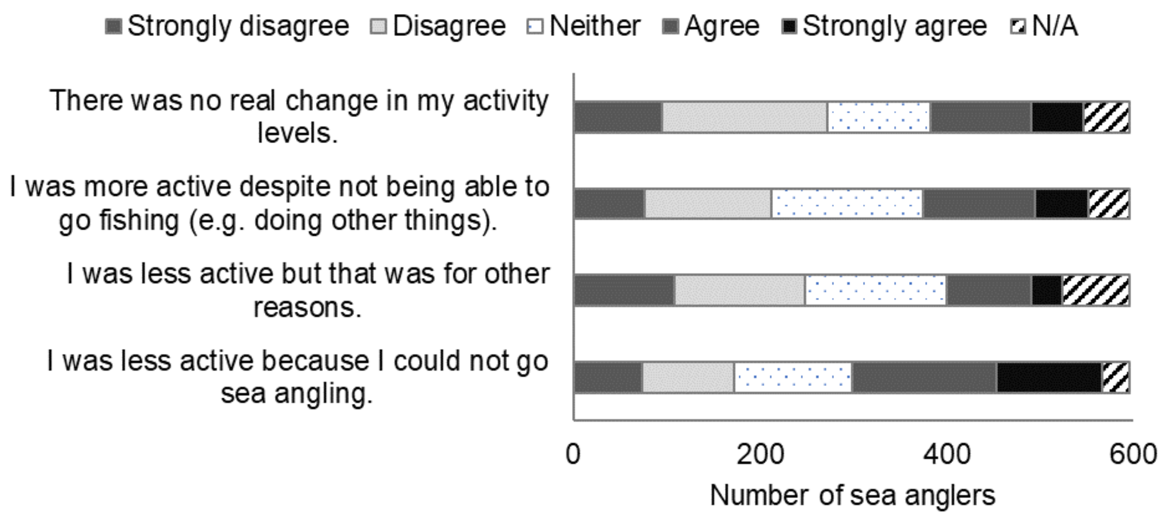
3.3.2.5. Well-being

In a subjective measure, respondents were asked to recall the impact of not being able to go sea angling in 2020 had on their well-being. 43% of respondents reported that not being able to go sea angling because of COVID-19 had some form of negative impact on their well-being. For example, 67% said that they 'strongly agreed' or 'agreed' that they were less happy because they could not go sea angling (Figure 53b).

The well-being of individuals in the preceding two weeks was scored using the WHO-5 methodology (Figure 54a). Anglers were also questioned as to what extent their responses to the WHO-5 measures about their well-being in the preceding two weeks were due to being able to go sea angling. Of those who said their responses were due to being able to go sea angling, 18% had a high well-being score (67%-100%), 7% had a medium well-being score (33%-66%) and only 2% had a low well-being score (0-33%) (Figure 54b).

Using a general linear model, the other responses were reviewed as possible variables that could affect individual well-being scores (Table 21). Even though anglers said that being able to go fishing has resulted in high WHO-5 scores, age, physical and mental health status, angling activity, travel to fish during COVID-19, and July fishing activity in 2020 had significant effects ($p < 0.01$, Table 21).

A.



B.

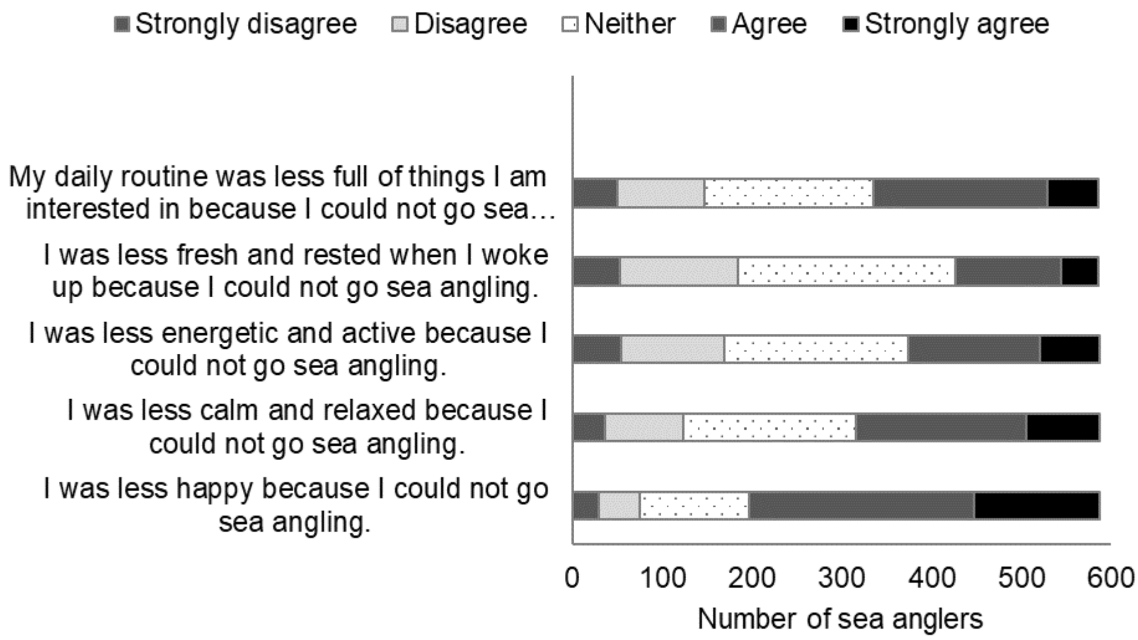


Figure 53. The role of COVID-19 on impacting levels of physical health (A) and well-being (B) and the relative importance of sea angling as a driver.

