



Opportunistic data for assessing abundance and site fidelity of fin whales (*Balaenoptera physalus*) in the Faro area, Portugal

Ginevra Gennari^{1,2} · Alfredo Rodrigues³ · Pedro Carvalho³ · Susana Gil³ · Ramiro Magno⁴ · Rita Castillo^{1,2,4} · Rui Peres dos Santos^{1,2,4,5}

Received: 6 November 2025 / Accepted: 2 March 2026 / Published online: 11 May 2026
© The Author(s) 2026

Abstract

The distribution and migration of fin whales (*Balaenoptera physalus*) remain poorly understood in parts of the North Atlantic. One of these regions is the Algarve in southern Portugal, which is shaped by seasonal upwelling and the exchange of Atlantic and Mediterranean waters. This area represents a potentially critical yet poorly understood habitat for this species. This study presents the first comprehensive assessment of fin whale abundance and site fidelity in the Faro area, located approximately between 36–37° N and 8–7° W. Data was collected from 2020 to 2024 through photo-identification and GPS vessel tracks, in collaboration with a local whale-watching company. A regional catalog of 86 individuals was established, and an open spatially explicit capture-recapture model estimated a population of 1.476 individuals. Sightings peaked in spring, likely linked to phytoplankton blooms and foraging opportunities. While re-sighting rates were low, some individuals returned across years, indicating possible seasonal site fidelity. Our results demonstrate the value of data collected from platforms of opportunity in an under-surveyed region, providing a foundation for ongoing monitoring efforts. Results also highlight the Faro area's ecological relevance as a seasonal feeding ground for fin whales and offer insights to support future conservation in the eastern North Atlantic.

Keywords Algarve · Capture-recapture · Photo-identification · Whale-watching

Introduction

Abundance, defined as the number of individuals within a population (Marr 1951), is a fundamental parameter for ecosystem assessment and wildlife conservation strategies, serving as an essential metric for evaluating population status, monitoring trends, and identifying drivers of population growth or decline (Bonebrake et al. 2010; Tardy et al. 2023; Callaghan et al. 2024). The earliest attempts to estimate

marine mammal population sizes emerged in the 1960s, when researchers involved shore-based counts of the Eastern North Pacific stock of gray whales (*Eschrichtius robustus*) (Laake and Punt 2023); sea survey data to assess ringed seal (*Pusa hispida*) numbers (McLauren 1961) and ground-surveyed colonies of gray seal (*Halichoerus grypus*) pups to gauge the population (Russel et al. 2019). The advent of photo-identification techniques for individual cetaceans in the 1970s made it possible to apply mark-recapture methods to estimate cetacean abundance using natural markings. This approach was soon used for species such as humpback whales (*Megaptera novaeangliae*), southern right whales (*Eubalaena australis*), killer whales (*Orcinus orca*) as well as bottlenose dolphins (*Tursiops truncatus*) (Bigg 1982; Whitehead 1982; Hammond et al. 2021). However, detecting trends in marine wildlife populations has long been recognized as a challenge, particularly for broad-scale surveys of oceanic species, like cetaceans. Their biological and behavioral characteristics, such as spending most of their time submerged and ranging across vast distances, make data collection logistically challenging and even more

Responsible Editor: U. Siebert.

✉ Ginevra Gennari
ginevragennari@gmail.com

- 1 University of Algarve, Campus de Gambelas, Faro, Portugal
- 2 Centre of Marine Sciences (CCMAR/CIMAR LA), Campus de Gambelas, Faro, Portugal
- 3 OceanVibes Algarve, Faro, Portugal
- 4 Pattern Institute, Faro, Portugal
- 5 Mingan Island Cetacean Study (MICS), QC, Canada

difficult to estimate abundance among these species (Kaschner et al. 2012; Pace et al. 2017; Stephenson et al. 2021; Geelhoed et al. 2022).

Among cetaceans, the fin whale (*Balaenoptera physalus*) has experienced some of the most dramatic fluctuations in abundance over the past 200 years (Schleimer et al. 2019). During the commercial whaling era (approximately 1890–1980), more than 900,000 fin whales were harvested globally, resulting in a population decline of over 70% (Edwards et al. 2015). Fin whale abundance in the post-whaling era appears to have increased off the west coast of the USA, along the coast of western Greenland, in the Northeast and Central Atlantic, and the northern Gulf of Alaska (Edwards et al. 2015). However, in other regions, the extent of their recovery remains uncertain due to limited data (Edwards et al. 2015). In 2018, the total abundance of this species was estimated at approximately 79,000 individuals in the North Atlantic, and it remains classified as 'Vulnerable' on the IUCN Red List of Threatened Species (Cooke 2018). Despite fin whale is a widely distributed and long-lived species inhabiting warm to cold oceans globally, most studies report a hiatus in its distribution between 20°N and 20° S (Edwards et al. 2015). Fin whales in the central and eastern North Atlantic undertake long-distance migrations between summer high-latitude feeding grounds and winter low-latitude breeding grounds (Lydersen et al. 2020). While densities generally shift northward in spring and southward in fall and winter, individuals continue to occur at higher latitudes even during winter months in the North Atlantic (Ramp et al. 2024). Within this basin, seven fin whale stocks are currently recognized by the North Atlantic Marine Mammal Commission (NAMMCO): Eastern Canada, Western Greenland, three partially mixing central stocks (Eastern Greenland, Western Iceland and Eastern Iceland/Faroe Islands), Norway, and Spain. Morphometric and genetic evidence further suggests that at least the Northwest Atlantic and Northeast Atlantic represent distinct populations (Lydersen et al. 2020). However, numerous exceptions to these migration patterns have been documented (Falcone et al. 2022). Year-round resident populations with limited or variable migratory patterns have been recorded in the semi-enclosed, warm waters of the Gulf of California (Bérubé et al. 2002; López et al. 2019) and the Mediterranean Sea (Notarbartolo-di-sciana et al. 2003; Castellote et al. 2011; Geijer et al. 2016). While fin whales are known to range across the entire North Atlantic basin, they also exhibit strong site fidelity to specific feeding grounds, suggesting regional variations in population dynamics and highlighting the importance of long-term, small-scale studies (Schleimer et al. 2019).

Understanding these dynamics is crucial for estimating population trajectories, which have been approached

through analyses that integrate abundance estimates with harvest statistics and other relevant data (Biuw et al. 2024). There are two primary methods for measuring abundance: line-transect surveys and capture-recapture methods. Vessel line-transect methods (Burnham and Anderson 1976) have been widely used to estimate whale abundance, including for Antarctic minke whales, fin whales in the North Atlantic, and baleen whales in the North Pacific (Calambokidis and Barlow 2004; Barlow et al. 2011; Vikingsson et al. 2013; Leonard and Øien 2020). These methods require measuring the perpendicular distances of animals from the survey track, with representative coverage typically achieved through systematic transect lines that uniformly span the study area (Norris et al. 2017).

Capture-recapture (or mark-recapture) techniques rely on the ability to uniquely identify and track individuals based on photographs of their natural markings, where re-sightings of marked individuals are used to calculate abundance (Dawson et al. 2008; Bertulli et al. 2018; Schleimer et al. 2019). The choice of method depends on whether the population being studied is closed, remaining unchanged during the investigation, or open, subject to changes through birth, death, and migration (Schwarz and Seber 1999). Within this field of research, Spatially Explicit Capture-Recapture (SECR) models are increasingly being utilized for abundance estimation, offering a key advantage over non-spatial methods by mitigating the edge effect (i.e., temporary immigration/emigration) (Efford and Boulanger 2019). For cetaceans, most capture-recapture methods rely on individual identification, which is typically achieved through one of three approaches: satellite telemetry (Sepúlveda et al. 2018; Andrews et al. 2019), genotyping (Palsbøll et al. 1997), and photo-identification (Photo-ID) (Hammond 1990). These methodologies typically rely on data collected from vessel-based or aerial surveys, which are highly resource-intensive and require extensive data collection over many years, making them costly (Tyne et al. 2016; Bertulli et al. 2018). To mitigate this, whale-watching (WW) has emerged as a valuable source of opportunistic data (Peres dos Santos et al. 2025), where observations are gathered during regular tours with paying customers. In this context, the photo-identification technique is commonly used, allowing individuals to be identified based on natural markings, with the collected photos processed to obtain individual resighting over time (Würsig and Würsig 1977).

Between 1998 and 2008, WW experienced significant growth in Portugal, accounting for approximately 23% of total revenues in Europe, the highest share on the continent (Forli et al. 2024). Of the 90 licensed WW companies in mainland Portuguese waters, 52 operate along the southern coast, known as the Algarve region (Forli et al. 2024). Despite intensive WW in the Algarve region, dedicated

survey efforts to cetacean species have been limited, and information regarding their occurrence, spatial distribution, habitat preferences, and abundance remains scarce (Correia et al. 2014; Cartagena-Matos et al. 2021).

We hypothesize that fin whales show seasonal site fidelity in the Algarve, with higher occurrence during spring months, and WW vessels can provide valuable insights into their distribution, movement patterns, and abundance. This study aims to provide a baseline understanding of the status of fin whales in the Faro area (central region of the Algarve coastal waters) using opportunistic data collection from WW, specifically photo-identification and vessel tracks. First, a fin whale catalog is created, and the population size is estimated during consecutive years. Second, the degree of site fidelity and movement patterns is assessed during successive years and different seasons. Finally, this study evaluates the effectiveness of opportunistic data collection from WW vessels as a cost-efficient alternative for long-term monitoring of fin whale populations within the Faro area.

Material and methods

Study area

The researched Faro area is situated along the southwestern coast of the Iberian Peninsula, in the Algarve region, extending from 36.7° N to 37.1° N and from 7.6° W to 8.4° W, encompassing approximately 2,700 km² (Fig. 1A). Off-shore waves affecting the Algarve shore are driven by SW and SE components, and they originate from the Atlantic or the area between Gibraltar and the coast (Vicente et al.

