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Aerial Photo-Identification of Sperm Whales (*Physeter macrocephalus*)

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Abstract

Photo-identification is a staple tool used in cetacean conservation studies since the 1970s to monitor individuals on a regional and ocean basin-wide scale to infer critical information about habitat use, suitability, and shifts. This technique has been extensively used on sperm whales globally since it was developed in 1982, initially using the tail fluke from deep diving whales and the dorsal fin when appropriate. From the mid 2010s onwards, the emergence of domestically available unoccupied aerial systems (drones) has reshaped how whale research can be conducted. Herein, we describe the suitability of aerial images to determine the identity of individual sperm whales (*Physeter macrocephalus*) using all available identifiable markings along their dorsal side to complement the use of fluke notches and dorsal fin scars photographed from the surface of the sea from boat-based platforms for photo-identification and to maximize opportunities to identify and monitor sperm whales. Drone data were gathered while flying over sperm whales in Andenes, Norway; Shetland, Scotland; Dursey Island, Ireland; and Faial and São Miguel Islands, Azores, Portugal, between 2017 and 2024, which enabled the entire dorsal surface of sperm whales to be captured and assessed. Aerial photographs and videos were used to differentiate between 336 individual sperm whales using physical characteristics. We identified the main features of sperm whales through aerial drone images, as well as their prevalence in Atlantic high latitude foraging grounds and lower latitude nursery grounds. We discuss the advantages of using aerial drone photographs to identify sperm whales in addition to traditional boat-based photo-identification.

Key Words: sperm whale, photo-identification, drone, Norway, Azores, life history

Introduction

Photo-identification has been a powerful population monitoring tool for cetaceans since the 1970s when it was first developed using cameras with black and white film tape to photograph bottlenose dolphin (*Tursiops truncatus*) and killer whale (*Orcinus orca*) dorsal fins (Würsig & Würsig, 1977; Bigg, 1982). The development of photo-identification rapidly evolved over time as the available technology advanced and was applied to other cetacean species (Balcomb et al., 1982; Würsig & Jefferson, 1990). Humpback whales (*Megaptera novaeangliae*) were identified by the ventral fluke coloration and scars/marks, while southern right whales (*Eubalaena australis*) were identified by callosity patterns on their head (Katona et al., 1979; Jurasz & Palmer, 1981; Payne et al., 1983; Würsig & Jefferson, 1990).

Photo-identification was applied to sperm whales (*Physeter macrocephalus*) for the first time in 1982 off Sri Lanka using black and white and color film cameras (Whitehead & Gordon, 1986; Gordon, 1987). Permanent notches and deformities along the fluke trailing edge as well as any notches or wounds present on the dorsal fin or along the body were used to differentiate between individuals (Childerhouse et al., 1995; Dufault & Whitehead, 1995). Over time, photo-identification became the foundation of many sperm whale research projects globally (Whitehead & Gordon, 1986; Gordon, 1987; Arnbom & Whitehead, 1989), benefiting from the increasing affordability of digital SLR cameras and larger telephoto lenses (Markowitz et al., 2003; Steiner et al., 2012; Rødland & Bjørge, 2015; Kobayashi & Amano, 2019; van der Linde & Eriksson, 2019).

Traditional photo-identification based on fluke trailing edge shape has several limitations. Calves do not normally display the fluke upon diving (and when they do, there is often an indistinct trailing edge; Gero et al., 2009; Frantzis et al., 2014; Sarano et al., 2022). Whitehead (2001) noted that younger sperm whales were less marked on their flukes, and individuals with estimated lengths of < 10 m that were < 15 y of age were less likely to deep dive or raise their tail above the surface resulting in fewer opportunities to gather fluke photo-identification data on calf and juvenile sperm whales in contrast to older, larger whales.

Without using the fluke for identification, calves have been identified to date using the dorsal fin and body where identifiable markings were visible from a boat, but these characteristics can vary considerably in usefulness depending on the individual and their surfacing behavior (Gero et al., 2009, 2015). Peduncle humps were also used by Frantzis et al. (2014) to aid in calf identification. To ensure each sperm whale is identified, regardless of behavior, marks on other body parts (e.g., head, body, flanks) can be used for identification purposes, ideally by taking pictures from both sides of the animal or from an elevated position (Alessi et al., 2014; Frantzis et al., 2014; Rødland & Bjørge, 2015; Oyarbide et al., 2023). Additionally, identifiable features have been used from an underwater perspective for sperm whales in situations in which the photographer/videographer was in the water with the animal capturing data from all visible sides of near surface whales (Sarano et al., 2022).