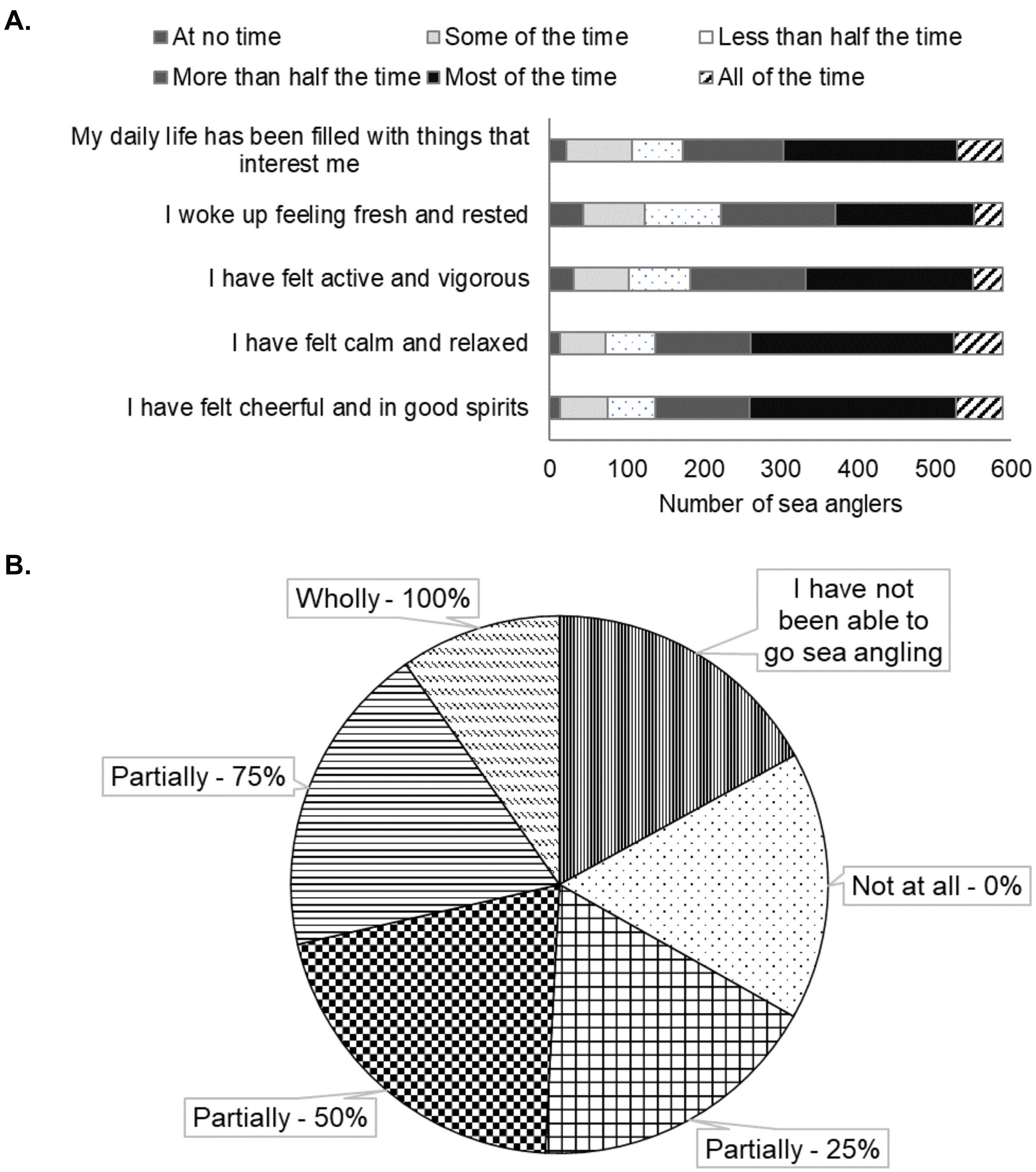


Figure 54. A. Impact of COVID-19 on wellbeing and B. how important restrictions on sea angling are for these outcomes.

Table 21. A generalised linear model of the impact of multiple predictors on the mental health and well-being of sea anglers. Bold text shows the predictors which had an impact on the mental health and well-being score ($p < 0.05$).