2008). The southern boundary of the Iberian upwelling is separated from the Northwest African upwelling by the Gulf of Cádiz and the entrance to the Mediterranean Sea (Relvas and Barton 2002). During summer, the establishment of a thermally induced low-pressure center over the Iberian Peninsula generates westerly winds off the southern Portuguese coast, driving local upwelling in this area (Ferreira et al. 2022).

Data collection

Data collection took place year-round during whale-watching trips operated by Ocean Vibes WW, including daily excursions with customers and dedicated scientific surveys. Customer trips averaged 2.5 h, with up to three departures per day during peak season. Scientific surveys typically ranged from 3.5 to 4 h and were conducted without a fixed schedule, depending on the weekly operational plan. Fin whale photo-ID images were collected from 2020 to 2024, while vessel tracks were automatically recorded every 15 s for the entire duration of the trips, for the years 2021 (from August onwards) to 2024 (Fig. 1B). Survey efforts were weather-dependent, and operations were suspended when marine weather conditions were not suitable. Fin whale sightings were documented from the vessel, with trained observers gathering data. When a fin whale was sighted, photo-IDs (chevron and dorsal fin) were collected for individual identification using a Canon 7D and an objective 70–300 mm Tamron. During dedicated scientific surveys, aerial images of the body, chevron, and peduncle were also taken whenever possible at 20 m altitude from the animal, using the drone DJI Mini 2. Sightings data were annotated to document the date, vessel trip number, sighting number, time,

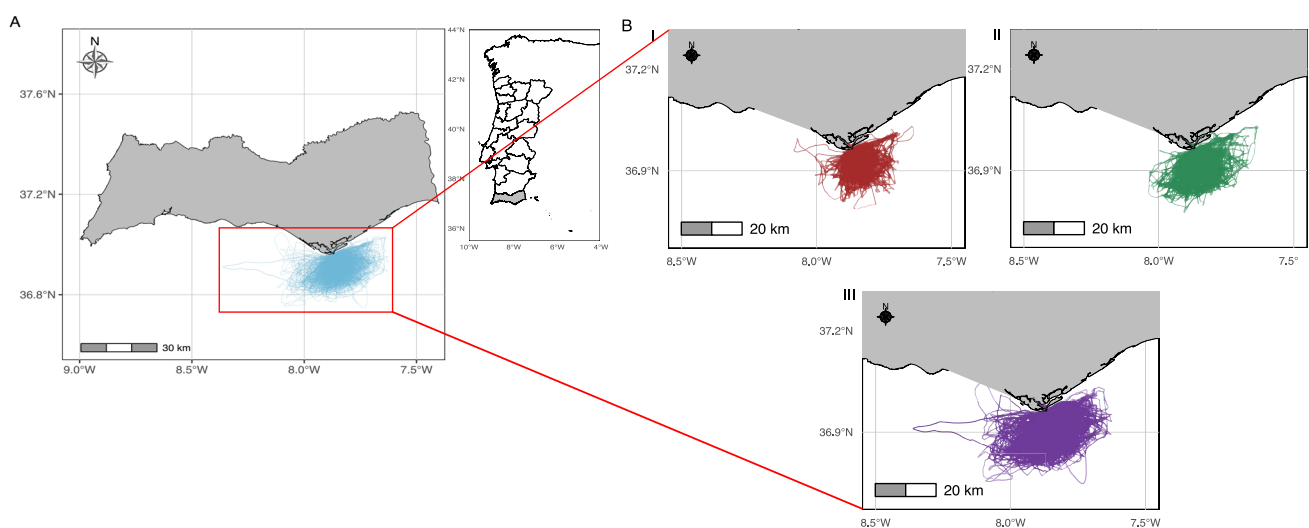


Fig. 1 (A) Map of the Algarve region, shaded in gray with the red box highlighting the study area off the coast of Faro. In blue, the vessel tracks recorded during whale-watching trips from 2022 to 2024. The

top-right inset shows the location of the Algarve on the Portuguese mainland. (B) Each panel represents the vessel tracks recorded in a different year: (I) 2022 in red, (II) 2023 in green, (III) 2024 in violet

the presence of other species, the clue that enabled the animal detection (e.g., birds, blow) and the animal behaviors (Table 1).

Photograph identification

Photo identification of fin whales (Hammond et al. 1990) primarily relies on identifying distinctive features such as notches, nicks, and disfigurements of the dorsal fins, along with the chevron–blaze patterns on their right side and the left body portion visible during surfacing sequences (Aglar et al. 1990; Ramp et al. 2020). All the fin whale photo-ID images taken between 2020 and 2024 were renamed with a standardized identifying label that included the WW company abbreviation, the date, the region, and the picture number, as in the following example: OVB.2024–05-18.ALG.7183. Each picture was cropped to a 2:1 aspect ratio, ensuring that no important parts of the animal were removed. The photos were then imported and analyzed using MICS-PIX, a web-based, multi-species software for processing, matching, and storing digital photo-identification images (Paquet et al. 2009). Before uploading to MICS-PIX, dorsal fin photographs were categorized into nine groups based on their shape and marks (1-Hocked; 2-Pointy Tip; 3-Classic; 4-Broad tip; 5-Triangular; 6-With notch; 7-With prominent notch; 8-Deformation/Amputation; 9-Unknown) (Paquet et al. 2009). More information about each individual was added, including location, exact GPS coordinates when available, whether the individual was a calf, and other relevant comments. Lastly, each photo was assigned a quality rating, starting with ‘Cat*’, meaning the best possible quality, and going down to the letter C or D for poor-quality photos. After the importation of MICS-PIX, three independent researchers verified and confirmed the distinguishing features of each individual. In the case of no matches for a

picture, a code number was given to that individual in the catalogue; if a match was found, both pictures were assigned to the same code.

Open population capture-recapture analysis

The R package *openCR* (open population capture-recapture) (Efford 2024) was employed to estimate population density, fitting an open-population spatial model based on the Jolly-Seber Schwarz-Arnason (JSSA) framework (Jolly 1965; Seber 1965; Schwarz and Arnason 1996), accounting for temporary immigration, emigration, births, and deaths of individuals. The parameters estimated were super-population density (superD), the detection function intercept (λ_0), and detection function scale (σ). Super-population density refers to the number of animals found within a particular area, with each animal assumed to have an activity center and a central location. Since animals are more likely to be detected close to this center and less likely to be seen farther away, estimating density requires considering the spatial nature of the sampling process (Efford 2025b). The detection function intercept indicates the probability of detecting an individual when its activity center is located directly at a detector. Lastly, the detection function scale describes how the detection probability decreases with increasing distance from the activity center. Because fin whale sightings were recorded during vessel-based surveys spread across the study area, we created a virtual grid with 1 km² cell resolution. Grid cells were treated as traps, with encounter histories constructed based on the presence or absence of individuals within each cell during specific sampling occasions. Cells were classified as ‘active’ if visited by a vessel during a survey, and ‘inactive’ if not. Each detection event was geo-referenced by assigning it to the centroid of the corresponding grid cell. Similarly, the presence or absence of individuals was linked to the coordinates of the grid cell’s center point, resulting in a geo-referenced encounter history.

Due to data limitations, the years 2020 and 2021 were excluded from the capture-recapture model. In 2020, vessel tracks were not available, while in 2021, they were only partially recorded. Additionally, individuals without geographic coordinates were also excluded from the analysis.

Software and packages

Statistical analyses were conducted using the R statistical software (R Core Team 2023). In addition to the *openCR* (version 2.2.7) (Efford 2024) and *secr* (version 5.2.1) (Efford 2025a) packages, other relevant packages were employed, including the *tidyverse* (version 2.0.0) suite (Wickham et al. 2019), *ggplot2* (version 3.5.1) (Wickham 2016) for advanced plotting, *ggspatial* (version 1.1.9)

Table 1 Overview of the animal behaviors documented in our study (Arranz et al. 2021; Sprogis et al. 2023; Keen et al. 2024; Rychwalski and Herr 2024; Peres dos Santos et al. 2025)

Behavior	Description
Feeding/Foraging	Feeding: dynamic open-mouth pursuit and subsequent engulfment of preys in a single massive gulp Foraging: strategies that animals use to search for and aggregate preys
Logging/Resting	Logging: animals remained motionless on the surface with no other behavioral events visible Resting: low activity level on the surface, moving slowly with relaxed ventilation and uncommon or absent dives
Milling	Active animals, but with no directed course and no indication of feeding
Travelling	Constant movement in the same direction, regular and relatively brief dive intervals, and relatively brief surfacing

(Dunnington 2017) for spatial data visualization, and the R compendium *azores.fkw* (version 1.0.0) (Peres dos Santos et al. 2025) for the capture-recapture model.

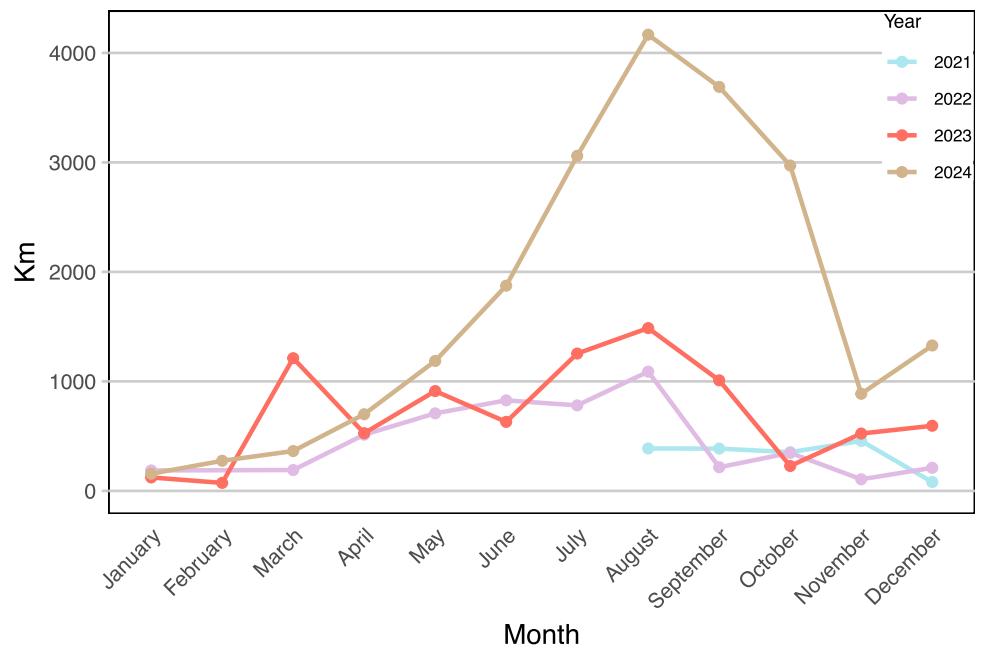
Results

Descriptive analysis

A total of 881 trips were conducted from 2021 to 2024, as no effort data were available for 2020, resulting in a total of 36.072 km (Fig. 2). The year 2024 contributed the highest monthly total with 20.658 km, followed by 2023 with 8.573 km, 2022 with 5.176 km, and finally 2021 with 1.665 km. In 2022 and 2024, the trend was similar: kilometers increased during spring and peaked in August, the month with the highest recorded distances of the year (1.089 km and 4.166 km respectively). In both years, a general downward trend was then observed during autumn and winter. In contrast, 2023 did not follow a clear pattern, with the largest increase occurring in August and in March and May. Data for 2021 covers the period from August onward, preventing observation of a whole annual trend.

