Fine-scale distribution and seasonality of harbour porpoises (*Phocoena phocoena*) investigated with citizen science

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ABSTRACT

Information on the distribution of harbour porpoises (*Phocoena phocoena*) in the Western Baltic has been obtained by passive acoustic monitoring, visual surveying and acoustic surveying. Here, we collected complementary data on the presence of porpoises around the Danish Island of Funen using citizen science. Porpoise sightings were reported with the custom-made mobile app 'Marine Tracker', disseminated to the public through community meetings, newspaper articles, radio interviews and posters. App users could choose between three types of reports: 'single porpoise', 'multiple porpoises' and 'mother & calf porpoises'. A total of 7,755 credible porpoise sightings were reported from Funen between 2019 and 2022. These observations were primarily concentrated around larger harbour towns, but also in less populated parts of southern Funen, which previously had not been recognised as a significant porpoise habitat. A high proportion of 'mother & calf' observations in this area may indicate its importance for future conservation efforts. Citizen science data provided insights into the spatial and temporal distribution of porpoises, particularly the timing and spatial distribution of 'mother & calf' pairs during summer months. Our study highlights the possibilities of citizen science as a tool to complement traditional surveying techniques to understand marine mammal distribution.

KEYWORDS: HARBOUR PORPOISE; CITIZEN SCIENCE; POPULATION MONITORING; TEMPORAL AND SPATIAL DISTRIBUTION

INTRODUCTION

The harbour porpoise (*Phocoena phocoena*) is the most common cetacean in the Western Baltic and the only cetacean species known to breed there (Wiemann *et al*., 2010; Lah *et al*., 2016). The Belt Sea population inhabiting the Western Baltic is listed as 'Vulnerable' on the HELCOM Red List, whereas the Baltic Sea population is listed as 'Critically Endangered' (Hammond *et al*., 2008; HELCOM, 2013; Braulik *et al*., 2020). A recent study based on large-scale European surveys indicated a yearly 2.7% decline in the Belt Sea population during the past decade (Owen *et al*., 2024), calling for continued monitoring of Danish harbour porpoises.

Over the past two decades, the abundance and distribution of harbour porpoises in this area have been examined by visual surveys from vessels or planes, satellite tracking of individuals and passive acoustic monitoring (e.g., Sveegaard *et al*., 2011; Lacey *et al*., 2022). These methods have strengths and weaknesses. Ship-based and

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aerial surveys may provide both abundance and distribution data, but the results only cover a short time span and are, at present, conducted every five to 10 years in this area (Viquerat *et al*., 2014; Unger *et al*., 2021; Forney *et al*., 2021; Sveegaard *et al*., 2022). Passive acoustic monitoring can be done from a moving vessel towing hydrophones (Sveegaard *et al*., 2011), or by stationary dataloggers deployed on the ocean floor (e.g., Benke *et al*., 2024). Acoustic loggers detect harbour porpoises within a range of a few hundred metres and therefore have limited spatial coverage but longer temporal coverage. Satellite tracking of tagged porpoises began in 1997 and has, since then, provided essential information on distribution for the designation of protected areas in Danish waters (Teilmann *et al*., 2008; Sveegaard *et al*., 2018). This information is based on individual movements and, although approx. 150 individual porpoises have been tagged since 1997, data from these animals may or may not be representative of the entire population.

Despite extensive studies on the Belt Sea population using various methods, important questions remain: Are all significant porpoise hotspots known, or could smaller, important local areas go undetected by current surveys? Are specific areas used for breeding and nursing? Answers to these questions could support the existing management and conservation efforts for harbour porpoises in the inner Danish waters. Conservation efforts in Danish waters are ongoing, with 28% designated as Natura 2000 areas. While these designations help prevent new disturbances, they do not currently mitigate existing ones, and most are not specifically designated for harbour porpoises. These designations protect the areas from new disturbances but do not currently address existing ones.

