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Using opportunistic data to study the distribution and abundance of a warm water elasmobranch at the northern edge of its range

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Abstract

Detecting changes in the distribution and abundance of marine species that are cryptic or occurring in very low abundances is difficult, but essential for assessing their status and informing management. One way of quantifying these changes is through the collation of opportunistic records. We reconstruct the population trajectory and distribution of the common stingray *Dasyatis pastinaca* around Great Britain, using opportunistic records, mostly obtained by recreational anglers. We tested if *D. pastinaca* declined in abundance and body size in response to fishing and if their distribution has shifted northwards in response to warming seas. We obtained 518 records covering the period 1838-2020. After correcting for observation effort, *D. pastinaca* catches reported by anglers showed no long-term trend over 50 years, but with a decrease from 1970-1995 and an increase in abundance since 1995. While records of species occurrence were found around much of Great Britain, nearly all were from south of 54° latitude, and records have contracted southwards since 2000. No trend in maximum size through time was detected. In conclusion, we did not find support for the hypothesized declines in abundance and body size or a northward shift in distribution of *D. pastinaca* and instead found a southward contraction.

Keywords: conservation, fisheries management, Dasyatidae, elasmobranch, historical ecology, recreational angling, climate change

Introduction

Detecting changes in the distribution and abundance of uncommon marine species is difficult (Pikitch, 2018), but essential for assessing their population status and identifying whether management actions are required and effective. Many sharks and rays are threatened by fisheries (e.g. Dulvy *et al.*, 2021; Pacoureau *et al.*, 2021). Their distribution and local abundance may also shift in response to oceanographic and climate changes (e.g. Chin *et al.*, 2010; Osgood *et al.*, 2021; Hammerschlag *et al.*, 2022), with the latter likely to exacerbate risks from fishing (Walker *et al.*, 2021). Yet, we have little idea of the conservation status of hundreds of species of sharks and rays, including taxa that are infrequently recorded (Walls & Dulvy, 2020, 2021).

Stingrays (Dasyatidae) are a diverse group of batoid elasmobranchs mainly found in tropical and subtropical regions (Last *et al.*, 2016). The common stingray *Dasyatis pastinaca* (Linnaeus, 1758) occurs in the eastern Atlantic and Mediterranean Sea from the shore to about 200 m depth but is more commonly recorded in shallow waters (< 50 m). While this species has quite a large distribution including the Mediterranean, they are considered less common in northern Europe, as this appears to be at the minimum thermal tolerance of its range (Heessen *et al.*, 2016). The British Isles are on the northern edge of its distribution where it is the only demersal stingray species frequently encountered (Last *et al.*, 2016; Ebert & Dando, 2020) and is not commercially fished. The species is suspected to have declined by at least 30% through European and north African waters over a three generation period (3 times 7.5 years), and is assessed as Vulnerable on the International Union for Conservation of Nature (IUCN) Red List of Threatened Species (Jabado *et al.*, 2021), but the abundance data underpinning this assessment are scarce. Because of their infrequent capture in systematic fisheries-independent scientific demersal fish trawl surveys (which may relate to limited overlap between surveys and the spatial distribution of the common stingray as well as their small population size), such surveys are unable to provide reliable abundance trends (Martin *et al.*, 2010; Heessen *et al.*, 2016; Rindorf *et al.*, 2020).

Common stingrays *Dasyatis pastinaca* have been documented by naturalists (under a wide variety of names) as occurring around Great Britain for over 330 years, in Scotland, (Sibbald, 1684; Raye, 2018), England and Wales (Pennant, 1796; Couch, 1841; Herdman & Dawson, 1902). It was reported as most common on the English south coast (Yarrell, 1859) and common in south Wales (Dillwyn, 1848), and was mostly recorded very close to shore (Couch, 1841; Yarrell, 1859). Over 100 years later Wheeler (1969) showed the distribution of *D. pastinaca* all around Great Britain, noting the Thames estuary as a particularly important habitat. Yet despite attracting this level of interest for many years, and being a warm water species on the northern edge of its range in warming seas, there has been no research on how the distribution or abundance of this species may have changed through time around Great Britain. As a result of its larger size and distinctive nature (a relatively rare, venomous species typically associated with warmer waters), the common stingray is popular in recreational sea angling in the UK, where it can be caught on a wide range of baits fished on the seabed (https://britishseafishing.co.uk/common-stingray/#, https://hookpoint.co.uk/how-to-catch-stingray/). This means that there are records available that may provide insights, previously overlooked, on contemporary population size and distribution. When these available historical and contemporary records are considered together, there is an opportunity to examine temporal changes to this population over the last two centuries. Historic data are often being incomplete and patchy and subject to bias that can change through time. These complications, however, do not lessen the value of historical records, and past studies have shown that the detection and explanation of historical trends and variability are essential to informed management (e.g. Swetnam *et al.*, 1999; Thurstan *et al.*, 2015).

We define 'opportunistic records' as those that are not the direct result of a scientific field survey aimed at quantifying fish abundance. Opportunistic records therefore include those from commercial fisheries, recreational fisheries, naturalists and the general public, and single records in scientific papers, but not those from scientific trawl surveys. Opportunistic records can be useful as an indicator of local population status or trends (e.g. Grant *et al.*, 2022), although they can also be problematic due to a lack of time series consistency, and underlying observation effort may be unclear (Swetnam *et al.*, 1999). The difficulty of monitoring uncommon species that are seldom caught in scientific surveys is illustrated in a study on angelsharks *Squatina squatina* in Wales, UK (Hiddink *et al.*, 2019). The northeast Atlantic is one of the most intensively monitored oceans in the world, nevertheless only a handful of angelshark were caught in >40 years of scientific fisheries-independent trawl surveys (>25,000 hauls) (Heessen *et al.*, 2016). In contrast to this paucity of records, 1,860 angelshark records from a 50-year period were collated from the coastal waters of Wales using interviews, charter-boat skipper log books and other opportunistic sources (Hiddink *et al.*, 2019). The angelshark study estimated that there had been a 70% decline in abundance over 46 years, with continued presence in Cardigan Bay. Although Hiddink *et al.* (2019) made corrections for observation effort by taking account of the number and age distribution of the observers, uncertainty remains about the reliability of opportunistic records for the estimation of abundance and distribution trends. If trends estimated using opportunistic records are driven mainly by changes in observation effort over time, it can be expected that different uncommon species would show similar trends in abundance and distribution that are all following the observation effort, when using the same type of opportunistic data for different species. However, if the number of records for different species show divergent trends in space and time, we can be more confident that opportunistic records provide an indication of real population trends rather than changes in observation effort alone. For example, in the Mediterranean Sea the number of opportunistic sightings of bluntnose sixgill shark *Hexanchus griseus* have been decreasing while the number of opportunistic sightings of shortfin mako *Isurus oxyrinchusis* are increasing, meaning that it can be inferred that the population size trend of shortfin mako is more positive than that for bluntnose sixgill shark (Bargnesi *et al.*, 2022).