Throughout the study period, 170 fin whale sightings were recorded. Fin whales were recorded in every month of the year (Fig. 3). January and October had the lowest number of observations, with only one sighting each month, followed by July, which had three sightings. Sightings increased noticeably in February and March, with 17 and 16 observations respectively, and continued to rise through spring, reaching 40 in April and peaking in May with 51 sightings, the highest monthly total.

Fig. 2 Monthly kilometers covered per year from 2021 to 2024



All observed behaviors registered in our study followed a similar annual pattern, with a main peak between April and May and a secondary, smaller peak in August (Fig. 4). Among them, feeding/foraging was the most frequently recorded, with 75 observations out of 170, showing a sharp peak in May and followed by a noticeable decline through summer and autumn. Travelling was the second most common behavior, with 30 observations out of 170. Other behaviors, such as logging/resting and milling, showed lower frequencies throughout the year.

Fin whales were observed in 24% of all sightings in mixed-species groups. The most associated species was the short-beaked common dolphin (*Delphinus delphis*), present in 68% of the mixed-species encounters (Fig. 5). Common bottlenose dolphins (*Tursiops truncatus*) and common minke whales (*Balaenoptera acutorostrata*) were observed in 15% and 10% of the mixed-species groups, respectively. Striped dolphins (*Stenella coeruleoalba*) appeared in 4% of the cases, while sei whales (*Balaenoptera borealis*) were recorded in 2%. April stood out as a key month for species associations, with the highest number of mixed-species encounters. Notably, common dolphin was the only species observed in association with fin whales nearly every month, excluding only October and December. The only months in which no fin whale sightings in mixed-species groups were recorded were January, July, and November.

Photograph collection

The first regional catalogue of fin whales in the Algarve was created, with 86 unique individuals identified (Bp301-Bp386), and used to build the photo-identification catalogue.

Fig. 3 Monthly distribution of fin whale sightings recorded between 2020 and 2024

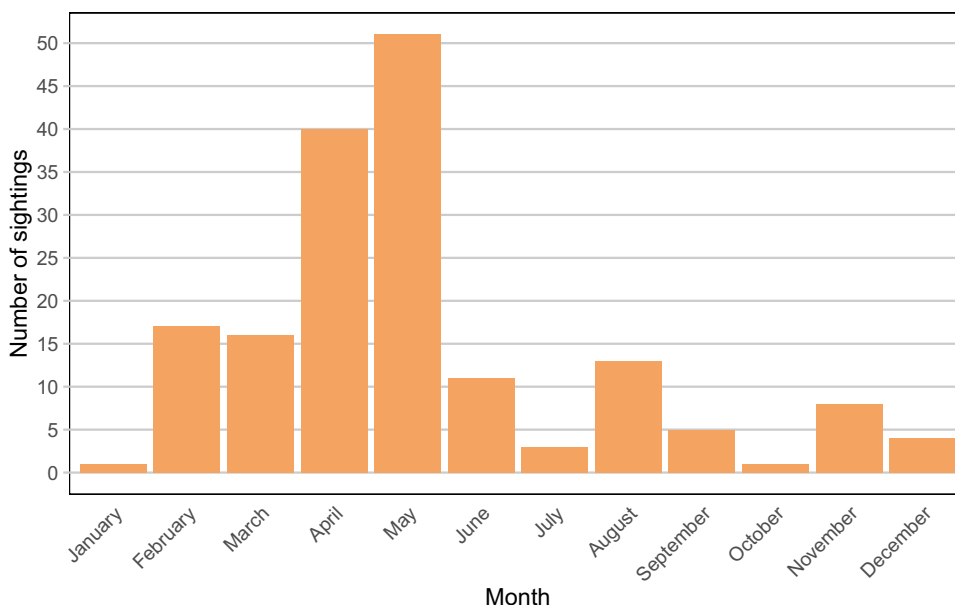
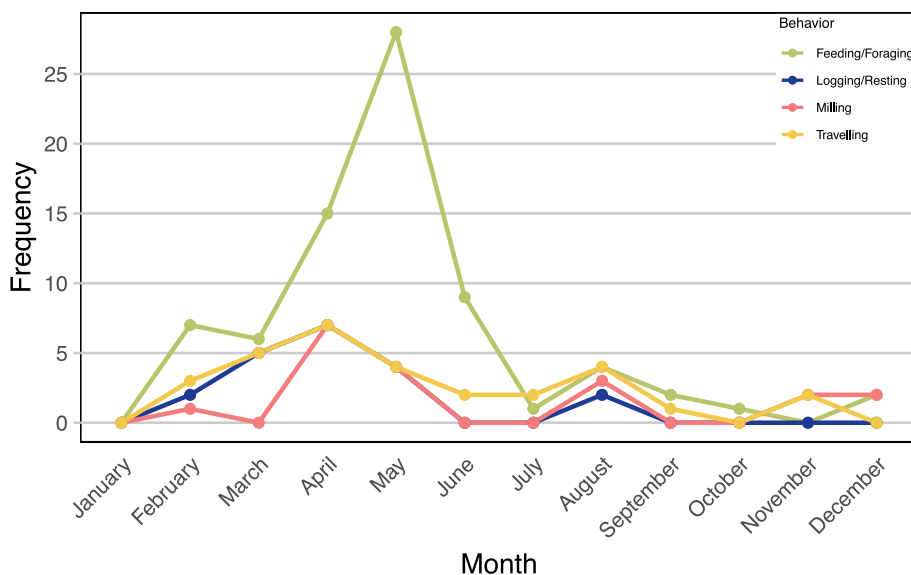


Fig. 4 Monthly frequency of fin whale observed behaviors (feeding/foraging, logging/resting, milling, travelling) throughout the year



The most prevalent dorsal fin shape was Type 3 – Classic (38%), followed by Type 4 – Broad tip (17%) and Type 5 – Triangular (15%). Approximately 10% of the identified individuals showed nicks and notches in the trailing edge of their dorsal fin, while approximately 20% were recorded with attachments. Identified fin whale individuals were sighted throughout the entire study period, from 2020 to 2024, with a progressive increase in the number of new individuals identified over time (Fig. 6). Through an analysis of inter-annual recaptures, two individuals were re-sighted twice, once in 2022 and again in 2023 (Fig. 6).

The intra-annual percentage of recapture was 7% for 2023, with one individual resighted in the same year, and 9% for 2024, with four individuals resighted in the same year. All intra-annually re-sighted individuals were

observed on consecutive days during spring, except for the one re-sighted in 2023 and one in 2024, each observed five days apart.

The most frequently sighted individual was Bp301, observed once in 2022 and twice in 2023, and identified by a distinctive mark on the anterior portion of its left head side (Fig. 7).

OpenCR model

For the Open Population Capture-Recapture model, only unique individuals identified from 2022 to 2024 with valid geographic positions were used, resulting in a total of 78 individuals. The parameters – the super-population density (superD), the maximum expected number of detections (λ_0),