Predictor Group	Predictor	Estimate	Standard error	t-stat	p-value
Mental Health and Wellbeing Score (WHO5) Intercept		-46.80	31.32	-1.49	0.136
Demographics	**Age**	**0.47**	**0.11**	**4.48**	**<0.001**
COVID-19 Risk Category	High Risk	0.56	4.17	0.13	0.894
	Low Risk	7.12	3.73	1.91	0.057
	Moderate Risk	1.02	3.64	0.28	0.780
	Prefer not to say	9.63	8.64	1.11	0.266
Physical and Mental health status	Prefer not to say	-0.92	4.29	-0.21	0.831
	Yes I have a mental health issue	**-10.71**	**4.88**	**-2.19**	**0.029**
	Yes I have a physical health issue	**-13.88**	**4.46**	**-3.11**	**0.002**
	Yes I have a physical and mental health issue	**-8.95**	**2.54**	**-3.52**	**<0.001**
	Percentage score of Mental health and wellbeing during lockdown	**-0.33**	**0.05**	**-6.37**	**<0.001**
Expenditure	April Expenditure (£)	0.01	0.01	1.04	0.300
	Typical April Expenditure (£)	0.01	0.01	0.82	0.415
Angling Activity	Angling activity since lockdown	-10.83	6.07	-1.79	0.075
	Future centrality of sea angling in the next 12 months	**2.19**	**0.97**	**2.25**	**0.025**
Travel less during COVID to go sea angling (those applicable)	**Definitely untrue**	**51.45**	**22.02**	**2.34**	**0.020**
	N/A	41.92	22.01	1.91	0.057
	I am not sure	**48.92**	**22.08**	**2.22**	**0.027**
	Somewhat true	**44.07**	**21.86**	**2.02**	**0.044**
	Somewhat untrue	**53.09**	**22.05**	**2.41**	**0.016**
	Very True	**44.27**	**21.60**	**2.05**	**0.041**
Fishing close to home	**I definitely did not fish close to home**	**40.87**	**20.71**	**1.97**	**0.049**
	N/A	**43.64**	**21.21**	**2.06**	**0.040**
	I am not sure	**50.29**	**21.26**	**2.37**	**0.018**
	I somewhat fished closer to home	**50.79**	**21.08**	**2.41**	**0.016**
	I somewhat did not fish close to home	**43.86**	**20.99**	**2.09**	**0.037**
	I definitely did fish closer to home	**47.15**	**21.18**	**2.23**	**0.026**
June Fishing Activity 2020	I fished less than I did this month last year	1.17	6.30	0.19	0.853
	I fished more than I did this month last year	7.45	7.34	1.02	0.311
	I was not fishing	1.09	6.37	0.17	0.864
	I fished the same amount as I did this month last year	4.57	6.72	0.68	0.497
July Fishing Activity 2020	I fished less than I did this month last year	7.09	7.42	0.96	0.340
	I fished more than I did this month last year	10.22	8.08	1.26	0.207
	I was not fishing	6.12	7.76	0.79	0.431
	I fished the same amount as I did this month last year	**18.14**	**7.65**	**2.37**	**0.018**

4. Discussion

4.1. Data collection

4.1.1. Participation

The WPS results from the 2020-21 online panel were significantly larger than those presented in the 2016-19 face-to-face surveys. As COVID-19 made face-to-face surveys impossible, a side-by-side comparison of the two survey methods was not feasible. Consequently, it was not possible to validate if the increase observed was due to survey approach or an increase in the number of fishers. There were mixed results on changes in participation from the COVID-19 survey (Section 3.3), but there was an 18% increase in freshwater rod licence sales from 2019 to 2020. However, the increase in the estimates from the WPS in the 2020 were unrealistic with an estimate of almost 3.5 million sea anglers, so must be mainly due to the use of an online panel rather than face-to-face survey. The numbers of individuals that had been freshwater angling from the WPS was lower that the number of licence sales using the face-to-face methods in 2019, but much higher using the online panel in 2020. This will include individuals fishing without a rod licence, but the level of non-compliance found during enforcement activities is generally low. It has been observed elsewhere that online panels tend to attract more active individuals, and household face-to-face surveys are likely to encounter less active people as they are more likely to be at home. Hence, it is likely that the true answer will be somewhere between the two methods, but are likely to be closer to the face-to-face approach based on the number of freshwater anglers. A side-by-side comparison of face-to-face and online methods is needed to make a direct comparison.

To maintain consistency in the time series of sea angling catches, it was not possible to use the unrealistic results from the online 2020-21 WPS. Instead, the results for all previous years from 2016-2019 of the WPS were used to predict participation for 2020-21 using the effort model. This did not account for any COVID-19 related changes that were likely to have increased participation, so was likely to represent an underestimate of participation.

4.1.2. Diary panel

Recruitment for the diary panel continued to increase on previous years, with the largest number to date in 2021 (2,729) signing up. The panel largely reflected previous years in terms of profile with a more avid and older sample than the sea angling population as a whole. 23.1% of diarists classed themselves as frequent sea anglers (35 times a year or more) compared to 8.9% of the WPS 2019 and 52.5% of the panel were 55 years old or over compared to 28.9% in the WPS 2019. Diarists were also likely to have been fishing for longer than the general population, but in relation to self-definition of experience the picture was mixed. Diarists were more likely to class themselves as being ‘intermediate’ or ‘experienced’, but also less likely to class themselves as ‘very experienced’ than the general population of sea anglers.

Despite high numbers of diarists, data completion remained a challenge. Around two thirds of diarists entered data in the year, but only 51.7% entered at least six months of data and had fished in the year. In part, this may be due to lower overall levels of fishing activity in 2020, possibly caused by the COVID-19 pandemic. Fewer diarists fished in 2020 and 2021 than in 2019, for example, with 849 out of 2,237 diarists in 2020 compared to 988 out of 2,188 diarists in 2019. In addition, fewer sessions were recorded by diarists that had fished: 3.5 sessions per diarist who fished in 2020 compared to 4.6 in 2019. Due to COVID-19, some periods of 2020 saw almost no sea angling activity and may have affected overall effort resulting in reduction of data recording.