Citizen science (i.e., data collected by non-scientific members of the public) was introduced in the 1980s and has become an important supplement to wildlife conservation efforts (Haklay *et al*., 2021). Having volunteers collect and count flora and fauna offers some interesting possibilities for biological monitoring (e.g., Horne, 2013; Chandler *et al*., 2017; Lodi & Tardin, 2018). One concern when using citizen science is the quality of data, both in terms of how it is being sampled in time and space, but also regarding how observations are classified (Embling *et al*., 2015). Studies nonetheless show that citizen science data can be of high quality (Finger *et al*., 2023). Advancing citizen science methodology through online fora and specially designed mobile apps significantly boost data quality and quantity (Silverton, 2009; Kress *et al*., 2018; Garcia-Soto *et al*., 2021;).

For example, between 2000 and 2002, over 800 citizens collected 6,000 observations of whales in Danish waters as part of the Danish project *Fokus på hvaler* (Danish for *Focus on whales*), providing valuable data on harbour porpoise distribution, with high abundance in the Little Belt (Kinze *et al*., 2003). A German citizen science initiative has been ongoing since 2012, documenting sightings and strandings of multiple marine mammal species (Ocean Museum Germany) and contributing to distribution maps in the Baltic Sea.[5] In Ukraine, researchers have used citizen science methods to study the effects of military activities on dolphins (*Delphinus delphis* and *Tursiops truncatus*) and harbour porpoises (Węgrzyn *et al*., 2023). These initiatives highlight the potential for public participation to improve our understanding of marine mammal distribution and human impacts.

Here, we analysed observation data on harbour porpoises collected through citizen science methods around the Island of Funen in the inner Danish waters to investigate temporal and spatial distribution and possibly determine high-density hotspots. Data were gathered through a custom-made mobile app over a four-year period and resulted in over 7,700 porpoise sightings. We hypothesised that there would be detectable observer effort biases, with more porpoise detections during weekends and major summer vacation weeks. We also hypothesised that, despite these biases, it would be possible to detect temporal and spatial patterns for porpoises, with special emphasis on 'mother & calf' pairs.

MATERIALS & METHODS

The study area encompassed the coastal waters around the Danish island of Funen, located in the western Baltic. The island supports high densities of harbour porpoises; however, concerns have arisen due to a recent decline in this population (Sveegaard *et al*., 2011; Unger *et al*., 2021; Owen *et al*., 2024). Residents of Funen have ready access to coastal beaches, where many enjoy sailing and kayaking. Human populations are centred in small towns, with stretches of rural areas in between.

[5] *https://www.deutsches-meeresmuseum.de/en/science-research/news/map-of-sightings*

Our project, called *Fyn Finder Marsvin* (Danish for 'Funen Finds Porpoises'), gathered information from the public about porpoise distribution through a custom-made mobile phone app, Marine Tracker. The app, available for both Apple and Android devices, required user consent for location access, as it relied on the user's location to collect data. When starting the app, the user could select any of the following options to submit observations: 'single porpoise', 'multiple porpoises' or 'mother & calf porpoises'. Data entry was made as simple as possible to avoid tiring users and maximise the number of reports. When an observation was entered, the app automatically logged the date, time (±1 min) and GPS coordinates of the entry location (±5 m), along with selected observation category. This data was stored on a website and could be accessed and downloaded in a CSV file. The app also contained a map where users could observe sightings reported for the past three days.[6]

In April 2019, the Marine Tracker app was launched with a series of meetings for potential users. Eleven meetings took place between April and June 2019 in the larger towns on Funen: Middelfart, Odense, Svendborg and Kerteminde. These meetings attracted a range of participants, from four to over 30. The participants included seniors, people working in local areas and those who had a recreational interest in activities at sea. Some events took around 30 minutes, while others lasted a full day. The initiative was publicised across both print and broadcast media, including national and local newspapers, popular Danish science magazines and radio. For example, a regional radio broadcaster – Denmark's Radio Channel 4, Funen – agreed to provide information about the project with brief public service announcements in the spring of 2019, 2020 and 2021.