Fig. 5 Monthly occurrence of mixed-species encounters observed with fin whales

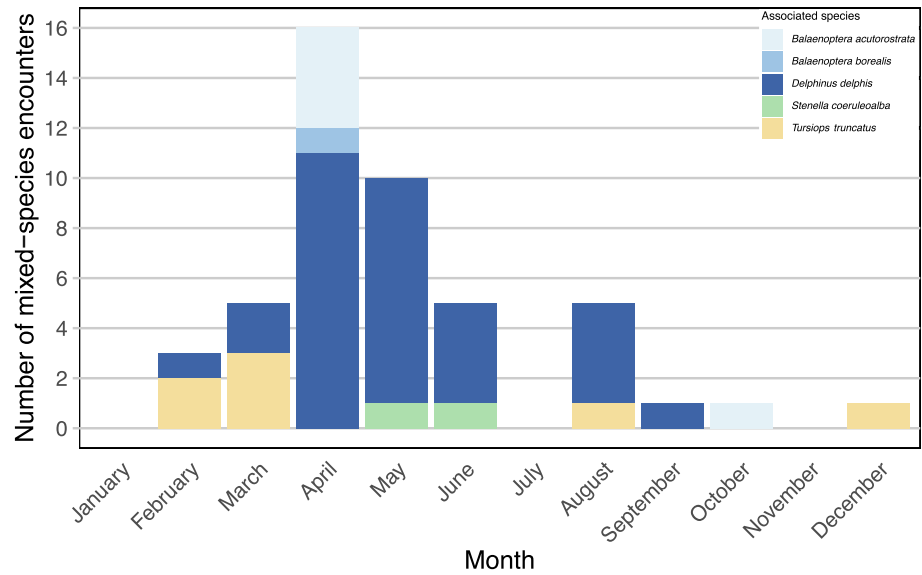
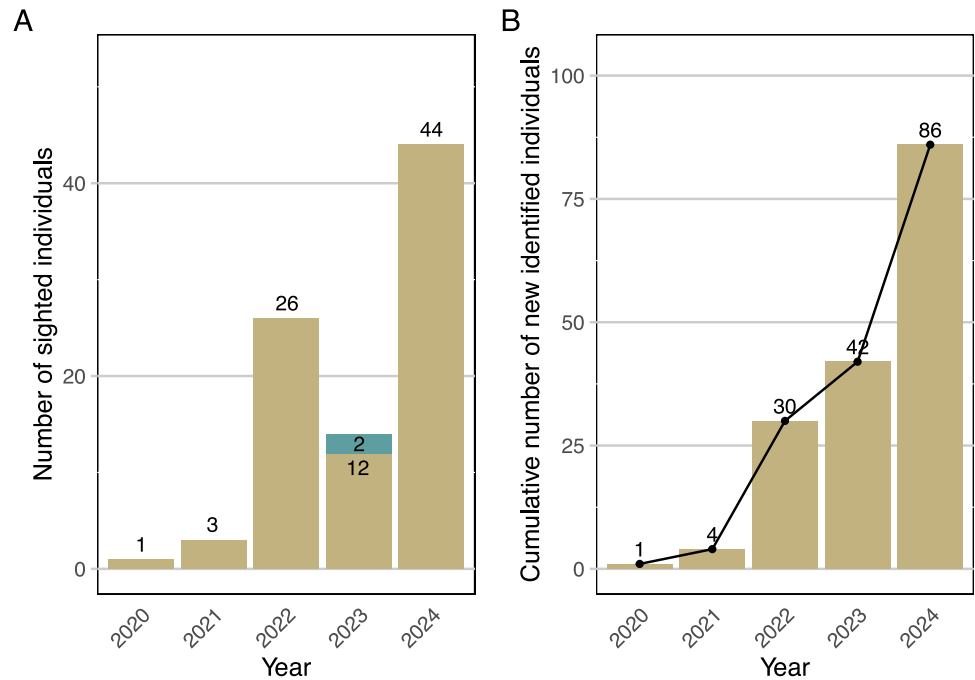


Fig. 6 (A) The number of fin whale individuals identified each year is shown, with new individuals identified highlighted in beige and inter-annual re-sighted individuals in turquoise. **(B)** A discovery curve is used to depict the cumulative number of new identified individuals over time



and home-range size (σ) – were extracted from the best-fitted open population capture-recapture model, selected using Akaike Information Criterion (AIC). The Algarve fin whale population size estimation (AFWPSE) was derived from the estimated density (Table 2).

Discussion

Fin whale occurrences in the Faro area reveal important aspects of the species’ seasonal distribution and habitat use in the Northeast Atlantic. Photo-identification across multiple years of monitoring supports the role of this region as

a regularly used area during spring, possibly linked to foraging opportunities. While these results point to the Faro area as a transit zone or a seasonal feeding ground, certain elements remain unclear and merit further attention. Among them are the low rate of individual re-sightings and the scarcity of inter-annual recaptures.

Our results reveal that fin whales were recorded throughout the entire study period, from 2020 to 2024, displaying a clear seasonal pattern in their occurrence. Sightings occurred in all months, with the highest numbers reported in April and May. The increased occurrence during these months, along with the re-sighting of five individuals within the same year in these periods – one in 2023 and four in

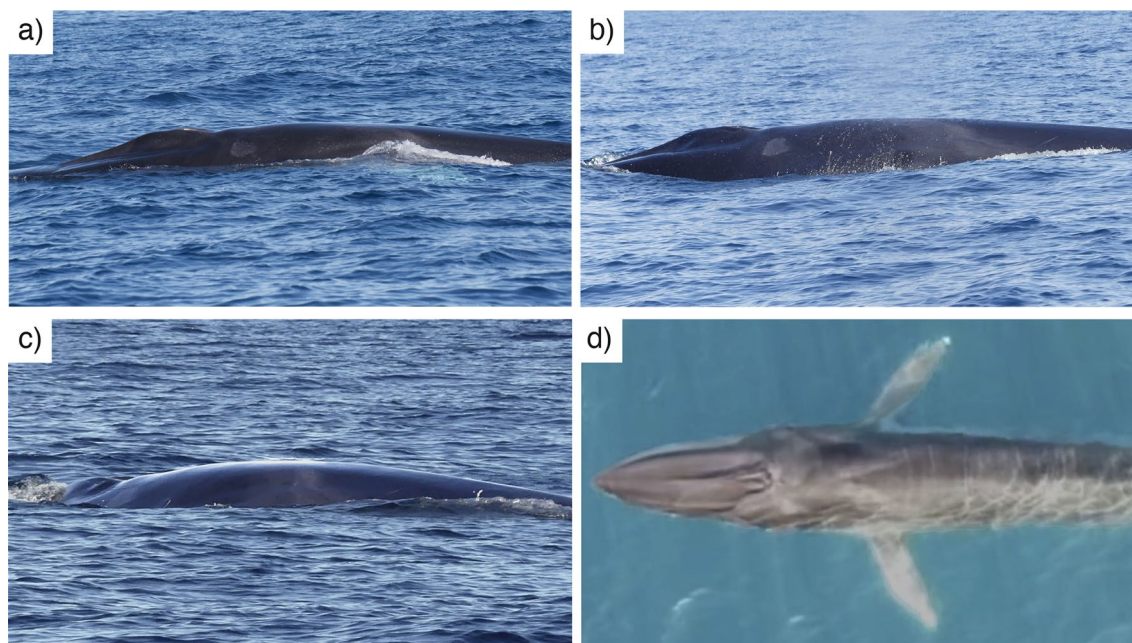


Fig. 7 Photographs of the left side front and aerial view front of the most frequently sighted fin whale individual, Bp301, documented on **a)** 2022–04–15; **b)** 2023–03–23; **c)** 2023–03–27; **d)** 2023–03–27. (Photos taken by Ocean Vibes; drone picture taken by Jan Hofman under the permit number AOC/08/2022)

Table 2 Summary of parameters from the open population capture–recapture model, including population density (superD), encounter rate (λ_0), activity range (σ), and Algarve fin whale population size estimation, along with their respective standard errors (SE), lower confidence limits (lcl), and upper confidence limits (ucl)

Variable	Estimate	SE	lcl	ucl
SuperD (individuals/km ²)	$3,35 \times 10^{-3}$	$2,28 \times 10^{-3}$	$8,86 \times 10^{-4}$	$1,27 \times 10^{-2}$
λ_0	$2,10 \times 10^{-6}$	$1,29 \times 10^{-6}$	$6,33 \times 10^{-7}$	$6,99 \times 10^{-6}$
σ (m)	15.216,27	5.475,44	7.516,41	30.803.91
AFWPSE (individuals)	1.476	1.002	390	5.588

2024 – just a few days apart, suggests that fin whales were likely taking advantage of abundant food resources available in the area during spring. This hypothesis is further supported by the initial behavior recorded during the sightings. In April and May, the most frequent behavior observed was feeding/foraging, indicating active exploitation of prey-rich zones. Such behavior suggests that the area may serve as a seasonal feeding hotspot for fin whales.

In contrast, during the rest of the year, behavioral records were more varied, with fewer instances of feeding noted. This seasonal presence appears to coincide with the progression of the North Atlantic Spring bloom, which begins around December–January at approximately 35°N and expands across the basin through spring months (Visser et al. 2011; Meyer et al. 2024), covering latitudes from 30°N to 50°N and longitudes from 60°W to 0°W (Martinez et al. 2011). Of all fin whale sightings, 24% occurred in

tos taken by Ocean Vibes; drone picture taken by Jan Hofman under the permit number AOC/08/2022)

mixed-species groups, with the short-beaked common dolphin being the most frequently associated species. During spring blooms, these conditions may encourage species to co-occur in shared feeding grounds, potentially enhancing foraging efficiency through associative behaviors (Syme et al. 2021). This finding is consistent with a study conducted in the New York Bight, where short-beaked common dolphins were observed in association with fin whales during three out of four mixed-species foraging events (Lomac-MacNair et al. 2022). However, a study in southern California bight recorded fin whales and common dolphins in mixed-species groups during traveling behavior (Bacon et al. 2017). Another study in different Italian seas (Pelagos Sanctuary, central and southern Tyrrhenian Sea, Sicily Channel, and western Ionian Sea) recorded mixed groups of common dolphins and fin whales mainly during feeding and/or travelling activities (Pace et al. 2015). Further research is needed to investigate the factors driving these interactions and the potential benefits they may confer in the Algarve region.

Photo-identification studies of fin whales in the North Atlantic have primarily focused on the northwestern Atlantic and the Mediterranean Sea. The most extensive existing catalogue is maintained by Allied Whale at the College of the Atlantic (USA), comprising 841 fin whale individuals photographed since 1968, mainly off the northeastern coast of the United States (Robbins et al. 2008). In the Mediterranean Sea, a catalogue of 507 fin whale individuals has been maintained since 1990 by several research groups

(Zanardelli et al. 2022). This study successfully identified 86 unique fin whale individuals, thereby creating the first regional catalogue for the Algarve. Vessel-based photo-identification of fin whales relies on two distinctive features: marks and shape of the dorsal fin and body pigmentation patterns (Agler et al. 1990, 1993; Tardy et al. 2023). Although dorsal fin characteristics can allow individual recognition from both sides, this method may be limited when individuals lack distinctive features such as nicks, notches, or attachments (Elliser et al. 2022), as identification based entirely on dorsal fin shape can be more challenging due to changes over time (Degollada et al. 2023). In this study, approximately 70% of the identified individuals lacked distinctive markings, which may have reduced identification accuracy and increased the likelihood of misidentification. Conversely, when using pigmentation patterns as criteria for photo-ID, such as the chevron-blaze pattern or the left front portion of the body, individuals can't be matched from opposite sides, limiting the ability to confirm identity across different angles. To address these issues, unmanned aerial vehicles (UAVs; i.e. drones) have emerged as a valuable tool in wildlife research over the past decade (Fiori et al. 2017; Ryan et al. 2022; O'Callaghan et al. 2024). Their growing adoption is driven by several advantages, including ease of deployment and maneuverability, operational flexibility, and the ability to obtain close-range observations in a non-invasive and cost-effective manner, with minimal disturbance when operated at appropriate altitudes (Degollada et al. 2023; Evans et al. 2025). Moreover, the aerial perspective provided by drones enables the acquisition of images and recordings that allow for the identification and characterization of different types of behavior (Baird et al. 2021; Degollada et al. 2025). In our study, consistent with previous research, the drone's zenith perspective enabled the identification of individual fin whales by observing the pattern formed where the left and right chevron branches converge along the dorsal midline (Degollada et al. 2023), as well as any other distinctive markings present on the body. Applying both vessel-based photo-identification and aerial images, manual matching software and semi- or fully automated identification tools should be considered valid approaches. While the accuracy of these computerized identification software is still under evaluation and largely depends on the algorithms used (Besson et al. 2022; Patton et al. 2025), their greatest significant advantage lies in the potential to drastically reduce the amount of time and effort needed to identify individuals from photographs, making them particularly valuable for large datasets and long-term monitoring programs (Cheeseman et al. 2021; Thompson et al. 2021).