Efforts have continued to address both these factors. In 2021 more publicity was sent via the Environment Agency to freshwater Fishing Licence holders, to try to attract those that may fish predominantly in freshwater and occasionally in the sea (less avid sea anglers). More resource was put into ensuring better data completion, including: monthly newsletters for diarists; texts and polling via surveys platforms (to help address the issue of emails being blocked by spam filters); and improvements to the mobile app. Further surveying of diarists who had not completed data (such as a representative random sample of those without data) would be useful to understand non-response better.

4.2. Catches

The main difference to previous years was the development and implementation of model-based estimation rather than the traditional reweighting approach that was applied annually (Hyder et al., 2020b, 2021). Due to the small number of sea anglers responding in the WPS and the size of the diary panel, the number of characteristics that could be included was limited by the number of sea anglers responding to both the diary and WPS (Hyder et al., 2020b). Hence, the analysis was a trade-off between the number of individual strata and the numbers of anglers in each stratum, limiting the precision of the estimates. In addition, the annual approach meant that catch estimates varied a lot between years, reflecting uncertainty in the estimates rather than real differences. Model-based approaches provided several benefits when compared to traditional reweighting approaches. Firstly, they have often been used when data sets are small or biased as they can make efficient use of the information in a dataset. Secondly, information from other sources such as previous studies and expert elicitation can be included in the models to provide more accurate estimates. Finally, multiple years of data can be used in the models accounting for differences between years. Statistical model-based approaches have been used in many other fields and are starting to be applied to recreational fisheries to explain factors driving catches (e.g. Tate et al., 2020; Navarro et al., 2020). They have also been used successfully with non-probability sampling to generate reasonable estimates from election polls (Lauderdale et al., 2020). However, the main challenge with model-based approaches is that they are much more complex statistically and less intuitive to understand. In addition, it is unclear if model-based approaches generate more robust estimates than reweighting. As a result, the use of model-based needs to be considered carefully before implementation.

Bayesian models were developed for participation, avidity, catch per angler, and weight of individual fish. These were combined to generate numbers and tonnages caught by sea anglers. Generally, all the models fitted the data well and were better than null models, showing that appropriate variables were included. In addition, posterior predictive checks showed good agreement with the data, indicating a good model fit. Simulation approaches were developed to assess performance of model-based approaches against reweighting for participation and total numbers caught, and identify the more robust analytical approach to use. In both simulations, MRP outperformed reweighting generating lower errors and explaining more of the variance, alongside producing a notable improvement in the estimates. This clearly demonstrated that, despite the complexity of MRP, this approach should be used instead of reweighting as it was more robust and provided better estimates.

There were issues with the model-based approaches, with further work needed to improve the models. For avidity, it was challenging to develop a good model due to the distribution of the data and size of the WPS, so it would be useful to consider how to include additional datasets (e.g. other countries data and freshwater angling) and develop expert elicitation to improve definition of the priors and distributions. For catch per angler, it would be useful to assess the assemblages of species that can be caught together and how targeting influences catches in order to inform the model. In addition, it would be beneficial to consider modelling individual sessions rather than anglers, as this would account for different approaches depending on the fishing situation. Additional variables that might explain individual fish weight could be included in the models, but this would involve data on individual fish length-weight relationships. Finally, including ICES divisions in the model would allow a better estimation of catches at this scale.

Estimates of the number of fish kept and returned by MRP were generally lower than estimates using reweighting. The primary reason for this difference is a combination of both lower cpue and lower average weight per fish caught compared to reweighting. Where catches were found to be larger in 2020-21, this was primarily due to the higher number of anglers estimated by MRP. Finally, whilst there were differences in the catches estimated by MRP and reweighting, the precision of the estimated number and tonnage of fish caught using MRP was much higher for most species. This increase in precision became particularly apparent when partitioning the catches into smaller geographical regions (e.g. individual countries within the UK).

Each year, the model-based approach estimated that around 7.1 million fish were retained, weighing 3,600 tonnes, and 28 million were released weighing 11,800 tonnes, representing a release rate of around 80%. The models generated more consistent and robust results for the whole time series, so were used. Catch composition was similar between years with mackerel, whiting, lesser spotted dogfish, and sea bass the most four commonly caught fish.

4.3. Assessment of potential bias

All approaches for collecting data on sea angling are subject to error, with uncertainty generated from two sources: measurement error; and biases from issues with design and implementation of each survey and methods used for extrapolation (Pollock et al., 1994; ICES 2010; Jones and Pollock, 2013). Diary surveys are used in many countries (Bellanger and Levrel, 2017), but are subject to a larger set of biases than onsite approaches (Jones and Pollock, 2013). In 2018–19, two sources of potential bias were examined relating to the composition of the diary panel and the analytical method used.

An onsite survey was done in England in 2012 that combined an onsite survey of shore and private boat with a charter boat diary to estimate catches (Armstrong et al., 2013). Onsite sampling is considered the ‘gold standard’ for recreational fisheries surveys (ICES, 2010; Armstrong et al., 2013). However, the estimates from the 2012 study were much lower than generated from the offsite diary (Hyder et al., 2020b; 2021; this study). There were a number of possible reasons for the differences which are discussed at length in previous reports (Hyder et al., 2020b, 2021). However, it was not possible to determine the extent to which the higher catch estimates are due to survey bias, random sampling error, or changes in fish abundance. Without running both an onsite and diary survey in parallel, it is very difficult to understand the relative importance of each of the potential reasons for the differences.