Data was downloaded from the open-source app database and extracted into Microsoft Excel. Further analyses were made in MatLab (ver. 2019b, MathWorks, Natick, MA, USA) and QGIS (ver. 3.28 Firenze, Free Software Foundation, Boston, USA). There is always a risk of erroneous observations being entered, both by typing errors and observations not entered at the location where the porpoise was observed. Double entries and observations occurring on land (defined as being more than 200 m from the water) were excluded using QGIS. Though a few observations were reported in other Danish waters and even in neighbouring countries, the majority of observations were made around Funen. In this analysis, we included data in a bufferzone, collected within a 15 km radius from the shoreline around the island of Funen. This area was chosen to encompass observations from boat and shore in the coastal region, including a 200 m inshore zone to capture coastal observations.

A two-sample F-test was conducted to test if porpoise observations correlated with municipality size. A t-test was used to test for significant differences in the number of observed 'mother & calf' pairs between summer (June, July and August) and non-summer months. An exponential model was used to test differences between any increase in 'mother & calf' observations and multiple porpoise observations. A p-value of 0.05 was used for statistical significance.

RESULTS

A total of 13,883 porpoise sightings were reported with the Marine Tracker app from April 2019 to December 2022. After filtering out double entries and locations on land, a total of 7,755 sightings remained (Table 1). Over the course of the project, the frequency of reports declined, with 2,960 observations April–December 2019 and 1,030 observations the final year (2022).

Spatial distribution

Porpoise sightings were widely distributed around Funen (Fig. 1). The majority of observations over the four years were single individuals (range = 45–48%), followed by multiple individuals (range = 34–38%) and 'mother & calf' pairs (range = 17–19%; Table 1). Single porpoise sightings were dispersed along the Funen shoreline, with dense concentrations near key harbour towns and the southern region (Fig. 1A). Multiple porpoise sightings were also widespread along the coastline, with an area of low density in the northern part, high density along the entire Middelfart coastline, and smaller peaks near other larger towns (Fig. 1B). 'Mother & calf' observations were also widely distributed around the island, with lower densities observed in the northern part of Funen