Two of the 86 identified fin whale individuals were recorded in multiple years, both first observed in 2022 and

re-sighted in 2023. This results in an overall re-sighting rate of approximately 2.5%, which is lower than those reported in other studies. In the northwestern Mediterranean Sea, re-sighting rates were estimated at 16.3% (Tardy et al. 2023) and 14% (Zanardelli et al. 2022). In contrast, in the Gulf of Maine, 43% of identified fin whale individuals have been observed across multiple years (Robbins et al. 2008). The notably lower rate found in this study could be attributed to several factors. Most importantly, the studies cited above are all based on long-term monitoring programs. Those conducted in the Mediterranean Sea span approximately 10 to 20 years. At the same time, the Gulf of Maine study extends over four decades, providing the opportunity for more detailed insights into population structure and dynamics (Lindenmayer et al. 2012). Secondly, survey effort may also play a key role. Variability in the number of trips conducted, seasonal coverage, and weather conditions can all influence sighting probabilities and the chances of re-identifying individuals. In our study, survey effort varied markedly among years, with 2024 accounting for more than half of the total kilometers surveyed. As expected, higher effort yielded more newly identified individuals. However, when encounter rates were standardized by survey effort (individuals per kilometer surveyed), they did not increase proportionally with effort. Notably, 2022 had the highest encounter rate despite a lower survey effort compared to subsequent years. This observation suggests that interannual variability in encounter rates is not solely driven by differences in survey effort but may also reflect ecological or distributional factors. Thirdly, Mediterranean fin whale subpopulation is considered resident. A study in this area has observed limited interannual variation in fin whale distribution, along with the recurring use of specific hotspots (Panigada et al. 2024); these factors are especially significant in geographically constrained environments like the Mediterranean Sea, where the relatively enclosed nature of the basin may contribute to higher re-sighting rates.

The lower re-sighting rate observed in our study area may also reflect the high mobility of North Atlantic fin whales, whose movements span broad areas across the North Atlantic but also include regular exchange with the Mediterranean Sea. Several studies have documented the northward spring migration of fin whales, providing evidence for a central migratory corridor located in mid-Atlantic waters. Satellite-transmitter data and passive acoustic monitoring in the Azores Archipelago revealed two peaks in fin whale occurrence. The first occurs during spring-early summer, specifically between March and May. Multiple studies have demonstrated that, during this period, fin whales use the Azores as a feeding area, exploiting the high productivity associated with the Mid-Atlantic Ridge (Silva et al. 2013; Valente et al. 2019; Pérez-Jorge et al. 2020). This

feeding phase precedes the onset of their northern migration. Model predictions further indicated that fin whale presence expanded into the Irminger Sea, reaching the western coast of Iceland by June and July (Pérez-Jorge et al. 2020).

Regarding their southward migration during winter, a second peak occurred between September and December, with calls detected daily from October onward, peaking in November and December (Romagosa et al. 2020). This peak in singing activity corresponds to the presumed breeding season, suggesting that some fin whales may mate in or around the Azores (Romagosa et al. 2020). A satellite-tracking study in Svalbard (2015–2019) revealed that two individuals reached the west coast of Portugal mainland (Lydersen et al. 2020). The first left Svalbard on 11 October 2015 along a more offshore western route, arriving in southern Portugal in late November 2015; the second departed on 23 September 2019 via a more eastern pathway along the continental shelf, stopping multiple times and continuing south to the Moroccan coast before returning to western Portugal in late December 2019 (Lydersen et al. 2020). Supporting this, a study that employed ocean-bottom seismometers across a vast region off southwest Portugal (35–37°N; 8.5–11.5°W) documented the presence of fin whales from November to January, suggesting that this area could serve as a breeding ground for Atlantic fin whales (Pereira et al. 2020). This discrepancy highlights the complex population structure in the Northeast Atlantic and suggests that further research is needed to clarify their migratory routes, timing, and breeding areas of these populations.

As the sole oceanographic connection between the Atlantic Ocean and the Mediterranean Sea, the Strait of Gibraltar constitutes an essential migratory corridor. The north-eastern North Atlantic (NENA) subpopulation appears to migrate between the North Atlantic Ocean and the Balearic Islands through this pathway (Castellote et al. 2011; Tardy et al. 2023). Acoustic data collected off the southwest coast of Portugal suggested that movements between the North Atlantic and the Mediterranean Sea were primarily undertaken by NENA subpopulation entering the Mediterranean from spring to fall (Pereira et al. 2020). In contrast, another study reported a predominant westward migration towards the Atlantic Ocean between May and July, often involving juveniles and calves, and an eastward flow into the Mediterranean during November and December (Gauffier et al. 2018). This latter finding aligns more closely with the study's results, which revealed a peak in fin whale sightings in the Faro area during May. The spring/summer migration towards the Atlantic likely enables fin whales to exploit alternative feeding grounds, including distinct preys and higher biomass, whereas the winter movement into the Mediterranean suggests that whales may use this basin for breeding and calving, benefiting from its milder winter

conditions compared to the North Atlantic Ocean (Castellote et al. 2011; Gauffier et al. 2018).

In our study, the continued increase in the cumulative number of identified individuals suggests that a substantial portion of the population had yet to be observed. However, inter-annual recaptures indicate that some individuals return to the area. Nonetheless, these recaptures involved only a small portion of the overall population, considering that 86 individual fin whales were identified, and the abundance estimate for the area reaches 1,476 individuals. If site fidelity existed, it would imply more recaptures.

Our population size estimate is comparable to the one reported for the North-western Mediterranean Sea between 2008 and 2019, with 1,295 individuals estimated from genotype sampling and 1,549 individuals estimated through photo-identification data (Tardy et al. 2023), but represents less than half of the population calculated in the western Mediterranean Sea in the summer of 1991, which was estimated at 3,583 individuals (Forcada et al. 1996). However, the abundance estimate provided in this study should be interpreted with caution, as it is associated with a relatively large confidence interval driven by three main factors. (I) Limited sample size and the short time series, based on a few consecutive years of data, reduce the model's ability to provide a comprehensive overview of the population. (II) Low re-sighting rate indicates that only a small fraction of the population present in the study area was repeatedly identified, suggesting that the sampled individuals represent only a subset of the fin whales using the Algarve. Although the age structure of individuals using the Faro area remains unknown, the potential presence of younger or more transient individuals could contribute to reduced site fidelity and lower recapture rates. (III) The estimate may be affected by effort bias due to higher vessel-based survey activity during spring and summer. Since no correction for sampling effort was applied, the abundance estimate might be overestimated and skewed toward periods of greater observation activity. Given these limitations and the fact that the forecast of fin whale abundance considers only the individuals reported in the area off Faro, future assessments could be improved by incorporating sightings per unit effort, extending data collection across a greater number of years, integrating age-class composition and expanding coverage to other parts of the region. This would enable a more accurate and unbiased assessment of fin whale abundance in the Algarve.

This study highlights the value of collecting data aboard WW vessels, particularly in areas where such operations exist but scientific monitoring is limited. However, data gathered from platforms of opportunity have inherent limitations, which can vary depending on the type of platform and the observer's experience (Stack and Currie 2022). Firstly, to comply with WW regulations in the Algarve, each

sighting was limited to a maximum of 30 min (Decree-Law No. 9/2006, of January 6th), which constrained the ability to take high-quality photos for identification. Additionally, it is worth noting that the absence of vessel track data for the years 2020 and 2021 creates a significant research gap, which limits the accuracy of fin whale population size estimation. Nevertheless, as observed in other regions, partnerships with WW operators have proven valuable for collecting non-invasive data on cetaceans, offering important insights for conservation efforts (Peres dos Santos et al. 2025).

In conclusion, this study offers the first insight into the presence and population structure of fin whales in the Faro area, highlighting its potential as a significant seasonal feeding ground in the Northeast Atlantic. Despite inherent limitations linked to data collection from platforms of opportunity, such as restricted sighting durations and incomplete spatial coverage, the results demonstrate the value of WW collaborations in generating non-invasive data. Establishing the first regional photo-identification catalogue, along with evidence of seasonal recurrence and occasional inter-annual re-sightings, suggests that this area may hold ecological relevance for part of the North Atlantic fin whale population. Continued research in this region will be essential to improve the accuracy of abundance estimates, assess site fidelity, and clarify the Faro area's role within broader migratory and foraging dynamics of fin whales in the North Atlantic.

Acknowledgements The authors would like to acknowledge all the biologists from Ocean Vibes, including Miguel Alves and Inês Rocha, who have actively contributed to the vessel effort collection. Rui Peres dos Santos was supported by a PhD grant funding (UI/BD/151306/2021) from the Foundation for Science and Technology (FCT), Portugal. This study received Portuguese national funds from FCT through projects UIDB/04326/2020 (<https://doi.org/10.54499/UIDB/04326/2020>) and LA/P/0101/2020 (<https://doi.org/10.54499/LA/P/0101/2020>).