Aerial photo-identification has also been used to study large cetacean species since the 1980s with manned aircraft such as fixed-wing planes to photograph North Atlantic right whales (*Eubalaena glacialis*) and bowhead whales (*Balaena mysticetus*) capturing overhead photographs of surfacing whales (Kraus et al., 1986; Rugh, 1990). The disadvantages of this aerial methodology include the high cost of flight time and the noise created by large aircraft that may affect animal behavior (Erbe et al., 2018).

The rapid development of domestically available and more affordable unoccupied aerial systems (hereafter UASs or drones) has enabled the advancement of research studies using aerial data (Fiori et al., 2017; Johnston, 2019; Álvarez-González et al., 2023). A variety of cetacean species have been identified using aerial images taken by drones, including bottlenose dolphins (Cheney et al., 2022), Risso's dolphins (*Grampus griseus*; Hartman et al., 2020), Australian snubfin (*Orcaella heinsohni*) and Australian humpback (*Sousa sahulensis*) dolphins (Christie et al., 2021), pygmy killer whales (*Feresa attenuata*; Currie et al., 2021), belugas (*Delphinapterus leucas*; Ryan et al., 2022), long-finned pilot whales (*Globicephala melas*; Zwamborn et al., 2023), killer whales (Durban et al., 2015), dwarf sperm whales (*Kogia sima*; Baird et al., 2021), Antarctic minke whales (*Balaenoptera bonaerensis*; Pallin et al., 2022), North Atlantic right whales (Martins et al., 2020), southern right whales (Christiansen et al., 2022), gray whales (*Eschrichtius robustus*; Christiansen et al., 2021), bowhead whales (Koski et al., 2015), humpback whales (Napoli et al., 2024), fin whales (*Balaenoptera physalus*; Degollada et al., 2023), and blue whales (*Balaenoptera musculus*; Ramp et al., 2021).

Drones have also been used to estimate the size and mass of sperm whales to date (Dickson et al., 2021; Glarou et al., 2022); however, to the best of our knowledge, drone aerial images have not been used for photo-identification of sperm whales. Herein, we characterize the types of sperm whale markings that can be recorded using a UAS, and we assess the potential use of drones to recapture individuals between years, demonstrating how UAS use can complement existing identification methodologies to enable additional opportunities to identify sperm whales at sea.

Methods

Study Areas

Dedicated fieldwork took place at Andenes, Andøya, Norway, in 2020 and 2022-2024, primarily within Bleik Canyon and Andfjord. Off the Azores Islands (Portugal), fieldwork was undertaken off Faial Island in 2017 (under Research Permit Nos. 37/2016/DRA and 80/2017/DRA) and around the coast of São Miguel from 2021 to 2024 (under Permit Nos. DRAM/LEMASM/2021/001, DRAM/LEMASM/2022/005, DRAM/LEMASM/2022/004, DRAM/LEMASM/2023/008, and DRAM/LEMASM/2024/008). Opportunistic data collection also took place at Shetland, Scotland, and at Dursey Island, Ireland, in 2022 (Figure S1; supplemental figures and video footage for this article are available on the *Aquatic Mammals* website).

Fieldwork was conducted using rigid inflatable boats (RIBs) or small fiberglass vessels (< 12 m) either during commercial whale-watching operations (with Whale2Sea in Norway) or dedicated research trips (University of the Azores, University of Tromsø in Norway; Picos de Aventura, Azores Boat Adventures, and Terra Azul in the Azores). Trips took place during good environmental conditions—≤ 2 m swell and ≤ 3 Beaufort sea state with some exceptions of 3 m swell at a Beaufort sea state of 4. Precipitation occurred in some instances (rain or snow) during some field days.

Sperm whales were primarily located using a directional hydrophone in Norway, and on some occasions from a land lookout at the Andenes lighthouse (~ 45 m above sea level) using 25 × 80 bigeye binoculars. Once the sperm whale being acoustically tracked stopped clicking (indicating it likely would resurface), the whale was located with the naked eye. In the Azores, sperm whales were spotted from land by vigias (land lookouts) using 15 × 80 binoculars, and the vessel was directed towards the animals while they remained at the surface. A directional hydrophone was used to locate echolocating sperm whales when no vigia was available.

Once at the surface, the sperm whale was approached within 50 to 100 m, and the vessel was positioned behind or to one side of the whale. Photo-identification photos of sperm whales (e.g., body, dorsal fin, fluke) were taken using DSLR and mirrorless cameras with telephoto zoom lens when possible as part of existing long-term monitoring efforts in Norway and the Azores.