One large challenge for an offsite diary survey is to create a representative panel of sea anglers that requires the least possible post-stratification and reweighting to reduce bias. Recruitment of diarists would usually be done through a randomised telephone or postal survey, but this would be very difficult in the UK due to low participation and response rates. Instead, a non-probabilistic approach was used to generate the diary panel involving a wide range of outreach methods to seek volunteers across all regions and angler characteristics. This has the potential to introduce biases in panel composition, with more avid, older and experienced sea anglers engaging in the diary, which is likely affect the levels of catches. To assess the bias in the Sea Angling Diary panel composition, a small validation panel was recruited of 120 sea anglers from three English regions using a postal survey of 50,000 houses (Hyder et al., 2021). The demographic and avidity profile of the validation panel was more similar to the diary panel than the overall population of sea anglers from the WPS. An explanation is that older and more avid anglers were more likely to volunteer to keep a catch diary. It is possible that the approach used to recruit diarists has limited impact, instead driven by the types of anglers that are willing to keep a diary (Hyder et al., 2021).

4.4. Impact of covid

Using the evidence collected, COVID-19 had an overall negative impact on recreational sea angling in the UK in 2020, especially during the first lockdown in April 2020. This included participation and effort, physical activity, well-being, and expenditure of sea anglers. There remains an unknown long-term effect of this negative impact on recreational sea angling especially as the pandemic continues, which could affect restrictions, personal health, or willingness to fish. Participation and effort were negatively affected for many sea anglers by lockdown, health concerns and other personal circumstances related to COVID-19, which impacted mental well-being and physical activity. When reviewing diarist participation in sea angling during COVID-19 in 2020, an overall reduction was found in the number of diarists fishing, number of sessions and number of catches. The data shows that the number of sessions per diarist increased during July, August and September of 2020 suggesting compensation of activity for when it was restricted. In total, 67% of respondents reported reduced happiness and 45% were less active due to sea angling restrictions.

The survey was limited in nature by some factors. The population surveyed was a research panel of sea anglers in the UK created to provide data for the Sea Angling Diary on participation, catches, and expenditure. This panel was itself a convenience sample and self-selected, and previous analysis has shown some bias as they were generally older, more avid, and had been fishing for more years when compared to the general population of sea anglers (Hyder et al., 2020b). It has been suggested that the participants were more engaged in angling and therefore more likely to sign up to the diary project (Hyder et al., 2020b). The respondents to this survey were a self-selected sample of that panel and as such cannot be taken to be representative of the sea angling population of the UK. However, this study was unique in that it has years of evidence that define and account for bias in the sample size. The reasons that this approach was taken are that there was no database of sea anglers in the UK from which a representative sample of sea anglers could be drawn; alternative methods such as a randomized face-to-face survey were not possible during the pandemic and this, and other methods, such as postal surveys would have been prohibitively expensive. The timescale for capturing some data on the impact of the pandemic to avoid recall bias was very short, so the most efficient method was to use the Sea Angling Diary Project. A larger, more representative diary panel, with a randomised representative sample, might help address these issues in future surveys. Reweighting this sample was not possible as due to the lack of data on UK sea angling 2020 population at the time of analysis. Although the impact of this bias was unknown and it can be assumed from other research that overall COVID-19 had a negative effect on sea anglers, especially during the first lockdown. However, it was likely that other circumstances of COVID-19 caused greater impact and that not being able to go sea angling was not the only cause.

This survey was taken at a specific point in time to assess the immediate impacts of the COVID-19 pandemic mid-way through 2020. It was designed with an expectation that the pandemic restrictions would likely be short-lived, and the survey took place before the second wave and subsequent second lockdown in the UK from 2020 to 2021. To investigate the further effects of the pandemic and the second lockdown on angler participation, physical activity, well-being and expenditure, a subsequent survey on the longer-term impacts of COVID-19 on sea angling could be conducted. It can be seen from the participation levels in the Sea Angling Diary results, those diarists who continued to fish as the second lockdown came into force in December 2020, although this was overall lower than in 2019.

A change in people's exercise routines, prolonged (two weeks or more) self-quarantine and government-imposed social distancing and isolation negatively impacted well-being, such as an increase in stress and depression (Hawryluck et al., 2004; Dwyer et al., 2020). There is a base of knowledge that explains the benefits of being in nature for health and well-being (Chaudhury & Banerjee, 2020; O'Brien & Forster, 2020). In the UK generally, there was an increased desire to spend more time amongst nature following lockdown (Lemmey, 2020), which is an integral part of recreational sea angling and is an important motivation for going sea angling (Brown, 2019). However, for some individuals, access to nature was restricted during the pandemic, specifically during lockdowns, and there was likely a negative impact as the added value of exercising in nature was not realized. To understand the more general impact of sea angling on physical activity, well-being, and expenditure in 2021, two new surveys will be done. These surveys utilise an expanded set of questions about impact of sea angling on physical health and well-being based, where possible, on additional validated measures. These data will provide a set of findings some of which will allow comparative analysis to the results presented here and help understand further information about the impact of the pandemic on anglers during 2021.