Author contributions Ginevra Gennari: conceptualization, data curation, formal analysis (lead), investigation, methodology, resources, visualization and writing – original draft. Alfredo Rodrigues: data curation, methodology, resources and reviewing. Pedro Carvalho: data curation, methodology. Susana Gil: data curation, methodology. Ramiro Magno: formal analysis, methodology, resources and reviewing. Rui Peres dos Santos: conceptualization, data curation, formal analysis, investigation, methodology, resources, visualization, reviewing, supervision (equal). Rita Castilho: conceptualization (supporting), funding acquisition, project administration, reviewing, supervision (equal).

Funding Open access funding provided by FCT|FCCN (b-on). Rui Peres dos Santos was supported by a PhD grant (UI/BD/151306/2021) from the Foundation for Science and Technology (FCT), Portugal. This study was funded by Portuguese national funds through the FCT projects UIDB/04326/2020 (<https://doi.org/10.54499/UIDB/04326/2020>) and LA/P/0101/2020 (<https://doi.org/10.54499/LA/P/0101/2020>).

Data availability Data associated with this manuscript are available from the corresponding author on reasonable request.

Declarations

Competing interests The authors have no relevant financial or non-financial interests to disclose.

Ethics approval Whale watching activities performed in this study were conducted in accordance with Portuguese legislation, specifically Decree-Law No. 9/2006, of January 6th. Drone-based sampling was conducted under permit number AOC/08/2022.

Open Access This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit <http://creativecommons.org/licenses/by/4.0/>.

References

- Agler BA, Beard JA, Bowman RS, Corbett HD, Frohock SE, Hawvermale MP, Katona SK, Sadove SS, Seipt IE (1990) Fin whale (*Balaenoptera physalus*) photographic identification: methodology and preliminary results from the Western North Atlantic. Rep Int Whaling Comm 12:349–356
- Agler BA, Schooley RL, Frohock SE, Katona SK, Seipt IE (1993) Reproduction of photographically identified fin whales, *Balaenoptera physalus*, from the Gulf of Maine. J Mammal 74:577–587. <https://doi.org/10.2307/1382276>
- Andrews RD, Baird RW, Calambokidis J, Goertz CEC, Gulland FMD, Heide-Jorgensen MP, Hooker SK, Johnson M, Mate B, Mitani Y, Nowacek DP, Owen K, Quakenbush LT, Raverty S, Robbins J, Schorr GS, Shpak OV, Townsend FI Jr, Uhart M, Wells RS, Zerbini AN (2019) Best practice guidelines for cetacean tagging. IWC J Cetacean Res Manag 20:27–66. <https://doi.org/10.47536/jcrm.v20i1.237>
- Arranz P, Glarou M, Sprogis KR (2021) Decreased resting and nursing in short-finned pilot whales when exposed to louder petrol engine noise of a hybrid whale-watch vessel. Sci Rep 11:21195. <https://doi.org/10.1038/s41598-021-00487-0>
- Bacon CE, Smultea MA, Fertl D, Würsig B, Burgess EA, Hawks-Johnson S (2017) Mixed-species associations of marine mammals in the Southern California Bight, with emphasis on Risso's dolphins (*Grampus griseus*). Aquat Mamm 43:177–184. <https://doi.org/10.1578/am.43.2.2017.177>
- Baird RW, Mahaffy SD, Lerma JK (2021) Site fidelity, spatial use, and behavior of dwarf sperm whales in Hawaiian waters: using small-boat surveys, photo-identification, and unmanned aerial systems to study a difficult-to-study species. Mar Mamm Sci 38:326–348
- Barlow J, Calambokidis J, Falcone EA, Baker CS, Burdin AM, Clapham PJ, Ford JKB, Gabriele CM, LeDuc R, Mattila DK, Quinn TJ, Rojas-Bracho L, Straley JM, Taylor BL, Ju R, Wade P, Weller D, Witteveen BH, Yamaguchi M (2011) Humpback whale abundance in the North Pacific estimated by photographic capture-recapture

- with bias correction from simulation studies. *Mar Mamm Sci* 27:793–818. <https://doi.org/10.1111/j.1748-7692.2010.00444.x>
- Bertulli CG, Guéry L, McGinty N, Suzuki A, Brannan N, Marques T, Rasmussen MH, Gimenez O (2018) Capture-recapture abundance and survival estimates of three cetacean species in Icelandic coastal waters using trained scientist-volunteers. *J Sea Res* 131:22–31. <https://doi.org/10.1016/j.seares.2017.10.001>
- Bérubé M, Ju R, Dizon AE, Brownell RL, Palsbøll PJ (2002) Genetic identification of a small and highly isolated population of fin whales (*Balaenoptera physalus*) in the Sea of Cortez, México. *Conserv Genet* 3:183–190. <https://doi.org/10.1023/A:1015224730394>
- Besson M, Alison J, Bjerge K, Gorochoowski TE, Høye TT, Jucker T, Mann HMR, Clements CF (2022) Towards the fully automated monitoring of ecological communities. *Ecol Lett* 25:2753–2775. <https://doi.org/10.1111/ele.14123>
- Bigg M (1982) An assessment of killer whale (*Orcinus orca*) stocks off Vancouver Island, British Columbia. *Rep Int Whal Comm* 32:655–666 (Accessed on 3 December 2025)
- Biuw M, Lindstrøm U, Jackson JA, Baines M, Kelly N, McCallum G, Skaret G, Krafft BA (2024) Estimated summer abundance and krill consumption of fin whales throughout the Scotia Sea during the 2018/2019 summer season. *Sci Rep*. <https://doi.org/10.1038/s41598-024-57378-3>
- Bonebrake TC, Christensen J, Boggs CL, Ehrlich PR (2010) Population decline assessment, historical baselines, and conservation. *Conserv Lett* 3:371–378
- Burnham KP, Anderson DR (1976) Mathematical models for non-parametric inferences from line transect data. *Biometrics* 32:325. <https://doi.org/10.2307/2529501>
- Calambokidis J, Barlow J (2004) Abundance of blue and humpback whales in the eastern North Pacific estimated by capture-recapture and line transect methods. *Mar Mamm Sci* 20:63–85. <https://doi.org/10.1111/j.1748-7692.2004.tb01141.x>
- Callaghan CT, Santini L, Spake R, Bowler DE (2024) Population abundance estimates in conservation and biodiversity research. *Trends Ecol Evol* 39:515–523. <https://doi.org/10.1016/j.tree.2024.01.012>
- Cartagena-Matos B, Lugué K, Fonseca P, Marques TA, Prieto R, Alves F (2021) Trends in cetacean research in the eastern North Atlantic. *Mammal Rev* 51:436–453. <https://doi.org/10.1111/mam.12238>
- Castellote M, Clark CW, Lammers MO (2011) Fin whale (*Balaenoptera physalus*) population identity in the western Mediterranean Sea. *Mar Mamm Sci* 28:325–344. <https://doi.org/10.1111/j.1748-7692.2011.00491.x>
- Cheeseman T, Southerland K, Park J, Olio M, Flynn K, Calambokidis J, Jones L, Garrigue C, Jordán AF, Howard A, Reade W, Neilson J, Gabriele C, Clapham P (2021) Advanced image recognition: a fully automated, high-accuracy photo-identification matching system for humpback whales. *Mamm Biol* 102:915–929. <https://doi.org/10.1007/s42991-021-00180-9>
- Cooke JG (2018) *Balaenoptera physalus*. The IUCN Red List of Threatened Species 2018: e.T2478A50349982. <https://doi.org/10.2305/IUCN.UK.2018-2.RLTS.T2478A50349982.en> Accessed on 11 December 2025
- Correia AM, Tepsich P, Rosso M, Caldeira R, Sousa-Pinto I (2014) Cetacean occurrence and spatial distribution: habitat modelling for offshore waters in the Portuguese EEZ (NE Atlantic). *J Mar Syst* 143:73–85. <https://doi.org/10.1016/j.jmarsys.2014.10.016>
- Dawson S, Wade P, Slooten E, Barlow J (2008) Design and field methods for sighting surveys of cetaceans in coastal and riverine habitats. *Mammal Rev* 38:19–49. <https://doi.org/10.1111/j.1365-2907.2008.00119.x>
- Degollada E, Amigó N, O’Callaghan S, Varola M, Ruggero K, Tort B (2023) A novel technique for photo-identification of the fin whale, *Balaenoptera physalus*, as determined by drone aerial images. *Drones* 7:220. <https://doi.org/10.3390/drones7030220>
- Degollada E, Tort B, Mészáros D (2025) Drones applied to Cetacean Research: A case study of Fin whales. In: IntechOpen eBooks. <https://doi.org/10.5772/intechopen.1010029>
- Dunington D (2017) ggspatial: Spatial Data Framework for ggplot2. <https://doi.org/10.32614/cran.package.ggpspatial>
- Edwards EF, Hall C, Moore TJ, Sheredy C, Redfern JV (2015) Global distribution of fin whales *Balaenoptera physalus* in the post-whaling era (1980–2012). *Mammal Rev* 45:197–214. <https://doi.org/10.1111/mam.12048>
- Efford M (2024) Open Population Capture-Recapture [R package openCR version 2.2.7]. <https://cran.r-project.org/package=openCR/>.
- Efford M (2025a) Spatially Explicit Capture-Recapture [R package secr version 5.2.1]. <https://cran.r-project.org/package=secur>.
- Efford M (2025b) A tutorial on fitting spatially explicit capture-recapture models in secr 5.2. University of Otago. <https://www.otago.ac.nz/density/pdfs/secur-tutorial.pdf> Accessed on 5 June 2025
- Efford MG, Boulanger J (2019) Fast evaluation of study designs for spatially explicit capture-recapture. *Methods Ecol Evol* 10:1529–1535
- Elliser CR, Van Der Linde K, MacIver K (2022) Adapting photo-identification methods to study poorly marked cetaceans: a case study for common dolphins and harbor porpoises. *Mamm Biol* 102:811–827. <https://doi.org/10.1007/s42991-021-00194-3>
- Evans LI, Van Aswegen M, Feinberg S, Currie JJ, Stack SH, Szabo A, Bejder L (2025) Elevating Photo-Identification: Aerial-Identification improves Re-Sight rates and supports Long-Term monitoring of humpback whales. *Marine Mammal Science*. <https://doi.org/10.1111/mms.70078>
- Falcone EA, Keene EL, Keen EM, Barlow J, Stewart J, Cheeseman T, Hayslip C, Palacios DM (2022) Movements and residency of fin whales (*Balaenoptera physalus*) in the California Current System. *Mamm Biol* 102:1445–1462. <https://doi.org/10.1007/s42991-022-00298-4>
- Ferreira S, Sousa M, Picado A, Vaz N, Dias JM (2022) New insights about upwelling trends off the Portuguese Coast: an ERA5 dataset analysis. *J Mar Sci Eng* 10:1849. <https://doi.org/10.3390/jmse10121849>
- Fiori L, Doshi A, Martinez E, Orams MB, Bollard-Breen B (2017) The use of unmanned aerial systems in marine mammal research. *Remote Sens* 9:543. <https://doi.org/10.3390/rs9060543>
- Forcada J, Aguilar A, Hammond P, Pastor X, Aguilar R (1996) Distribution and abundance of fin whales (*Balaenoptera physalus*) in the western Mediterranean Sea during the summer. *J Zool* 238:23–34. <https://doi.org/10.1111/j.1469-7998.1996.tb05377.x>
- Forli MJ, Santos RPD, Rodrigues A, Castilho R (2024) The impact of touristic whale-watching on *Delphinus delphis* and *Tursiops truncatus* in the Algarve Coast: combining acoustic analysis and land observations. *Ocean Coast Manag* 259:107431. <https://doi.org/10.1016/j.ocecoaman.2024.107431>
- Gauffier P, Verborgh P, Giménez J, Esteban R, Sierra JS, De Stephanis R (2018) Contemporary migration of fin whales through the Strait of Gibraltar. *Mar Ecol Prog Ser* 588:215–228. <https://doi.org/10.3354/meps12449>
- Geelhoed S, Authier M, Pigeault R, Gilles A (2022) Abundance and Distribution of Cetaceans. In: OSPAR (2023) The 2023 Quality Status Report for the Northeast Atlantic. OSPAR Commission, London. <https://oap.ospar.org/en/ospar-assessments/quality-status-reports/qsar-2023/indicator-assessments/abundance-distribution-cetaceans/>
- Geijer CKA, Di Sciara GN, Panigada S (2016) Mysticete migration revisited: are Mediterranean fin whales an anomaly? *Mammal Rev* 46:284–296. <https://doi.org/10.1111/mam.12069>
- Hammond PS (1990) Capturing whales on film—estimating cetacean population parameters from individual recognition data. *Mammal*