We should also keep in mind that opportunistic recording and fishing activities may favour different species at different times (Boersch-Supan *et al.*, 2019). For example, anglers may target particular fish species, and this may guide exact fishing location, gear, bait, and other factors (Lewin *et al.*, 2006). Collectively, opportunistic records can be useful for the study of 'rare' species, however, interpretations for how opportunistic records indicate changes at the population level need to be carefully considered with respect to available information the type of observations, on temporal changes and biases in observation effort (Swetnam *et al.*, 1999; Hiddink *et al.*, 2019).

Evidence from aquatic environments suggests that body size can decline as a result of climatic warming at the level of the individual, population and community (Daufresne *et al.*, 2009; Shackell *et al.*, 2010) as well as in response to exploitation pressure (e.g. Anderson *et al.*, 2008). Increasing sea bottom temperatures with climate change are likely to favour smaller species and individuals (Atkinson, 1994; Hiddink & ter Hofstede, 2008). Climate change is also likely to continue to result in a northward shift of the poleward edge of the distribution of species with warm-water affinities (Perry et al., 2005; Dulvy et al., 2008). It has been shown that fish species track temperatures under global warming by moving both latitudinally and into deeper water (Dulvy *et al.*, 2008; Burrows *et al.*, 2019). Large shifts in the distribution and abundance of elasmobranchs in the North Sea have been recorded (Sguotti *et al.*, 2016).

Species of highly mobile fish, such as sharks and rays, may be more responsive to temperature change in time and space than analogous communities on land, potentially as a consequence of living closer to their thermal limits (Burrows *et al.*, 2019). High fishing pressure has also resulted in a decrease in the abundance and body size of large-bodied and slow-reproducing fish species, including sharks and rays, over the last 100 years (Quero, 1998; Rogers & Ellis, 2000; Engelhard *et al.*, 2015).

This study aims to examine temporal occurrence records of *D. pastinaca* to determine if its geographic range has changed over the last two centuries and whether maximum reported sizes have reduced over time. Here we reconstruct the population trajectory and distribution of the common stingray *Dasyatis pastinaca* over nearly two centuries around Great Britain using opportunistic records, such as social media, newspapers, angling magazines and the scientific literature (where records did not come from systematic fisheries surveys). Recreational sea angling is popular in Great Britain (Hyder *et al.*, 2018) and provided most of the records used in this study. We hypothesize that common stingrays, like other large elasmobranchs (Walker & Hislop, 1998; Wolff, 2000; Rindorf *et al.*, 2020), have declined in abundance and body size in response to fishing and may have shifted their distribution northwards in response to climate change.

Methods

Opportunistic sightings of the common stingray *Dasyatis pastinaca* were compiled from publicly accessible information sources. The study area is the island of Great Britain (England, Scotland and Wales, including their component adjoining islands), and its surrounding seas. All records included in this paper are considered as opportunistic records, which are defined here as any records that were not the results of targeted survey effort in scientific trawl campaigns (e.g. Heessen *et al.*, 2016), and can therefore include records from the scientific literature..

A 'record' refers to an individual common stingray specimen encountered on one date, whereas a 'report' refers to a unique common stingray encounter event: one report could therefore comprise several common stingray records.

Data sources

Trophy-catch and magazine records

This study updated past compilations of two major recreational sea angling data sources which were identified and reviewed by Richardson *et al.* (2006); *SeaAngler* magazine (Kelsey media) and the annual reports of the National Federation of Sea Anglers (NFSA). The most popular recreational UK fishing magazine, *SeaAngler* produces 12-13 issues per year. Reader-submitted UK common stingray catches are published in *SeaAngler* if specimens met or exceeded the shore-based or vessel-based qualifying weight (9.1 kg and 11.3 kg, respectively), but may be mentioned for other reasons too. The number of submitted records is likely to depend on both the abundance of stingrays and the number of active anglers in a region.

Our search consisted of examining all pages of each *SeaAngler* issue, to find catch reports and common stingray-specific articles. A total of 598 *SeaAngler* issues published from March 1972 to July 2021 were reviewed. Issues published onwards from 2014 were accessed through a digitalised archive on go.readly.com, and hard copy issues published prior to 2014 were reviewed at Kelsey Media, Kent. We also extracted all records of the angelshark *Squatina squatina* from *SeaAngler*magazine using the same methodology for comparison of temporal and spatial trends. The NFSA produced annual reports of trophy catches (catches above a specified weight threshold) for a wide variety of species across the UK, including the species, weight and location of capture, from 1976 to 2002, and had 40,000 members in 2006, but is now defunct (Richardson *et al.*, 2006). These trophy records reports had a qualifying weight threshold of 15 kg for common stingray.

Books, scientific papers and historical literature

Where possible, Boolean operators (“and”, “or”) were used to ensure exact search terms were incorporated; minimising time spent reviewing irrelevant material. All searches (across all information sources) containing predefined terms (“Common stingray,” “stingray,” “*Dasyatis pastinaca*” or “*pastinaca*” and any spelling variations that the searches returned) were then examined for reports. If relevant data were not returned, the search string was adapted to increase its sensitivity to the study question, by including locations (United Kingdom, Wales, England, Scotland, Britain), and previous taxonomic classifications (*Trygon pastinaca*). The use of historical local names for the common stingray (e.g. English local names "fire-flare", "fiery-flare", or names in other languages (Welsh: “Morgath ddu”) did not yield any additional records. Private browsing options were used to avoid previously cached terms. The identified sources went through a manual four-stage screening process of search results to assess the material suitability: title relevance, abstract relevance, figures/image thumbnail and full text.

Historical literature is accessible via the Biodiversity Heritage Library (https://www.biodiversitylibrary.org/) and the websites archive.org and books.google.com. Searches returned natural history literature, personal accounts from fishermen, museum catalogues and zoological compilations of local fauna: collectively referred to here as "books". Peer-reviewed scientific literature ("scientific papers") was systematically searched using the search tools Google Scholar and ProQuest (Clarivate), and the publishers' websites for Wiley journals, Springer journals, ScienceDirect (Elsevier journals). Grey literature was also searched to ensure the comprehensiveness of the study as suggested by Haddaway and Bayliss (2015). This included other angling magazines separate from the trophy-catch dataset, and screening bibliographies of relevant material identified other relevant literature.