[6] *https://marinebiologicalresearch.firebaseapp.com/*

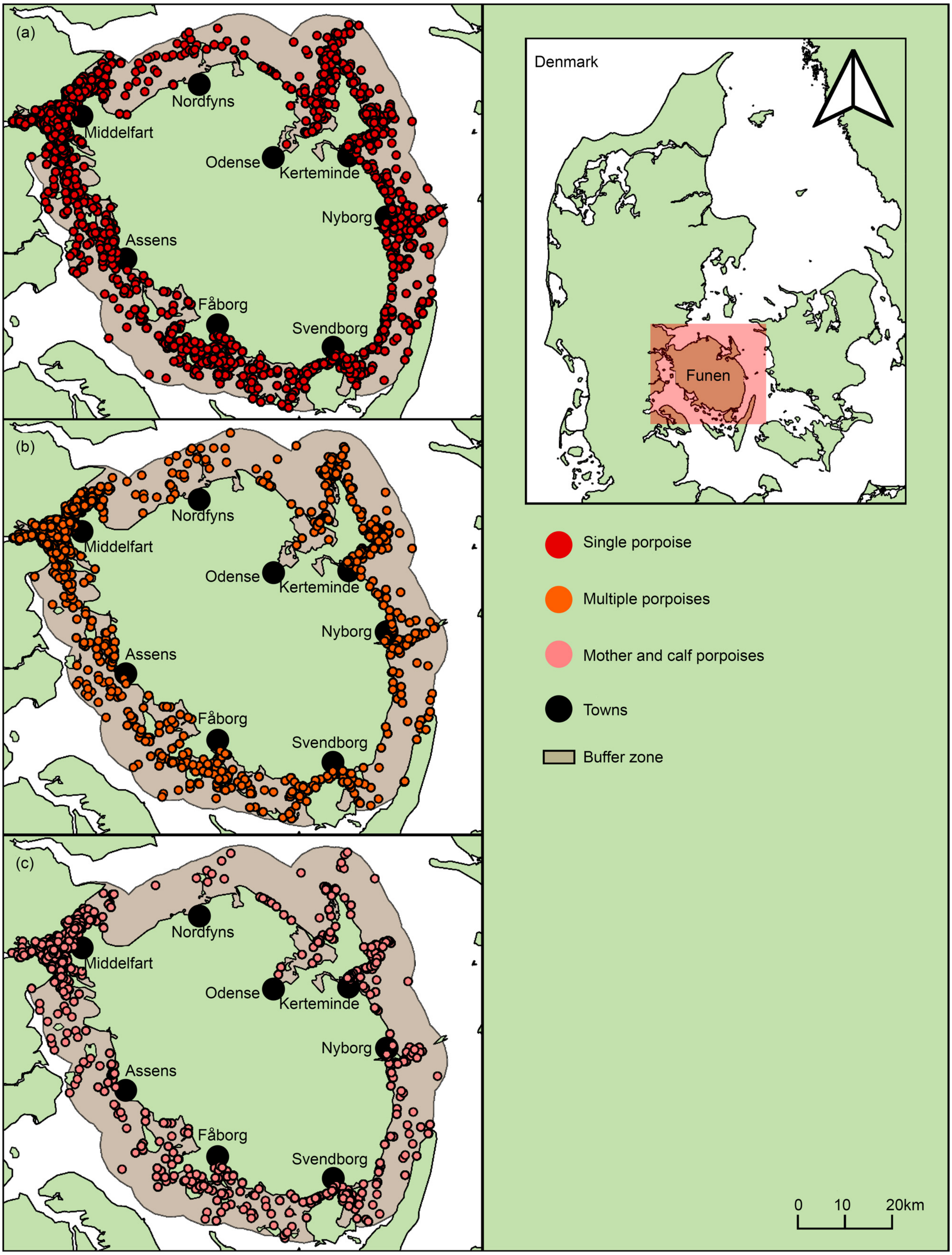

Figure 1. Porpoise observations reported with the Marine Tracker app (April 2019–December 2022). A–C) Spatial distribution of porpoise sightings within 15 km from the Funen shoreline, categorised as: A) 'single porpoise'; B) 'multiple porpoises'; and C) 'mother & calf' porpoises. Duplicate entries have been excluded.

(Fig. 1C). 'Mother & calf' sighting density was higher in sheltered waters, such as the fjords of Middelfart, Kerteminde, Svendborg and Nyborg (Fig. 1C).

Most observations (58%) were located within the municipality of Middelfart (Fig. 3). The number of observations in a municipality were not correlated with either its number of inhabitants (F-test, d.f. = 6, p = 0.72) or its size (F-test, d.f. = 5, p = 0.49).

Temporal distribution

Most sightings were reported during daylight, with a few occurring right after sunset and very few during dawn. The weekly number of observations increased during Week 23 (beginning of June) and again from Week 29 for about four weeks (mid-July to the beginning of August; Fig. 2A–B). In the first week of January and the second last week of November, there were no porpoises observed (Weeks 1 and 47). In general, from late August to late March the total number of observations are below 12 porpoises per week (Weeks 35–16).

There was a substantial increase in 'mother & calf' sightings in mid-June every year (Fig. 2A), and the share of 'mother & calf' relative total number of sightings was significantly higher during summer months (June to