- Rev 20:17–22. <https://doi.org/10.1111/j.1365-2907.1990.tb00099.x>
- Hammond PS, Francis TB, Heinemann D, Long KJ, Moore JE, Punt AE, Reeves RR, Sepúlveda M, Sigurðsson GM, Siple MC, Víkingsson G, Wade PR, Williams R, Zerbini AN (2021) Estimating the abundance of marine mammal populations. *Front Mar Sci*. <https://doi.org/10.3389/fmars.2021.735770>
- Jolly GM (1965) Explicit estimates from capture-recapture data with both death and immigration-stochastic model. *Biometrika* 52:225. <https://doi.org/10.2307/2333826>
- Kaschner K, Quick NJ, Jewell R, Williams R, Harris CM (2012) Global coverage of cetacean line-transect surveys: status quo, data gaps and future challenges. *PLoS ONE* 7:e44075. <https://doi.org/10.1371/journal.pone.0044075>
- Keen EM, Pilkington J, O'Mahony É, Thompson K-L, Hendricks B, Robinson N, Dundas A, Nichol L, Alidina HM, Meuter H, Picard CR, Wray J (2024) Correction: fin whales of the great bear rainforest: *Balaenoptera physalus velifera* in a Canadian Pacific fjord system. *PLoS ONE* 19:e0305297. <https://doi.org/10.1371/journal.pone.0256815>
- Laake JL, Punt AE (2023) Gray whale southbound migration surveys 1967–2006: an integrated re-analysis. *J Cetacean Res Manag* 12:287–306. <https://doi.org/10.47536/jerm.v12i3.559>
- Leonard D, Øien N (2020) Estimated abundances of cetacean species in the northeast atlantic from norwegian shipboard surveys conducted in 2014–2018. *NAMMCO Scientific Publications* Doi 10(7557/3):4694
- Lindenmayer DB, Likens GE, Andersen A, Bowman D, Bull CM, Burns E, Dickman CR, Hoffmann AA, Keith DA, Liddell MJ, Lowe AJ, Metcalfe DJ, Phinn SR, Russell-smith J, Thurgate N, Wardle GM (2012) Value of long-term ecological studies. *Austral Ecol* 37:745–757. <https://doi.org/10.1111/j.1442-9993.2011.02351.x>
- Lomac-MacNair KS, Zoidis AM, Ireland DS, Rickard ME, McKown KA (2022) Fin, humpback, and minke whale foraging events in the New York Bight as observed from aerial surveys, 2017–2020. *Aquat Mamm* 48:142–158. <https://doi.org/10.1578/am.48.2.2022.142>
- López MEJ, Palacios DM, Legorreta AJ, R JU, Mate BR (2019) Fin whale movements in the Gulf of California, Mexico, from satellite telemetry. *PLoS ONE* 14:e0209324. <https://doi.org/10.1371/journal.pone.0209324>
- Lydersen C, Vacquie-Garcia J, Heide-Jørgensen MP, Øien N, Guinet C, Kovacs KM (2020) Autumn movements of fin whales (*Balaenoptera physalus*) from Svalbard, Norway, revealed by satellite tracking. *Sci Rep* 10:16966. <https://doi.org/10.1038/s41598-020-73996-z>
- Marr JC (1951) On the use of the terms abundance, availability and apparent abundance in fishery biology. *Copeia* 1951:163. <https://doi.org/10.2307/1437549>
- McLaren IA (1961) Methods of determining the numbers and availability of ringed seals in the eastern Canadian Arctic. *Arctic* 14:162–175
- Meyer MG, Brzezinski MA, Cohn MR, Kramer SJ, Paul N, Sharpe G, Niebergall AK, Gifford S, Cassar N, Marchetti A (2024) Size-fractionated primary production dynamics during the decline phase of the North Atlantic spring bloom. *Glob Biogeochem Cycles*. <https://doi.org/10.1029/2023gb008019>
- Martinez E, Antoine D, D'Ortenzio F, De Boyer MC (2011) Phytoplankton spring and fall blooms in the North Atlantic in the 1980s and 2000s. *J Geophys Res Atmos*. <https://doi.org/10.1029/2010jc006836>
- Norris TF, Dunleavy KJ, Yack TM, Ferguson EL (2017) Estimation of minke whale abundance from an acoustic line transect survey of the Mariana Islands. *Mar Mamm Sci* 33:574–592. <https://doi.org/10.1111/mms.12397>
- Notarbartolo-di-sciara G, Zanardelli M, Jahoda M, Panigada S, Airoidi S (2003) The fin whale *Balaenoptera physalus* (L. 1758) in the Mediterranean Sea. *Mammal Rev* 33:105–150. <https://doi.org/10.1046/j.1365-2907.2003.00005.x>
- O'Callaghan SA, Abbar FA, Costa H, Prieto R, Gammell M, O'Brien J (2024) Aerial photo-identification of sperm whales (*Physeter macrocephalus*). *Aquat Mamm* 50:479–494. <https://doi.org/10.1578/AM.50.6.2024.479>
- Pace D, Mussi B, Airoidi S, Alessi J, Arcangeli A, Atzori F, Azzolin M, Campana I, Celona A, Friori C, Giacoma C, Gnone G, Luperini C, Mangano R, Miragliuolo A, Moulins A, Nuti S, Pellegrino G, Rosso M, Salvioli F, Tepischi P, Tringali M (2015) New insights on the presence and distribution of the endangered short-beaked common dolphin *Delphinus delphis* in Italian waters. *Biol Mar Mediterr* 22(1):262–263 (46th Congress of the Italian Society of Marine Biology)
- Pace RM, Corkeron PJ, Kraus SD (2017) State-space mark-recapture estimates reveal a recent decline in abundance of North Atlantic right whales. *Ecol Evol* 7:8730–8741. <https://doi.org/10.1002/ec.3406>
- Palsbøll PJ, Allen J, Bérube M, Clapham PJ, Feddersen TP, Hammond PS, Hudson RR, Jørgensen H, Katona S, Larsen AH, Larsen F, Lien J, Mattila DK, Sigurjónsson J, Sears R, Smith T, Sponer R, Stevick P, Øien N (1997) Genetic tagging of humpback whales. *Nature* 388:767–769. <https://doi.org/10.1038/42005>
- Panigada V, Bodey TW, Friedlaender A, Druon J-N, Huckstädt LA, Pierantonio N, Degollada E, Tort B, Panigada S (2024) Targeting fin whale conservation in the North-Western Mediterranean Sea: insights on movements and behaviour from biologging and habitat modelling. *R Soc Open Sci*. <https://doi.org/10.1098/rsos.231783>
- Paquet LF, Delary J, Ramp C, Sears R (2009) MICS-PIX: A web-based, multi species software for the processing, matching and storing of digital photo-identification images. Poster presented at the Eighteenth Biennial Conference on the Biology of Marine Mammals, Quebec, Canada
- Patton PT, Pacifici K, Baird RW, Oleson EM, Allen JB, Ashe E, Athayde A, Basran CJ, Cabrera E, Calambokidis J, Cardoso J, Carroll EL, Cesario A, Cheney BJ, Cheeseman T, Corsi E, Currie JJ, Durban JW, Falcone EA, Fearnbach H, Flynn K, Franklin T, Franklin W, Vernazzani BG, Genov T, Hill M, Johnston DR, Keene EL, Lacey C, Mahaffy SD, McGuire TL, McPherson L, Meyer C, Michaud R, Miliou A, Olson GL, Orbach DN, Pearson HC, Rasmussen MH, Rayment WJ, Rinaldi C, Rinaldi R, Siciliano S, Stack SH, Tintore B, Torres LG, Towers JR, Moore RBT, Weir CR, Wellard R, Wells RS, Yano KM, Zaeschmar JR, Bejder L (2025) Optimizing automated photo identification for population assessments. *Conserv Biol*. <https://doi.org/10.1111/cobi.14436>
- Pereira A, Harris D, Tyack P, Matias L (2020) Fin whale acoustic presence and song characteristics in seas to the southwest of Portugal. *J Acoust Soc Am* 147:2235–2249. <https://doi.org/10.1121/10.001066>
- Peres dos Santos R, Rodríguez Y, Sears R, Magno R, Castilho R (2025) Tour operators as a tool to improve information on data-deficient cetacean species. *Aquat Conserv Mar Freshw Ecosyst*. <https://doi.org/10.1002/aqc.70067>
- Pérez-Jorge S, Tobeña M, Prieto R, Vandeperre F, Calmettes B, Lehodey P, Silva MA (2020) Environmental drivers of large-scale movements of baleen whales in the mid-North Atlantic Ocean. *Divers Distrib* 26:683–698
- R Core Team (2023) R: A language and environment for statistical computing. Foundation for Statistical Computing, Vienna, Austria
- Ramp C, Gaspard D, Gavrilchuk K, Unger M, Schleimer A, Delarue J, Landry S, Sears R (2020) Up in the air: drone images reveal underestimation of entanglement rates in large rorqual whales.