In 2020 some countries, including England, Germany, Belgium, and Greece, reported that participation in freshwater recreational angling had increased. For example, in Belgium, there was a 30% increase in license sales compared to 2019 (Pita et al., 2021). In Germany, it was argued that there had been a shift in recreational angling from marine to freshwater, and globally this shift has been beneficial to species under recreational fishing pressure (Pita et al., 2021). In England, the increase in freshwater license sales suggested that more individuals were angling, and it may have been the case that more individuals are likely to be sea angling (Environment Agency, 2020; Pita et al., 2021). However, although participation may have increased, our data suggest that effort decreased and those surveyed were sea angling less often in 2020-21 than in 2019. However, this sample may be more experienced, avid, and older than the general population. In other countries, the COVID-19 outbreak lockdowns resulted in a higher participation rate and a change in angler characteristics, such as in Denmark, where individuals were more likely to be younger and less experienced when compared to previous years (Gundelund & Skov, 2021). There is currently no data that allows assessment of whether there were changes in participation and effort between fishing in freshwater and sea, although this could be collected in future surveys. In some countries, the lockdowns did not prohibit sea angling, such as in North America, where 92% of jurisdictions did not close or delay recreational fishing and in some, it was even encouraged as a safe activity (Paradis et al., 2021). It was and remains recognised that lockdowns had direct and indirect effects on individual health and well-being, but these have yet to be fully explored. An important factor in this research, which included anglers from across the UK, was that the restrictions and personal circumstances faced by citizens during 2020 varied enormously, from country to country, region to region, and month to month. The only time in which there was a uniform approach to restrictions across the whole of the UK was in April 2020 and it is the results relating to this period that are perhaps the strongest.

The impact of the first lockdown in the UK saw a reduction in participation, effort, and spending in sea angling. Although those who have been able to go back to sea angling have a high or medium WHO-5 score, other factors had significant effects, such as age, physical and mental health status, angling activity, travel to fish during COVID-19, and July fishing activity in 2020 had significant effects. In other studies of the general population in the UK, females reported higher levels of anxiety than males, and respondents who reported either self-isolating before the lockdown, increased feelings of isolation after the lockdown and having livelihood concerns due to COVID-19 had a higher association with poorer mental health and well-being (WHO-5) (White & van der Boor, 2020). It would have been interesting to gather further information regarding the general impact of COVID-19 on participants to measure the quality of life (WHO-QOL BREF) (Skevington et al., 2004; WHO, 2012), perceived stress (PSS-10) (Cohen et al., 1983), depressive symptoms (PHQ-9) (Spitzer et al., 1999), or anxiety (GAD-7) (Spitzer et al., 2006). This may have also improved the analysis and understanding of the impacts of COVID-19 and sea angling, especially if comparing individuals who had been angling in the previous two weeks from the time of taking the survey.

As the first study to understand the impacts of COVID-19 on sea anglers in the UK, this demonstrated some well-being benefits that marine recreational fishing can have on participants. Overall, this work has shown that COVID-19 has negatively affected sea angling in the UK. For sea angling diary participants, not being able to go sea angling had a negative impact on participation, effort, physical activity, and well-being. Government and local restrictions, personal health circumstances, aversion of risk, and other factors related to the pandemic are reasons participation and effort in sea angling reduced within the sample and therefore subsequently impacted the well-being and physical activity of participants. Similar to studies in other countries, it seemed being able to go sea angling again had a positive impact on the sample, implying that sea angling can make a positive contribution to physical activity and well-being (Lemmey, 2020; Gundelund & Skov, 2021; Howarth et al., 2021; Pita et al., 2021), although other factors can contribute to this. Further research is being conducted in 2021 and 2022 will contribute further data and knowledge to this (e.g. Britton et al., 2023). This research can contribute to a wider body of knowledge to better inform policymakers about the management of recreational marine fisheries. Lastly, the longitudinal information regarding the panel surveyed, and the continuing efforts of the Sea Angling Diary project to understand marine recreational angling within the UK into 2022, opens scope for further investigation to understand the long-term impacts of COVID-19 on well-being, expenditure, physical activity and participation. This full study has been published by Hook et al. (2022).

4.5. Further work

Further work is needed in the following areas: improving estimates of effort and characteristics of the sea angling population; increasing the size and representativeness of the diary panel; improving data completion from the diary panel; develop expert elicitation; and side-by-side validation with parallel onsite surveys. In addition, it would be useful to update estimates of the economic impact and develop a greater understanding of the social benefits of sea angling.

The numbers of sea anglers sampled in the WPS is low, limiting the number of variables that can be used in the analysis and the reliability of population estimates. In addition, the change in methodology from face-to-face to online resulted in large differences in the estimates, making future use of WPS uncertain unless side-by-side comparison of the two methods is done. The modelling approach developed in this study uses all years to reduce uncertainty, but a larger bespoke survey is needed. Hence, a large-scale bespoke survey done every five years covering both freshwater and sea angling would be beneficial. This could provide consensus if codeveloped with the angling community, supporting development of angling and implementation of the National Angling Strategy (Brown, 2019), but would require additional resource to implement.