Online searches: News articles, social media, forums, other sources

Further common stingray records were found in 34 databases using a search conducted across online angling forums (e.g. https://norfolkfishing.com/), social media platforms (e.g. Twitter, Facebook) and 'other' sources: the latter refers to data portals, local environmental record centres and museum catalogues (see the full list of sources in Supplementary material Table S1). A 'snowball' sampling procedure searched forum responses, article comments and social media post threads for common stingray mentions. This returned public discussion of a) qualitative spatial-temporal distribution and b) the number of fish encountered. Despite creating a non-random sample, this produced reports which would have otherwise gone undocumented. We followed the guidelines for the ethics of using social media in fisheries research in Monkman *et al.* (2018), and only included information that was accessible without creating an account.

Data extraction and handling

For each record we collected where available the: number of individuals, size (disc-width, weight and/or total length), sex, observation location, date-of-encounter (year and month) and type of data source (e.g. book, trophy records, forum). Although *D. pastinaca* is the only dasyatid stingray to occur regularly around British coasts, photographs were used where available to confirm identification against the most recent comprehensive identification source (Ebert & Dando, 2020), as some sources (e.g. social media, popular press) have reported rajid skates as 'stingrays' (e.g. https://www.ayradvertiser.com/news/16051350.stingray-found-ballantrae-beach). We also acknowledged the possibility that the much less abundant pelagic stingray (*Pteroplatytrygon violacea*) or vagrants (e.g. Tortonese's stingray *D. tortonesei*) could occur around Britain (Ellis, 2007; Ebert & Dando, 2020). When no photos were available, the identification of the original source was accepted. Because anglers and other sources are more likely to report and publicize large common stingrays (as 'trophy' or 'specimen' fish), the reported body sizes are likely to be skewed towards larger sizes (although small specimens can also be reported, especially in forums). Any changes in body size therefore need to be interpreted as changes in the maximum size of common stingrays in the population, rather than changes in the mean.

The date-of-encounter was documented for each stingray rather than the date-of-publication. The date-of-publication was used as a reference point if a past encounter was recalled. For example, a report "seven years ago" was assigned a date seven years prior to the date of publication. Positions of encounter locations were estimated based on given descriptions when longitudes and latitudes were not stated. Commonly, the location name was given if the encounter was shore-based. Less often, vessel-based encounters produced distance estimations from a land-based reference point. Many reports did not report the size of the stingray, but where the size was reported one of three measures could be given: disc width (the widest point of the fish), total length or weight. Because weight was most commonly reported, all measures were converted to weight from disc width (DW) and length, respectively, using the following equations that were developed for *D. pastinaca*: weight (g) = $0.0132\ DW^{3.06}$ (Froese & Pauly, 2004) where disc width was estimated from length using DW (cm) = 0.60 total length (cm) - 0.61 (Heessen *et al.*, 2016) for 29% of records.

We checked for presumed duplicate records by evaluating if there were records from the same location (0.1 degree precision) in the same year from different sources, and duplicates were removed.

Analysis

Analysis was restricted up to the last complete year of data, 2020. For most types of data collated here, it was not possible to correct for observation effort and calculate a catch per unit effort. However, for the trophy and magazine catches only, we used the *SeaAngler* magazine readership data as a proxy for sea angling effort to calculate the number of common stingrays reported per 1000 readers per year. The number of readers was considered as likely to broadly reflect angling effort and the number of catches that are reported (Richardson *et* *al.*, 2006). Magazine readership was supplied by the publishers of *SeaAngler* as the combined paper and online readership for the years 1974–2019. We did not find sources that could be used as a proxy for observation effort for the other data sources.

Biogeographic distribution shifts were quantified by estimating the maximum, median and minimum latitude of all records from a 5-year period. To reduce the influence of outliers when assessing distributional shifts, the maximum and minimum latitude were estimated as the 0.95^{th} and 0.05^{th} quantile of the latitude of records per 5-year period. Results from this analysis were only reported when there were >5 data points per 5-year period, resulting in estimates of latitude for years after 1965 only. We tested if the fraction of records from southeast England (east of 2° west longitude and south of 52° north latitude) changed over time. We also tested if the months in which stingrays were recorded changed over time, as it can be expected that they are seen earlier in the year with climate change (Schlaff *et al.*, 2014).

We also used the approach of McPherson and Myers (2009) to estimate the magnitude of any change in the common stingray population and sensitivity of this to a range of observation effort scenarios. This model builds on a different set of assumptions than the SeaAngler analysis and a comparison between the outputs of the approaches therefore helps us in assessing the robustness of our conclusions. The McPherson and Myers (2009) approach extracts the relative magnitude of population change in the number of reported sightings by fitting a series of generalized linear models the difference in the count data between any reference date and the most recent point with data (2020), to provide multiple estimates of declines under alternate scenarios of observation effort and explicitly address uncertainty over variations in observation effort. This approach enables to simulate various scenarios for proportional change in the observation effort. Values smaller than 0% suggest a declining trend, while values equal to or larger than 0% suggest a stable or increasing population. For more details about the analytical method see McPherson and Myers (2009).

Results

In total, we obtained 356 common stingray reports that contained 518 individual common stingray records (Table 1), reflecting that most reports were of a single stingray. Records covered the period from 1838 to 2020, but were very scarce and infrequent in the earlier years (0-2 records per 5 years). Most records were catches reported by recreational anglers through various sources, with around a third as catches reported in *SeaAngler* magazine. Forums, news articles and social media together contributed 23% of records. Most of the remainder came from online databases such as the NBN Gateway (https://nbn.org.uk/).There were several records from commercial vessels that were reported in a series of papers on notable fish captures (Wheeler & Blacker, 1969, 1972; Wheeler *et al.*, 1975).

The total number of common stingray records increased strongly over time, driven by an increase in reports in *SeaAngler* magazine, forums, social media and regional newspapers that have become available online since the year ~2000 (Figure 1A). *SeaAngler* contributed the largest dataset where the observation effort was likely to be relatively constant (unlike for example social media), and the temporal trend in the number of reports in this dataset was seen to fluctuate with an increase in *SeaAngler* reports during a period of declining readership since around the year 2000 (Figure 1B). Common stingray reports per 1,000 *SeaAngler* readers show a U-shaped pattern, with a decrease from 1970 to 1995, followed by an increase to a similar or even higher level than the start of the time-series by around 2015 (Figure 1C). The dip is caused by a lower number of reports in a period with a high readership in the 1990s (suggesting a lower abundance in that period), while the higher values at the start and the end of the time-series relate to higher numbers of reports in periods with a lower readership (suggesting a higher abundance). For comparison, angelshark records showed a very similar decline in reports per 1,000 readers at the start of the observation period, while the uptick in records and the sightings per 1,000 readers at the end of the observation period was very limited compared to the common stingray (Figure 1C). For both species, the non-linear GAM was a better fit to the data than a linear model (the AIC for the GAM was lower than for the linear model). This divergence in the trend between the two species in recent years suggests that the increase in stingray records since 1995 represents a real increase in abundance.