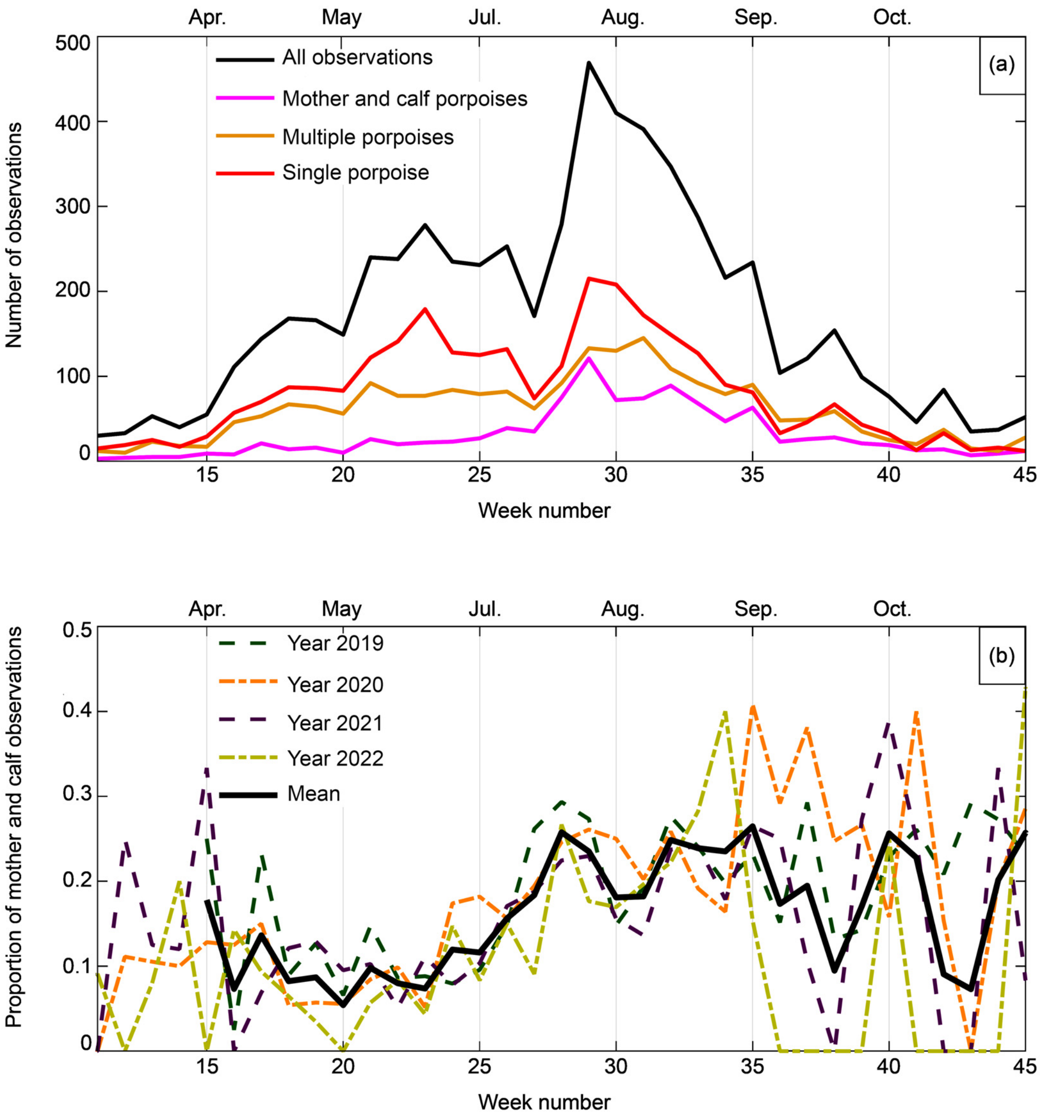

Figure 2. Temporal visualisation of porpoise observations reported via the Marine Tracker app. Weeks in lower x-axis and months in upper x-axis, starting with January as Month 1, Week 1–4, ending with December as Month 12, Week 50–52. A) Weekly distribution of each type of porpoise sightings around Funen. Data is combined from 2019 to 2022, starting January 1st. B) Proportion of 'mother & calf porpoises' observations (i.e., the fraction of total observations) from years 2019 to 2022, with the mean shown in black (Week 25).