Increasing the size and representativeness of the diary panel and the completion rates by diarists are key to improving data collection. New approaches are needed to recruit new diarists, as a significant number are lost each year due to survey fatigue. Social media approaches have been developed, but recruitment will become more challenging each year. Co-development of future surveys with the angling community is underway, with support from the Angling Trust to recruit diarists for 2022. Improving the experience of diarists through the further development of the mobile app and diary system, making data entry as simple as possible, will increase completion rates and improve data quality. Improvements have been made to increase the utility of the system to sea anglers this year, and more are planned to enhance the user experience (e.g. real-time catch reporting). In addition, a follow-up survey on the impact of non-response would help to assess potential bias.

Significant progress has been made in improving the analytical methods in this study, moving from a traditional reweighting to model based MRP methods, Further work is needed to refine the modelling approach including broader expert elicitation to develop priors, including diarist with less than 6 months of data, and modelling catches for individual sessions rather than for each angler. In addition, updated estimates of the economic impact and social benefits of sea angling are needed. In 2021, two surveys have been done. Firstly, a survey to understand the economic impact was done with the diary panel and a broader group of sea anglers using a similar approach to 2016-17. Secondly, a second survey was undertaken to understand in much more detail the impact of sea angling participation on physical activity and mental well-being. The outcomes from these studies, once available, will be useful in the context of future management of sea angling.

Finally, a side-by-side comparison between onsite and offsite (diary) in the same year that includes both the retained and release components of the catch is needed to assess the robustness of the diary panel. A similar approach is used in other parts of the world (e.g. Western Australia), where diary surveys are run annually with an onsite creel survey done every five years for comparison. This approach will generate times series needed for stock assessment, so regular (annual) consistent data collection is required to capture trends in sea angling catches (Hyder et al., 2017; 2018; 2020a).

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Appendix 1. COVID-19 survey

Your 'normal' sea angler participation

Q1 Approximately, on how many individual days did you go sea angling in 2019? Please enter a whole number only.

Q2 What types of recreational sea angling did you do in 2019? Please tick all that apply.

- Shore
- Private or rental boat
- Charter boat
- Kayak
- Other

Q3 Did you do any other types of angling in 2019? Please tick all that apply.

- Freshwater coarse fishing
- Freshwater game fishing
- Other
- N/A

Q4 In MILES, how far do you normally travel for a typical sea angling trip? Please enter the number of miles in whole numbers only.

Q5 How do you normally travel for a typical sea angling trip? Please select the mode of travel.

- Private car (your own)
- Private car (someone else's, inc. taxi)
- Train/tram
- Walk
- Bus
- Cycle
- Other

Q6 What proportion of fishing days in 2019 were undertaken near to home (i.e. no overnight stay) or away from home (involving an overnight stay)?

- All near to home (100%)
- Most near to home and some away from home (75/25%)
- Roughly equal near to home and away from home (50/50%)
- Some near to home but MOST away from home (25/75%)
- All away from home (100%)

Q7 How important was marine recreational fishing for your lifestyle, in relation to your social life, work, other hobbies, etc. PRIOR to the COVID 19 crisis? Please use the slider to indicate importance from 1 (not at all important) to 10 (very important).

Q8 How would you judge your fishing skills and knowledge compared to the average recreational fisher prior to the COVID-19 crisis? Please use the slider to indicate your skill from 1 (much lower) to 10 (much higher).

Q9 Generally, what proportion of fish that you catch in the sea do you normally keep and release? Please tick one option only.

- I keep all/vast majority of what I catch
- I keep roughly half of what I catch
- I keep some of what I catch
- I release most fish I catch
- I release all/vast majority of what I catch

Q10 In which months have you been fishing in the sea in 2020? Please select all that apply.

- January
- February
- March
- April
- May
- June
- July
- August
- September
- N/A I have not fished in 2020

Impact of COVID-19 on your Sea Angling

Q11 Since March, please say in which months you were unable to go sea angling at all or partially, specifically due to COVID-19? Please answer for all months. Answer about your ability to go, even if you would not have done so.

Month	N/A	Not prevented	Unable for part of month	Unable for whole month
March				
April				
May				
June				
July				
August				
September				

What was the SINGLE MOST IMPORTANT reason you were not able to go fishing for each of those months? Please tick one option that was most important in each month.

Month	Government lockdown or restrictions on travel / activities	Decision to isolate due to health advice / restrictions from government	Your own decision to minimise risk	Reliant on fishing with others (e.g. for travel)	Other (e.g. looking after others, childcare etc.)	N/A or I was not restricted this month
March						
April						
May						
June						
July						
August						
September						

Q13 Please say in which months you would normally have fished in the sea at that time of year?

Month	I would normally have fished	I would NOT normally have fished
March		
April		
May		
June		
July		
August		
September		

Since restrictions were relaxed

Q14 Have you been sea angling at all since lockdown restrictions were relaxed?

- Yes
- No

Q15 When you were able to go sea angling again, did you fish: Less than I did this month last year, The same amount as I did this month last year, more than I did this month last year, N/A I was not fishing

Month	Less than I did this month last year	The same amount as I did this month last year	More than I did this month last year	N/A I was not fishing
March				
April				
May				
June				
July				
August				

September				

Q16 Please use this box to explain why your sea angling activity may have been more or less than at the same time last year.