Records of common stingray were widely distributed around Great Britain, including all Welsh and most English coasts and to the east of Scotland, but we did not find records from the north and west of Scotland, few from northeast England, and only a single record from northwest England (Figure 2A). Nearly all (97%) records were from southern Britain south of 54° latitude. Although there were relatively few (n=8) records from Scottish waters, they occurred across several time periods (Figure 2). The highest concentration of records was found in southeast England: on the English Channel coast, centred around Hampshire and West Sussex and the coast of the greater Thames estuary (>80% in recent decades, Figure 2A & 3C). While formerly recorded around most of Britain, common stingray records are now only found in southern

Britain (Figure 2B-H). Despite an increase in the total number of stingray records over time in Britain, the last common stingray recorded in the waters of Scotland and northern England (>53°N) was 1991 and 1998 respectively. Most Welsh records were from the south (Bristol Channel, bordering England) since 1975, and mid Wales (Cardigan Bay) in 1975–1999. Since 2000 we found few Welsh records (1 in north Wales in 2008, none in mid Wales, and 4 in south Wales). Most records (76%) came from the coast (with a reconstructed position within 2 km of land) rather than further offshore, reflecting the fact that most records were reported by anglers fishing from the shore rather than reports by boat users. The spatial pattern for the common stingray contrasts strongly with that for the much less commonly recorded angelshark, for which *SeaAngler* records remain concentrated in Wales only where it is more commonly recorded than the common stingray (Figure S1).

The maximum and median latitude at which common stingrays have been found in Britain has significantly moved south by 150-350 km (Figure 3A, maximum latitude $R^2 = 0.47$, $F_{1,9} = 8.06$, $p = 0.019$, median latitude $R^2 = 0.81$, $F_{1,9} = 39.4$, $p < 0.001$). Given that the southern boundary of the distribution of the common stingray lies 1,000s of kms south of the study area, the minimum latitude is effectively defined by the boundary of the study area and did not show a change over time (minimum latitude $R^2 = 0.23$, $F_{1,9} = 2.76$, $p = 0.131$). The fraction of records from southeast England (east of 2° west longitude and south of 52° north latitude) seems to increase over time ($R^2 = 0.56$, $F_{1,4} = 5.19$, $p = 0.131$), with 88% of records from the period 2000–2020 coming from this region (Figure 3C). This is driven by a increase over time in the number of records from lower latitudes (Figure 3A, B&C, where stingray records were always more numerous, while the number of records at higher latitudes decreased in recent years (Figure 3B). The months in which common stingrays were recorded did not change significantly over time (linear regression, $F_{1,47} = 0.0021$, $p =0.61$, Figure S2).

Estimates of the magnitude of change in stingray abundance from any given reference year to 2020, based on unstandardized reports from *SeaAngler* using the McPherson and Myers method (2009) and assuming a linear change over time (Figure 4), indicates either no change or an increase in common stingray abundance, if no change in observation effort is assumed (0%). If observation effort is assumed to have halved (-50%), which Figure 1b suggests is plausible, the model predicts that the common stingray has increased from the 1970s and early 1980s to 2020 by a minimum of 10.2% (CIs -61.2 to +190.6%). If observation effort is assumed to have doubled (100%), the model predicts that the common stingray has decreased in abundance from the 1970s and early 1980s to 2020 by a maximum of 72.2%% (CIs 27.5 to 90.3%). This analysis therefore suggests that under the most plausible pattern of a decrease or stable observation effort, stingray abundance has increased. The decrease in abundance to 1995 and the subsequent increase to 2020 is represented by the inverted U-shape of the inferred changes in abundance in the figure. The low values on the left of the figure indicate little change in abundance from the start to the end of the time-series, and the high values in the middle of the figure indicate increases in abundance from around 1995 to the end of the time-series.

Most of the recorded weights were provided for trophy catches, and therefore were representative of the largest individuals in the population (15 to 20 kg) rather than an indication of the body size of the population in general. No trend in the recorded weight over time was detected (Figure 3D, $R^2 = 0.11$, $F_{1,3} = 0.39$, $p = 0.57$).

Discussion

Our study shows that changes in the distribution and abundance of an uncommon marine species can be evaluated by a retrospective analysis of opportunistic records. Here, we present evidence that, contrary to our expectations, the population of the common stingray around Great Britain has shown no long-term trend over 50 years, but with a decrease from 1970 to 1995 and an increase in abundance since 1995. The spatial distribution of records has become more concentrated in southern England, with very few recent Welsh records. This southerly shift in apparent distribution is driven mainly by an increase in records from around the Isle of Wight (possibly resulting from an increase in abundance or of targeted angling efforts for stingrays). Unfortunately, the spatio-temporal distribution of angling has not been mapped and it is therefore difficult to make detailed corrections for observation effort. Common stingray sightings have always been sporadic in Scotland, and none have been recorded there in the last 20 years. Because they have likely never been abundant in Scotland, records will have been more newsworthy, which may have lead to a higher likelihood of reporting. As such, an absence of records is likely to reflect a current rarity or absence of stingray in Scottish waters. As observation effort and reporting through online sources has been increasing substantially over time, it seems likely that this lack of records in Scotland and most of Wales represents a lower abundance of common stingrays there from 1975 onwards. Unsurprisingly, the number of records obtained from social media, forums and other internet-based media increased strongly after 2000, and these increases will reflect increases in the availability and use of these types of sources rather than an actual increase in common stingray abundance.

As for a previous study involving angelsharks (Hiddink et al., 2019), our findings from rich opportunistic data for stingrays provide a valuable complement to scientific trawl surveys: common stingrays were only caught in small numbers in an extensive program of trawling across the NW European shelf during the period 1977-2013 (Heessen et al., 2016), in contrast to the 356 stingray records we obtained. Additionally, both the trawling and opportunistic datasets appear to corroborate each other in terms of spatial occurrence, with most records around southeastern England/the Eastern English Channel (Heessen et al., 2016).

The ultimate challenge in the interpretation of opportunistic records is separating true population trends from changes in the observation effort (e.g. McPherson & Myers, 2009), and we could only estimate observation effort for one of the used data sources, the trophy fish catches. The interest in reporting of seldomly encountered and unusual fish may have varied over time (e.g. there was a set of papers describing 'rare and little-known' catches spanning 1966 to 1971, Wheeler & Blacker, 1969, 1972; Wheeler *et al.*, 1975). Only *SeaAngler* records yielded a suitable number of records for a quantitative analysis, limiting this most rigorous analysis to the years 1974-2019. The analysis of this dataset showed that common stingray abundance fluctuated with no long-term trend over 50 years, but with a decrease from the 1970s to 1995 and increased again since 1995no. The comparison of the temporal and spatial distribution of common stingrays with patterns of angelsharks recorded using the same method (*SeaAngler* reports) is informative (reported here, and in Hiddink *et al.*, 2019, although scale of the angelshark work there was more extensive because it also include interviews with fishers): while the number of common stingray reports was fairly stable from 1970, angelshark records declined strongly since the 1990s and has not recovered. While there have been very few records of common stingrays from north and mid Wales in recent decades, angelsharks maintain a stronghold in mid Wales, and Hiddink *et al.* (2019) report hundreds of records there since 2000. The divergent trends between these two species suggest that the observed patterns are unlikely to be solely driven by changes in observation and reporting effort, and instead reflect actual changes in stingray populations. They could nevertheless be partly driven by observation and reporting effort given that angling catches, especially for seldomly encountered species, can be highly reliant on a handful of anglers or charter boats, and if these change, this can make a large difference to the numbers of local records.