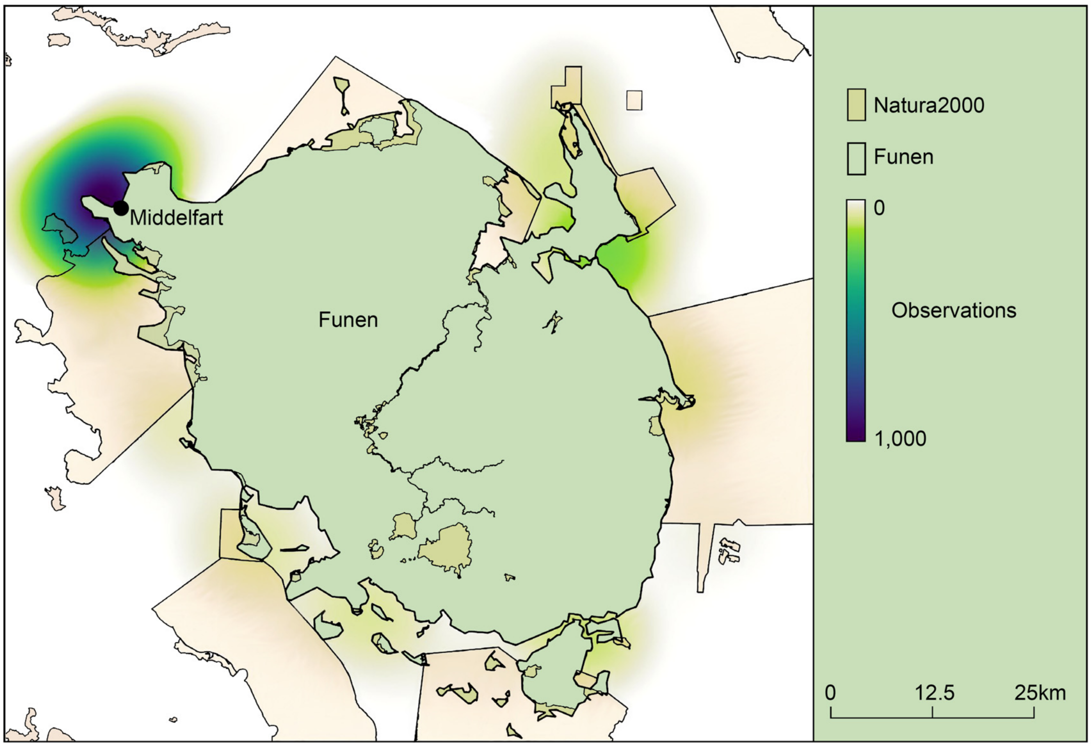

Figure 3. Density map of all observations reported with the Marine Tracker app. The map shows Funen, Denmark, and the protected Natura 2000 areas on and around Funen. Areas with higher porpoise sighting densities are darker blue, and lower porpoise sighting densities are lighter in colour.

September) than during the rest of the year (t-test, d.f. = 11, $p = 0.04$, Fig. 2B). In Week 23 (start of June), 'mother & calf' observations accounted for less than 1% of the total number of observations, which increased to 27% in Week 28 (mid-July; Fig. 2A–B). There was a significant exponential relationship between sightings of multiple porpoises and 'mother & calf' observations (adjusted $R^2 = 0.76$, $y = 2.77 \cdot e^{0.03x}$, F-test, $F = 12.3$, d.f. = 46, $p < 0.001$), indicating that, for every 100 additional 'mother & calf' observations, sightings of multiple porpoises would increase by approximately 30 sightings. The proportion of 'mother & calf' pairs among all observations reveal an increase beginning in May (Fig. 2B). In 2020, 'mother & calf' observations accounted for more than 40% of all porpoise sightings in September and late October. For the same period in 2022, there were no 'mother & calf' observations (Fig. 2B).