- Endanger Species Res 44:33–44. <https://doi.org/10.3354/esr01084>
- Ramp C, Lesage V, Ollier A, Auger-Méthé M, Sears R (2024) Migratory movements of fin whales from the Gulf of St. Lawrence challenge our understanding of the Northwest Atlantic stock structure. *Sci Rep* 14:11472. <https://doi.org/10.1038/s41598-024-62173-1>
- Relvas P, Barton ED (2002) Mesoscale patterns in the Cape São Vicente (Iberian Peninsula) upwelling region. *J Geophys Res Atmos*. <https://doi.org/10.1029/2000jc000456>
- Robbins J, Dendanto D, Giard J, Panigada S, Sears R, Zanardelli M (2008) Photo-ID studies of fin whales in the North Atlantic Ocean and the Mediterranean Sea. <https://www.rorqual.com/downloads/photo-id-studies-of-fin-whales-in-the-north-atlantic-ocean-and-the-mediterranean-sea.pdf> Accessed on 5 June 2025
- Romagosa M, Baumgartner M, Cascão I, Lammers MO, Marques TA, Santos RS, Silva MA (2020) Baleen whale acoustic presence and behaviour at a Mid-Atlantic migratory habitat, the Azores Archipelago. *Sci Rep* 10:4766. <https://doi.org/10.1038/s41598-020-61849-8>
- Russell DJF, Morris CD, Duck CD, Thompson D, Hiby L (2019) Monitoring long-term changes in UK grey seal pup production. *Aquat Conserv Mar Freshw Ecosyst* 29:24–39. <https://doi.org/10.1002/aqc.3100>
- Ryan KP, Ferguson SH, Koski WR, Young BG, Roth JD, Watt CA (2022) Use of drones for the creation and development of a photographic identification catalogue for an endangered whale population. *Arctic Sci* 8:1191–1201. <https://doi.org/10.1139/as-2021-0047>
- Rychwalski AN, Herr H (2024) Short communication: lateralised lunge-feeding behaviour in Southern Hemisphere fin whales at Antarctic feeding grounds. *J Cetacean Res Manage* 25:23–29. <https://doi.org/10.47536/jcrm.v25i1.947>
- Schleimer A, Ramp C, Delarue J, Carpentier A, Bérubé M, Palsbøll PJ, Sears R, Hammond PS (2019) Decline in abundance and apparent survival rates of fin whales (*Balaenoptera physalus*) in the northern Gulf of St. Lawrence. *Ecol Evol* 9:4231–4244. <https://doi.org/10.1002/ece3.5055>
- Schwarz CJ, Armanon AN (1996) A general methodology for the analysis of capture-recapture experiments in open populations. *Biometrics* 52:860. <https://doi.org/10.2307/2533048>
- Schwarz CJ, Seber GAF (1999) Estimating animal abundance: review III. *Stat Sci*. <https://doi.org/10.1214/ss/1009212521>
- Seber GAF (1965) A note on the multiple-recapture census. *Biometrika* 52:249. <https://doi.org/10.2307/2333827>
- Sepúlveda M, Pérez-Álvarez MJ, Santos-Carvallo M, Pavez G, Olavarría C, Moraga R, Zerbini AN (2018) From whaling to whale watching: identifying fin whale critical foraging habitats off the Chilean coast. *Aquat Conserv Mar Freshw Ecosyst* 28:821–829. <https://doi.org/10.1002/aqc.2899>
- Silva MA, Prieto R, Jonsen I, Baumgartner MF, Santos RS (2013) North Atlantic blue and fin whales suspend their spring migration to forage in middle latitudes: building up energy reserves for the journey? *PLoS ONE* 8:e76507. <https://doi.org/10.1371/journal.pone.0076507>
- Sprogis KR, Holman D, Arranz P, Christiansen F (2023) Effects of whale-watching activities on southern right whales in Encounter Bay, South Australia. *Mar Policy* 150:105525. <https://doi.org/10.1016/j.marpol.2023.105525>
- Stephenson F, Hewitt JE, Torres LG, Mouton TL, Brough T, Goetz KT, Lundquist CJ, MacDiarmid AB, Ellis J, Constantine R (2021) Cetacean conservation planning in a global diversity hotspot: dealing with uncertainty and data deficiencies. *Ecosphere*. <https://doi.org/10.1002/ecs2.3633>
- Syme J, Kiszka JJ, Parra GJ (2021) Dynamics of cetacean mixed-species groups: A review and conceptual framework for assessing their functional significance. *Front Mar Sci*. <https://doi.org/10.3389/fmars.2021.678173>
- Stack SH, Currie JJ (2022) Realising the potential of platforms of opportunity: re-thinking scientific data collection. In: Lück M, Porter BA (ed) *Advancing public and industry participation in coastal and marine sciences*. Newcastle upon Tyne (UK): Cambridge Scholars Publishing, pp 43–57. ISBN: 9781527587854
- Tardy C, Ody D, Gimenez O, Planes S (2023) Abundance of fin whales (*Balaenoptera physalus*) in the north-western Mediterranean Sea, using photo-identification and microsatellite genotyping. *Mar Ecol*. <https://doi.org/10.1111/maec.12737>
- Thompson JW, Zero VH, Schwacke LH, Speakman TR, Quigley BM, Morey JS, McDonald TL (2021) finFindR: Automated recognition and identification of marine mammal dorsal fins using residual convolutional neural networks. *Mar Mamm Sci* 38:139–150. <https://doi.org/10.1111/mms.12849>
- Tyne JA, Loneragan NR, Johnston DW, Pollock KH, Williams R, Bejder L (2016) Evaluating monitoring methods for cetaceans. *Biol Conserv* 201:252–260. <https://doi.org/10.1016/j.biocon.2016.07.024>
- Valente R, Correia AM, Gil Á, García LG, Sousa-Pinto I (2019) Baleen whales in Macaronesia: occurrence patterns revealed through a bibliographic review. *Mammal Rev* 49:129–151
- Vicente M, Falcão M, Santos MN, Caetano M, Serpa D, Monteiro C (2008) Environmental assessment of two artificial reef systems off southern Portugal (Faro and Olhão): A question of location. *Cont Shelf Res* 28:839–847. <https://doi.org/10.1016/j.csr.2007.12.009>
- Víkingsson GA, Pike DG, Desportes G, Øien N, Gunnlaugsson T, Bloch D (2013) Distribution and abundance of fin whales (*Balaenoptera physalus*) in the Northeast and Central Atlantic as inferred from the North Atlantic Sightings Surveys 1987–2001. *NAMMCO Sci Publ* 7:49. <https://doi.org/10.7557/3.2705>
- Visser F, Hartman K, Pierce G, Valavanis V, Huisman J (2011) Timing of migratory baleen whales at the Azores in relation to the North Atlantic spring bloom. *Mar Ecol Prog Ser* 440:267–279. <https://doi.org/10.3354/meps09349>
- Whitehead H (1982) Populations of humpback whales in the Northwest Atlantic. *Rep Int Whal Comm* 32:345–353 (Accessed on 3 December 2025)
- Wickham H (2016) *ggplot2: Elegant graphics for data analysis*. Springer-Verlag, New York
- Wickham H, Averick M, Bryan J, Chang W, McGowan L, François R, Grolemund G, Hayes A, Henry L, Hester J, Kuhn M, Pedersen T, Miller E, Bache S, Müller K, Ooms J, Robinson D, Seidel D, Spinu V, Takahashi K, Vaughan D, Wilke C, Woo K, Yutani H (2019) Welcome to the Tidyverse. *J Open Source Softw* 4:1686. <https://doi.org/10.21105/joss.01686>
- Würsig B, Würsig M (1977) The photographic determination of group size, composition, and stability of coastal porpoises (*Tursiops truncatus*). *Science* 198:755–756. <https://doi.org/10.1126/science.198.4318.755>
- Zanardelli M, Airoidi S, Bérubé M, Borsani JF, Di-Meglio N, Gannier A, Hammond PS, Jahoda M, Lauriano G, Di Sciarra GN, Panigada S (2022) Long-term photo-identification study of fin whales in the Pelagos Sanctuary (NW Mediterranean) as a baseline for targeted conservation and mitigation measures. *Aquat Conserv Mar Freshw Ecosyst* 32:1457–1470. <https://doi.org/10.1002/aqc.3865>