This study adds to a growing body of research using opportunistic records to reconstruct population and distribution trends of uncommon and cryptic marine animals (e.g. McPherson & Myers, 2009; Curtis et al., 2014; Barbini et al., 2015; Olson et al., 2018; Hiddink et al., 2019). For each of these studies, it seems likely that the probability of reporting an observation has been increasing over time, and the key to robust conclusions in each of these studies has been to separate the trends in abundance from the trends in observation and/or reporting effort, and different studies have taken different approaches. Olson et al. (2018) implicitly assumed that observation and reporting effort of killer whales *Orcinus orca* was constant as they did not correct for potentially changing effort levels. Barbini et al. (2015) used the number of classified advertisements offering fishing guide services published per year in a magazine as a measure of observation effort. Several studies have used the approach developed by McPherson and Myers (2009) that simulates various scenarios of change in the observation effort to evaluate the sensitivity of the inferred magnitude of decline to observation effort (Curtis et al., 2014; Hiddink et al., 2019), while Hiddink et al. (2019) also inferred observation effort from the age distribution and number of respondents. Despite the similarity in the methods and analyses among the studies mentioned above, the inferred relative abundance patterns vary widely among those studies and in comparison to the current results. As it seems likely that the probability of reporting an observation has increased over time for all studies, it is reassuring to see that these trends in the number of records and inferred abundance are different between stingrays (strong increase in recent years) and angelsharks (no or weak increase in recent years), as this gives confidence that we have been evaluating real trends in abundance and distribution rather than artefacts of the recording effort only, and it shows how opportunistic datasets can be valuable tools for illuminating spatial and temporal trends. The sensitivity analysis of our dataset using the McPherson and Myers (2009) method suggests that the long-term trends in common stingray abundance are not particularly sensitive to the halving in observation effort that the *SeaAngler* readership data suggest (the confidence intervals overlap with zero). A doubling in observation effort could have masked substantial declines in their abundance, but we have no evidence to suggest that observation effort is likely to have substantially increased.

The records presented here are largely from shallow coastal areas, because most of them were obtained from anglers fishing from the shore or small inshore boats. In other studies, very different habitat preferences of common stingray were inferred. For example, Martin *et al.* (2010) reported that this species was found offshore in deep waters where tidal currents are moderately intense, based on trawl survey data. This suggests that the mode of data collection has a major effect on the inferred pattern of habitat use. Because our records were mostly from coastal waters, we can only draw conclusions about changes in the distribution in coastal waters. Size may also play a role in habitat preference: based on limited common stingray records from trawl surveys, Heessen *et al.,* (2016) reported smaller individuals in shallower (mode = 40 cm DW at <50m water depth) water, with larger individuals in deeper water (mode = 70 cm DW).

Our hypothesis that common stingrays declined in abundance and maximum body size in response to fishing was not supported by the results, as no long-term decline in either parameter was obvious. Several other large species of rays have in fact increased in abundance in the Celtic Seas and displayed a fairly stable abundance in the North Sea in the last few decades (Engelhard *et al.*, 2015; Heessen *et al.*, 2016). Similarly, a shorter-term study using only scientific trawl records showed no significant change in common stingray abundance from 1995 to 2015 in the North Sea (Rindorf *et al.*, 2020). The observed maximum body sizes in our study (130 cm disc width (DW), 137 cm length which converts to 82 cm DW, 36 kg which converts to 126 cm DW) are very large compared to reported maximum body sizes of common stingray of 60–68 cm DW in other sources (Heessen *et al.*, 2016; Last *et al.*, 2016). Although these conversions from length and weight to DW depend on the accuracy of the relationship being used and are highly uncertain, it seems plausible that common stingray grows much larger than 60–68 cm DWLast *et al.* (2016) and Ebert and Dando (2020) note reports of up to 140 cm DW for common stingray are dubious, but lengths of up to 164 cm were reported in Heessen et al., (2016). Furthermore, the subtly different Tortonese's stingray *D. tortonesei* (not yet known to occur in British waters) is reported as attaining a greater DW than common stingray (84 cm), but the two species have only fairly recently been separated due to their morphological similarity, and thus their biological parameters are less well defined and possibly confounded. It is likely that the larger specimens we recorded represent expanded maximum sizes for common stingray, although we do not discount the possibility that individual Tortonese's stingray could occur as vagrants in British waters. It may be possible that this species attains larger sizes in these higher latitudes, given that this is a common pattern (Atkinson, 1994).

Our hypothesis that common stingrays would have shifted their distribution northwards to track changes in sea bottom temperature in response to climate change (Hiddink *et al.*, 2015) was not supported and we instead found an opposite pattern, with a contraction in common stingray record distribution towards the south-east coast of England. Our finding of a southward contraction is consistent with apparent disappearance from the south-eastern North Sea since the mid-1960s (Wolff, 2000). The distribution of angling effort alone cannot explain this, as areas of high angling effort are found throughout England and Wales and some parts of Scotland, and there is no reason to assume that rays are more favoured as a target species in the southern and southern-eastern English coasts than in the southwest or northeast (Monkman *et al.*, 2018; MMO, 2020). The southward shift of the distribution of common stingray records could be related to the divergent spatial patterns in human population growth in the UK, with greater growth in the south, and therefore the readership of the *SeaAngler* could have become more concentrated in the south. However, the geographic centre of human population density in Great Britain only shifted ~34 km to the southeast between 1970 and 2020 (https://en.wikipedia.org/wiki/Center_of_population), while the centre of stingray records shifted ~155 km south over that period, and the human population shift can therefore only explain a minor amount of this southward shift. Nevertheless, angling effort is not uniformly distributed and undergoes spatial and temporal changes in distribution, and a loss of effort (e.g. charter boats) for whatever reason might partly explain observed changes such as decreases in numbers observed in certain areas. Such a pattern of southward contraction of geographic range has only been observed (based on long-term scientific surveys) for a few fish species (Dover sole *Solea solea* and the Norway pout *Trisopterus esmarkii*) and about 10% of species of benthic invertebrates in the North Sea, in contrast to the majority of species which expanded north (Perry *et al.*, 2005; Hiddink *et al.*, 2015)(Burrows *et al.*, 2019). It is hard to explain this contraction of the distribution of the common stingray, in particular when the total number of records was highest in the later periods because of the increasing use of social media and online forums. The most plausible explanation is that parameters other than mean temperature, such as fishing pressure, food availability or availability of spawning habitat, are driving their range-shifts and -contractions (VanDerWal *et al.*, 2013). Commercial fishing continues around all of Great Britain without great shifts in effort distribution and is therefore not expected to lead to a spatial shift in records (Jennings *et al.*, 1999). Nevertheless, if populations in northern Britain are at their lower thermal tolerance limit, which is likely even though thermal limits have not been independently estimated, it could be expected that population density has always been very low. Therefore, it is possible that their naturally low abundance in the north of Britain has been reduced even further by factors such as commercial fishing, while denser populations in the south of Britain have tolerated fishing pressure better.