Physical activity

Q17 In general what additional effect did NOT being able to go sea angling specifically have on your physical activity. Please say to what extent you agree (Strongly agree, Agree, Neither, Disagree, Strongly disagree) with each of the following statements:

- I was less active because I could not go sea angling.
- I was less active but that was for other reasons.
- I was more active despite not being able to go fishing (e.g. doing other things).
- There was no real change in my activity levels.

Q18 Please comment if you wish.

Well-being

These questions ask about how you have been and what impact restrictions on, or being able to go, sea angling have had on how you feel.

Q19 In general, what additional effect did NOT being able to go sea angling have on your mental health and well-being. Please say to what extent you agree (Strongly agree, Agree, Neither, Disagree, Strongly disagree) with each of the following statements. Although lots of factors may have affected how you felt, please tell us about the specific impact of not sea angling.

- I was less happy because I could not go sea angling.
- I was less calm and relaxed because I could not go sea angling.
- I was less energetic and active because I could not go sea angling.
- I was less fresh and rested when I woke up because I could not go sea angling.
- My daily routine was less full of things I am interested in because I could not go sea angling.

Q20 During the LAST TWO WEEKS, how often were the following things true? All of the time, Most of the time, More than half the time, Less than half the time, Some of the time, At no time

- I have felt cheerful and in good spirits
- I have felt calm and relaxed
- I have felt active and vigorous
- I woke up feeling fresh and rested
- My daily life has been filled with things that interest me

Q21 To what extent are your responses due to now being able to go sea angling? Please say from 0% (not at all) to 100% (completely due to sea angling), or tick N/A.

- N/A – I have not been able to go sea angling
- Not at all - 0%
- Partially - 25%
- Partially - 50%
- Partially - 75%
- Wholly - 100%

Expenditure

Q22 What was your expenditure on sea angling (include in your estimate: terminal tackle, bait, rods, reels and other fishing equipment) in April 2020; and how does this compare with what you would have spent in a typical April? Please put a whole number of pounds (£) for each. Do not include pound sign, decimals or words.

- More
- Less
- No change

Impact on Fishing

Q23 If you have been able to go sea angling again, to what extent do you feel that the following statements are true (Definitely untrue, Somewhat untrue, Not sure / don't know, Somewhat true, Very true)? If you have not been sea angling since lockdown, please tick N/A.

- I have usually travelled less distance to go sea angling than normal
- I have chosen to fish closer to home than usual
- I have chosen to fish in places where I can avoid contact with other people more than usual
- I have not been on a charter boat when normally I would have been
- There are fewer people fishing in the sea where I fish
- There are more fish about / caught

Q24 Have you personally taken people fishing who have not fished in the sea before or recently, since the COVID-19 crisis began? Please tick all that apply.

- Yes – people who have never fished at all before
- Yes – people who have never fished in the sea before (but have in freshwater)
- Yes – people who have fished before but not recently
- No
- N/A – not been sea angling
- Don't know

Q25 If Yes, why do you think they have been sea angling? Please tick which one most applies.

- As an alternative to freshwater fishing (e.g. if sites too crowded)
- As an alternative to other activities that weren't permitted
- For health / well being
- Opportunities such as get fishing schemes / take a friend fishing
- Coverage of angling in the media
- N/A
- Something to address isolation
- Other

Q26 Do you know of other people who have not fished before who have done so since the COVID-19 crisis began? Please tick all that apply.

- Yes – people who have never fished at all before
- Yes – people who have never fished in the sea before (but have in freshwater)
- Yes – people who have fished before but not recently
- No
- N/A
- Don't know

Q27 In the next 12 months how much time do you expect you will spend on your recreational fishing habits in relation to the time spent on your social life, work, other hobbies, etc.? Please use the slider to indicate how much time you expect to spend on recreational fishing in the next 12 months from 1 (I plan to greatly reduce the time spent) to 5 (I plan to spend a lot more time than before)

Q28 Please comment on any of your answers, or more generally on the impact of COVID-19 on your recreational sea angling, if you wish to.

About You

These questions ask some details about you. This is really important information to help analyse answers to the rest of the survey against different groups. ALL information will be ANONYMOUS, it will be used in AGGREGATE TOTALS only and there will be no way of identifying responses with you. However, if you do not want to answer a question, just tick 'prefer not to say'.

Q29 What age are you? Please select one option, or select 'prefer not to say'.

Q30 Gender

- Female
- Male
- Other (please specify)

- Prefer not to say

Q31 In relation to COVID-19 which of the following health group are you in? Please tick one or 'prefer not to say'.

- Don't know
- High risk
- Low risk
- Moderate risk
- Prefer not to say

Q32 Do you have any physical or mental health concerns that have a substantial effect on your ability to do normal daily activities? Please select one option, or prefer not to say.

- Yes – physical health
- Yes – mental health
- Yes – physical and mental health
- Neither
- Prefer not to say

Q33 Which one of these best describes your background or race? Please tick one option or prefer not to say.

- Black or Black British
- Mixed Race
- Other (please specify)
- Prefer not to say
- White (British or English)

Q34 What is your current employment status? Please tick one option or prefer not to say.

- Employed full time
- Employed part-time
- Furloughed
- Other (please state)
- Prefer not to say
- Retired
- Self-employed full time
- Self-employed part-time
- Student / in education
- Unemployed

Q35 What is your postcode?

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