DISCUSSION

Spatial & temporal distribution

Our study provides new insights into the spatial and temporal distribution of harbour porpoises around the island of Funen. Porpoises were frequently observed in fjords and inlets, likely seeking shelter and abundant small prey fish, including Atlantic cod (*Gadus morhua*), herring (*Clupea harengus*) and gobies (*Gobiidae*) (Sørensen & Kinze 1994; Santos & Pierce, 2003; Read *et al.*, 2025). This may explain the higher number of sightings in southern and western Funen, where waters are more protected, compared to the more exposed northern coast with fewer observations (Fig. 1). Additionally, the southern side of Funen, being more sheltered, offers better observation conditions from shore. Distributional variations are important to inform conservation measures, as increases in the number of observations may help to identify critical habitats.

The timing of observations (Fig. 2A) closely follows the predicted density of potential observers in coastal areas – both diel and seasonal. Peaks in observations occurred around Week 23 (Danish Constitution Day) and Week 29 (Summer holiday). Observers staying longer after sunset or delaying submissions until after leaving the beach may explain why there were more late evening observations compared to early morning ones. The increase of observations during summer is readily explained by the typical seasonal human presence in coastal areas. The prevalence of single porpoise reports over multiple individual reports is consistent with previous observations of group size in this species (e.g., Jefferson *et al*., 2016; Elliser *et al*., 2018).

Hotspots

Most porpoises were observed near the town of Middelfart in the Little Belt area. Kinze *et al*. (2003) similarly reported the highest number of observations in this area. Despite multiple other factors influencing observations in the Middelfart region, such as vantage points from bridges, narrow passages enabling observations from two coastlines, project dissemination efforts and porpoise-watching tours, the extremely high number of observations per inhabitant suggests that Little Belt is a hotspot for porpoises. Similar conclusions were reached by acoustic survey efforts (Sveegaard *et al*., 2011), yet this section of Little Belt is not designated as a protected Natura 2000 area (Fig. 3). Our data strongly support the need for conservation efforts in this area. The second highest number of observations occurred in the waters of Kerteminde, where the Fjord&Bælt marine science centre hosts captive harbour porpoises, and both the local citizens and visitors are highly aware of porpoises (Wahlberg *et al*., 2023).

Mother & calf porpoises

The observations of 'mother & calf' pairs around Funen provide additional details about their temporal and spatial distribution. Notably, there was an increase (27%) in sightings during the summer months, starting in June and peaking in mid-July (Fig. 2B). These observations align with porpoise calving, which peaks in June–July (Sørensen & Kinze, 1994; Lockyer & Kinze, 2003). The proportion of observed 'mother & calf' pairs remains high until December, despite a decrease in the total number of observations (Fig. 2A–B). This is consistent with findings that calves stay with their mothers for 8–12 months after birth (Møhl-Hansen, 1954; Read, 1990; Sørensen & Kinze, 1994). The spatial distribution shows that 'mother & calf' pairs are frequently observed in fjords, likely due to the abundant food supply and shelter these environments provide, indicated by the high densities reported in Kerteminde Fjord, Svendborg Fjord and especially Middelfart (Fig. 1C).

Observation trends

Approximately one-third of all observations were reported in 2019, with numbers steadily decreasing in subsequent years (Table 1). This decline may be attributed to the initial media attention in 2019, as well as the impact of the COVID-19 pandemic, which resulted in societal lockdowns and reduced dissemination efforts from March 2020 to Summer 2021. Our observed decline aligns with data from the Ocean Museum Germany's interactive map, which shows a drop in reported sightings of live porpoises in the Baltic Sea from 1,454 in 2019 to 864 in 2021 (Ocean Museum Germany). However, these data represent a different region and population of porpoises than those in our study. Sustaining citizen engagement has also proven challenging in other citizen science projects (Hann *et al*., 2018). A 2.7% annual decline in the Belt Sea porpoise population over 18 years, as evidenced by Owen *et al*. (2024), may also contribute to the reduction in reported sightings.

Table 1

Porpoise observations reported with the app *Marine Tracker.*
The percentages of single, multiple, and mother and calf porpoise sightings are given for each year.