Future work aiming to use historical data, angling catches and other opportunistic to better understand population trends of uncommon marine fauna would benefit from approaches that avoid, or correct for, the biases that may be introduced by uneven observation and reporting efforts. For current angling effort, it should be possible to map the spatio-temporal distribution of angling effort through approaches such as field surveys, interviews and angling shop expenditure, but correcting fully for observation effort in historical data is unlikely to be possible. Comparison of the inferred trends in abundance using opportunistic sources with commercial landings and scientific trawl surveys might help us to understand which of these sources of data are most suitable for reconstructing abundance trends.

In conclusion, we did not find support for the hypothesized declines in abundance and body size or for northward shifts for the common stingray, and instead found a contraction of distribution records towards southern England. Divergence between the temporal and spatial distribution patterns of common stingrays and angelsharks using a similar methodology show that the observed patterns are not only driven by patterns in observation effort for large elasmobranchs in British waters. Therefore, opportunistic records can be suitable to better understand population trends of seldomly encountered, large and charismatic marine species. We did not find evidence of long-term decline in the population size of the common stingray around Great Britain, and abundance seems to have increased since 1995. The trend in records of common stingray around Great Britain therefore may not match the overall trend for the NE Atlantic as a whole that led to it being classified as Vulnerable by the IUCN based on scarce data in 2021 (Jabado *et al.*, 2021).

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Contributions

JGH and AM generated the idea. RC collated the records. JGH and RC analysed the data. All authors wrote and reviewed the manuscript.

Data Availability statement

On publication, the collated records will be made available as supplementary material.

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Table 1. Summary statistics of the eight sources of common stingray record used, their temporal range, the number of reports (of one or more stingrays at a particular time and location) and records (total number of individuals reported) in Great Britain

Type	**First record**	**Last record**	**Reports**	**Recorded numbers**
SeaAngler magazine	1952	2020	155	155
Online forum	1905	2020	75	79
Other	1857	2015	36	161
Book	1838	1987	30	50
News article	1980	2020	26	26
Social media	2011	2020	17	17
Scientific paper	1989	2003	9	10
NFSA	1970	1989	8	20
Total			**356**	**518**

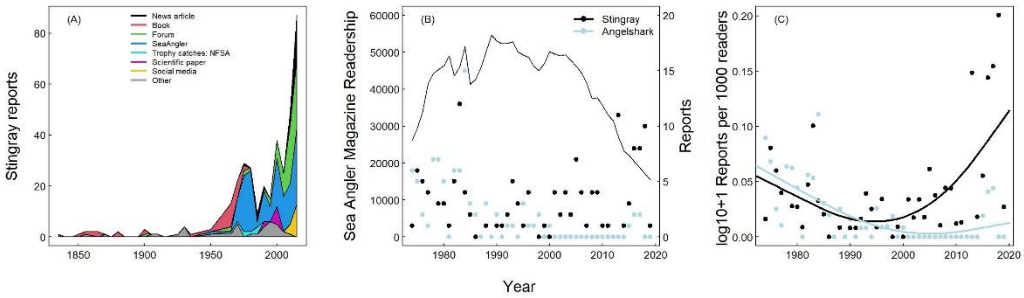

Figure 1. A) Temporal trends in the number of common stingray reports (one or more stingrays at one time and place) around Great Britain obtained from all data sources as total records per 5-year period from 1830 to 2020 (see Table 1). B) *SeaAngler* magazine readership (online and paper subscribers, left axis, line) and the number of common stingray (black points) and angelshark (blue points) reports in *SeaAngler* (right axis, per year) over the period from 1974 to 2020. C) The number of common stingray (black) and angelshark (blue) reports per 1,000 *SeaAngler* readers. The lines are GAMs fitted through the data (black: common stingray, effective df=2.91, F=5.236, p=0.0033, deviance explained = 29.9%, ΔAIC with linear model = -7.87, light blue: angelshark, effective df=2.79, F=14.32 p<0.0001, ΔAIC with linear model = -7.87, deviance explained = 49.8%). Note that the x-axes for A) covers a much longer period.

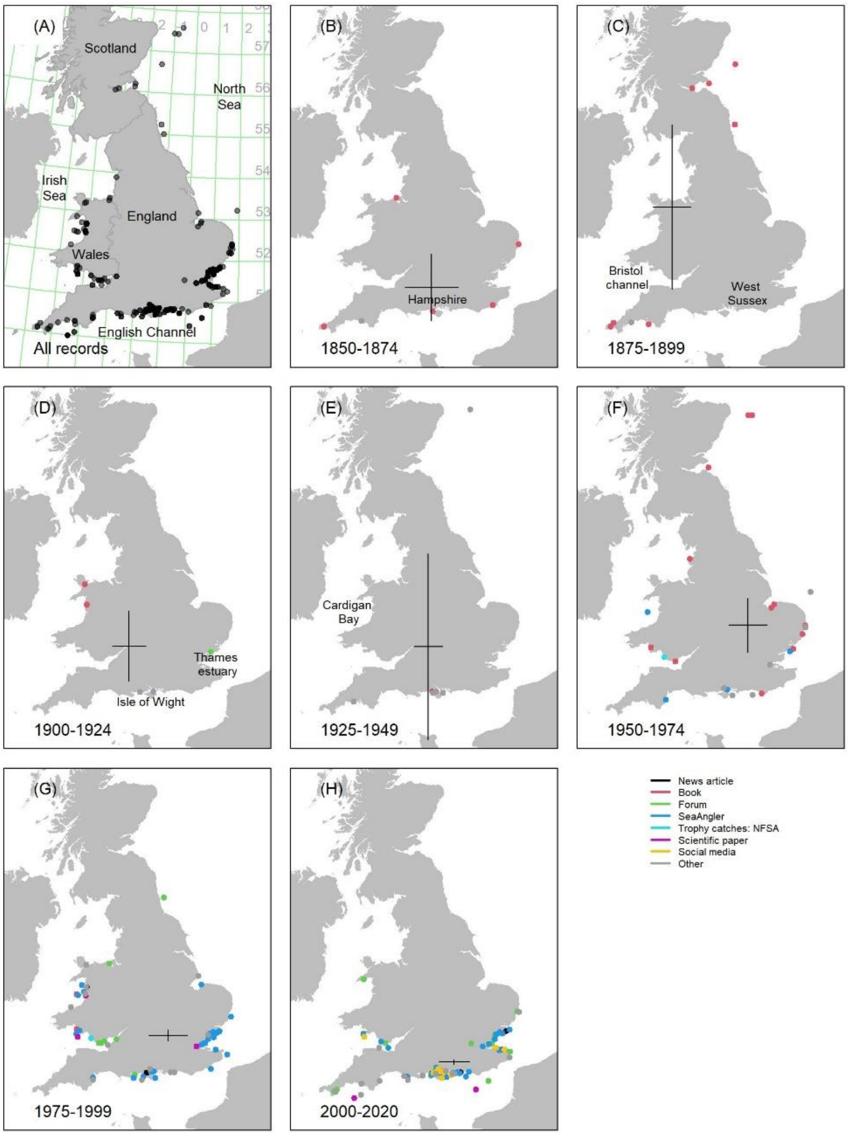

Figure 2. (A) The distribution of common stingray records around Great Britain from all sources based on reconstructed positions, showing degrees of latitude and longitude. All records are plotted in transparent grey scale. This results in the most persistent observation locations being represented by more intense shades and individual isolated locations being represented by transparent points. (B–H) Distribution by 25-year period of common stingray, over nearly two centuries. The 2000 onwards observation period is inevitably truncated and comprised of 20 years of records to 2020. The black crosses indicates the 95% confidence intervals around the mean latitude and longitude (centre of the cross) of all records for each period.

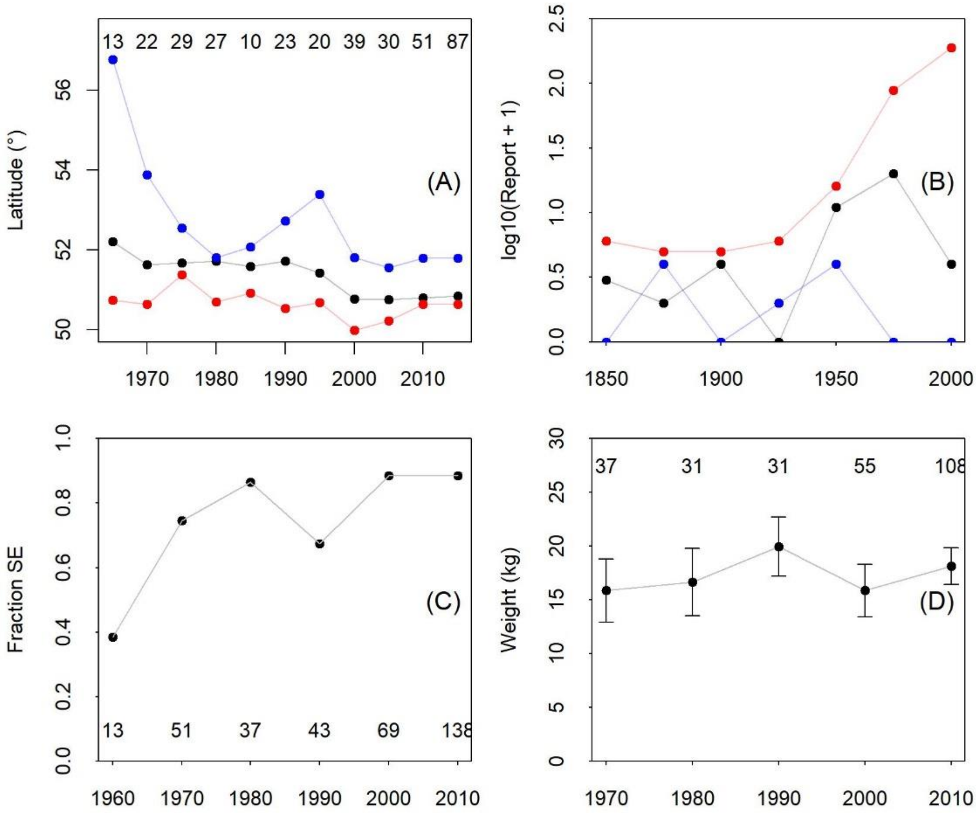

Figure 3. Temporal trends in the common stingray distribution and size around Great Britain. (A) The maximum (blue, 0.95th quantile), median (black) and minimum (red, 0.05th quantile) latitude of common stingray records per 5-year period. The minimum latitude of the study area is ~50°N. (B) Number of common stingray records by 4-degree latitude band per 25-year period. Red = 48 to 52°, black = 52 to 56°, blue = 56 to 60°. (C) The fraction of the total number of records from SE England. (D) The median reconstructed wet weight of stingrays (± 95% confidence intervals) per 10-year period. Points are only plotted for periods where the number of records n>5. The number of observations, N, is given below or above the data points. The indicated years the years at the start of a time period. X-axes differ between plots.