Year	Single porpoise	Multiple porpoises	Mother and calf porpoises	Total
2019	1,417 (48%)	996 (34%)	547 (18%)	2,960
2020	1,024 (47%)	740 (34%)	430 (19%)	2,194
2021	709 (45%)	603 (38%)	259 (17%)	1,571
2022	495 (48%)	354 (34%)	181 (18%)	1,030
Total	3,645	2,693	1,417	7,755

Citizen science methodology

The interdisciplinary nature of this study underscores the importance of collaboration between researchers and the public. Incorporating the 10 Principles of Citizen Science (ECSA, 2015) is crucial to reduce biased reporting and ensure observer credibility. Key principles include active citizen involvement, publicly available outcomes, mutual benefits for scientists and citizens, and participant feedback (ECSA, 2015). Additional measures, such as providing instructions upon initial app use, can further enhance data reliability (Clare *et al*., 2019; Sandahl & Tøttrup, 2020; Gutiérrez-Muñoz *et al*., 2021; Jäckel *et al*., 2023).

Study limitations

Citizen science faces multiple well-known challenges, such as reporting biases, repeated sightings and species misidentification (Frigerio *et al*., 2021). In this study, harbour seals (*Phoca vitulina*) and cormorants (*Phalacrocorax carbo*) may have been mistaken for porpoises, affecting data accuracy. Misclassifications can also occur when 'mother & calf' pairs are accompanied by opportunistic males (Jefferson *et al*., 2016; Elliser *et al*., 2018) or when older calves resemble adults, leading to 'multiple porpoises' classifications instead of 'mother & calf porpoises'. This is reflected in the strong correlation between these two categories in our data.

Another issue with our dataset is that it represents locations where people reported observing porpoises, rather than unbiased reports of confirmed porpoise presence. This distinction underscores a key limitation in citizen science data, requiring careful consideration when interpreting the results and creating distribution maps. On the other hand, citizen science data can help pinpoint areas where a specimen is found despite being missed when using traditional surveying techniques. In our dataset, this was evident from the many sightings we obtained from the southern Funen coast, where previous surveys had not indicated a porpoise presence.

The 'presence-only' approach used in our app design, categorising sightings without detailed information, could compromise the quality of reported data. Offering multiple input options and better citizen training, as done by Garcia-Cegarra *et al.* (2021), can improve data accuracy. Their study on the coast of northern Chile found that using photos improved data accuracy, as both trained and untrained participants reported more accurate sightings with additional visual inputs. In Denmark, where porpoises are the only regularly observed cetaceans, the app was kept simple to maximise participation. Additionally, Denmark's Data Protection Regulation prevented us from saving citizens' information, thereby limiting our ability to assess different methodologies' impacts on the quality of observations. Future studies could combine methodologies, such as Rodriguez *et al*. (2021), who integrated citizen science with passive acoustic monitoring to map dolphin distributions and correlate occurrences with tidal patterns.

Monitoring porpoises with citizen science

Despite its limitations, citizen science enables cost-effective and long-term monitoring which complements existing harbour porpoise survey methods. Our results align with traditional observation data (Kinze *et al.* 2003; Sveegaard *et al*., 2011; Gilles *et al*., 2023) and offer detailed spatiotemporal insights, particularly on 'mother & calf' pairs around Funen—information often missed by standard surveys. With proper quality controls, citizen science can be a vital tool for porpoise conservation in Denmark and beyond. Cross-border coordination will be increasingly important, especially for shared populations, such as the porpoises of Denmark and Germany.

Conclusion

Our study enhances the understanding of porpoise distribution along the Funen shoreline, identifying spatial and temporal patterns and potential porpoise hotspots in the south. While no direct link was found between sightings and human population size or municipality area, other factors likely play a role. Proximity to fjords may create favourable habitats with calmer waters and abundant prey, while engagement and awareness campaigns influence reporting rates. Even though data validation challenges exist, our findings align with traditional survey methods. This interdisciplinary approach underscores the value of researcher-citizen collaboration and demonstrates how integrating diverse datasets can improve ecological insights and public engagement.

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