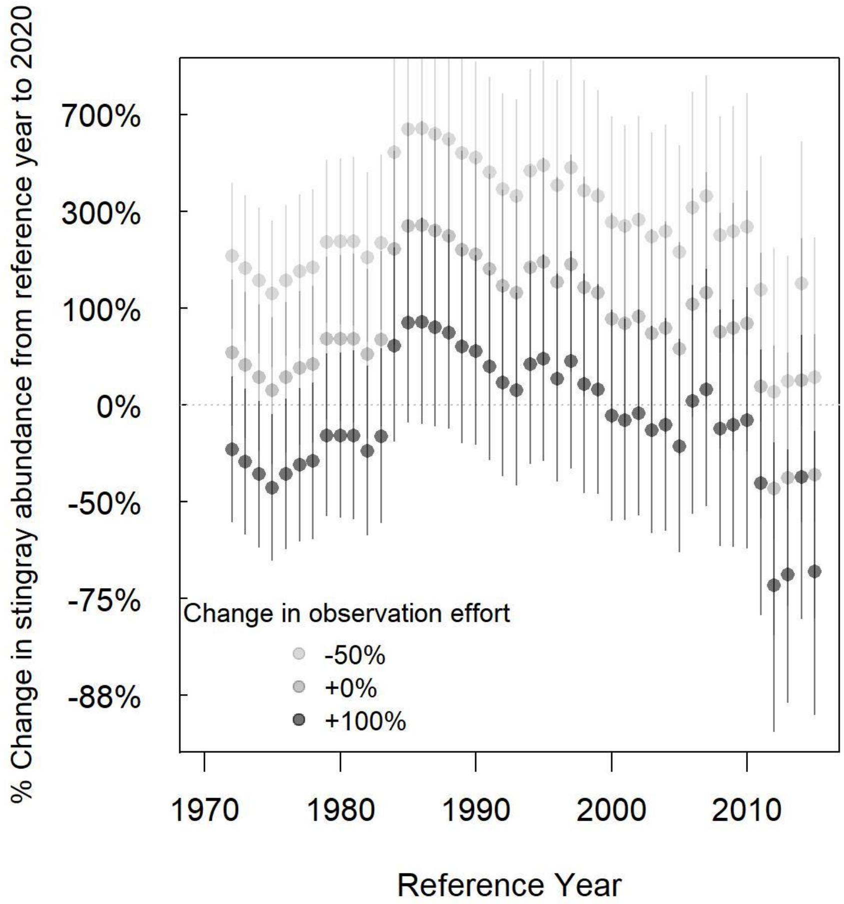

Figure 4. Estimates of the magnitude of changes in abundance of the common stingray in the UK using opportunistic data from multiple data sources, with 95% confidence bounds, between any chosen reference year and 2020, based on all reported observations. Different lines represent different assumed changes in observation effort.

Supplementary material

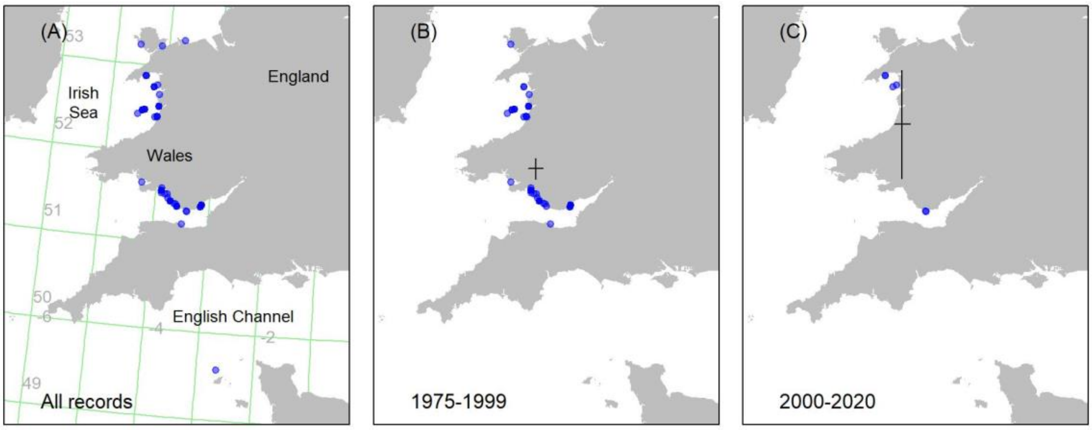

Figure S1. Angelshark distribution from magazine records only, extracted using the same methodology as for the common stingray. All records are plotted in transparent blue grey scale. This results in the most persistent observation locations being represented by more intense shades and individual isolated locations being represented by transparent dotspoints. (B–C) Distribution by 25-year period of angelshark. The 2000 onwards observation period is inevitably truncated and comprised of 20 years of records to 2020. The black crosses indicates the 95% confidence intervals around the mean latitude and longitude (centre of the cross) of all records for each period.

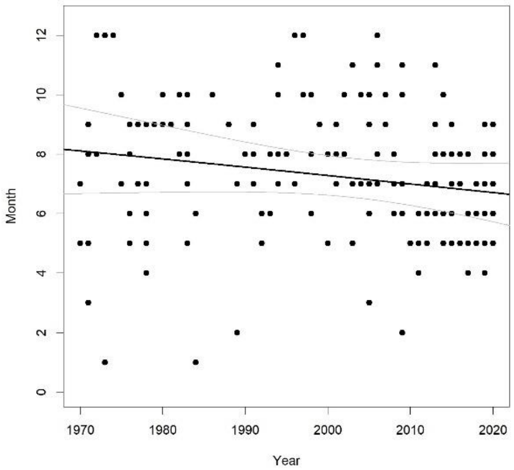

Figure S2. Month in which common stingray was recorded from 1970 onwards. The line indicates a binomial regression (because values are bounded between 1 and 12, converted to 0 to 1 for model fitting) with confidence intervals (GLM, $z_{1,265}$ = -1.318, p = 0.187). There was no significant change in the length of the sighting period over time (t_{47}=0.505, p=0.616).

Table S1. Information sources from which stingray records were compiled.

Source	**Link**	**Source category**
Chelmsford Weekly News	www.chelmsfordweeklynews.co.uk	News article
Daily Echo	www.dailyecho.co.uk	News article
East Anglian Daily Times	www.eadt.co.uk	News article
Express	www.express.co.uk	News article
Gazette News	www.gazette-news.co.uk	News article
ITV	www.itv.com	News article
Kent Online	www.kentonline.co.uk	News article
Planet Sea Fishing	www.planetseafishing.com	Forum
The News - Portsmouth	www.portsmouth.co.uk	News article
Press Reader	www.pressreader.com	News article
Veals Mail Order	www.veals.co.uk	News article
Wales Online	www.walesonline.co.uk	News article
West Sussex Today	www.westsussextoday.co.uk	News article
Archive	https://archive.org	Other
Biodiversity Library	www.biodiversitylibrary.org	Other
Angling Addicts	www.anglingaddicts.co.uk	Forum
Bristol Channel Federation of Sea Anglers (BCFSA)	www.bristolchannelfishing.com	Other
Charter Boats UK	www.charterboats-uk.co.uk	Other
British Marine Life Study Society	www.glaucus.org.uk	Other
World Sea Fishing	www.worldseafishing.com	Forum
Anchorman Charters	www.anchormancharters.co.uk	Other
The Database of Trawl Surveys	https://datras.ices.dk	Other
Fish UK	www.fish-uk.com	Forum
Freshwater Habitats	https://freshwaterhabitats.org.uk	Forum
National Biodiversity Network (NBN)	https://records.nbnatlas.org	Other

Natural History Museum (NHM)	https://data.nhm.ac.uk	Other
Norfolk Fishing	https://norfolkfishing.com	Forum
South-West Federation of Sea Angling (SWFSA)	https://swfsa.co.uk	Other
Underwater Fishing	www.underwaterfishing.co.uk	Forum
Wales Federation of Sea Anglers (WFSA)	https://www.wfsa.org.uk/	Other
Facebook (i.e., Natur Dyfi, BluePlanetSoc)	www.facebook.com	Social media
Tumblr	www.tumblr.com	Social media
Youtube	www.youtube.com	Social media
Instagram accounts (i.e., @southwalesfishing)	www.instagram.com	Social media
First Nature	www.first-nature.com	Forum
The Archive for Marine Species and Habitats Data (DASSH)	https://www.dassh.ac.uk/	Other