Aerial Photo-Identification Data Collection

Aerial photo-identification images were obtained using one of several multi-rotor quadcopter models (DJI Phantom Pro 3, DJI Phantom 4 Pro, Phantom 4 Pro V2.0, DJI Mavic Pro 2, and DJI Mavic Pro 3) that were operated using the DJI 4 Go app by a trained drone pilot (authors SAOC, FAA, HC, and RP). The drone was launched once the vessel was in position by a sperm whale and was flown typically at 25 m; heights ranged between 5 and 40 m (occasionally to 120 m) depending on the sighting circumstances (e.g., number of whales together, how widely spaced they were) while over sperm whales at the surface.

From 2020 onwards, high-resolution video footage (filmed in 4K/60fps) was taken during the drone's approach to sperm whales to ensure some identifiable data were gathered if the whale dived while it was approached. Data were then primarily gathered in the zenithal position at 90° (nadir view) directly above the animal. Both photographs and video footage were taken of each sperm whale at the surface, with footage prioritized over photographs when individuals socialized or rolled onto their sides to ensure opportunities to gather images for identification purposes were maximized. Aerial footage also facilitated more opportunities to capture the fluke when held just below the surface during good environmental conditions (Beaufort sea state < 2; 1 m swell) in which the fluke shape and trailing edge were visible.

Footage was recorded when a sperm whale's diving sequence began at the start of a shallow dive that it typically used to build momentum for a secondary deep dive. The body was most visible just before the animal dived when it displayed the head, body, tail stock, and tail fluke clearly. The wake created by diving whales' tails also provided a momentary white color contrast that highlighted details of the fluke's trailing edge, especially when notches were small in size (see supplemental video).

Image Quality Assessment

Photo-identification images were extracted either as stills from video files or directly from JPEG images collected by the drone when the target sperm whale displayed its body in a clear field of view (above and below water depending on environmental conditions) and where identifiable physical features were clearly visible along the dorsal surface or flanks of flown-over sperm whales.

Data were checked for image quality following Arnbom (1987), where the focus, exposure, orientation, and visibility of the sperm whale determined the suitability of the aerial data collected (Table 1). Flight data were reviewed for all photographs and videos taken during each flight; frames in which the sperm whale was most clearly visible and identifiable were utilized to develop a photo-identification catalogue using drone images per field season at each location.

Table 1. Aerial photograph quality assessment criteria for sperm whale (*Physeter macrocephalus*) photo-identification data collected using a drone; *Arnbom (1987).

Criteria	Description
Focus	Sharpness of the photo/video still*
Resolution	Photo/video still quality overall related to the megapixels captured in shot
Glare	Sun's strength and effect in overexposing or backlighting the animal
Orientation	Position of the sperm whale at the surface (e.g., dorsal, lateral, ventral sides)*
Wake	Body parts obscured by the sperm whale's wake or waves in poor weather
Fluke	Fluke captured above the water upon diving; visible underwater

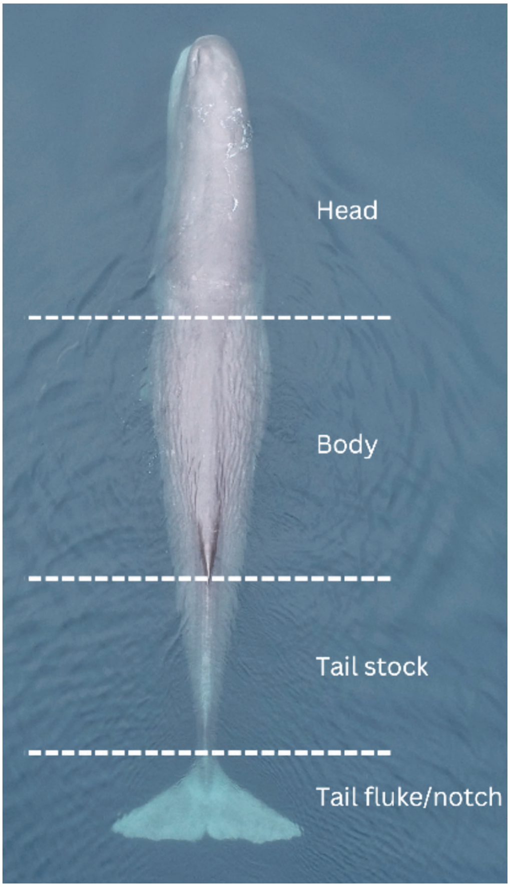

Figure 1. Example of the body sections used to differentiate between sperm whales (*Physeter macrocephalus*) for aerial photo-identification purposes marked on a male sperm whale off Andenes, Norway (Aerial still taken by Seán A. O'Callaghan)

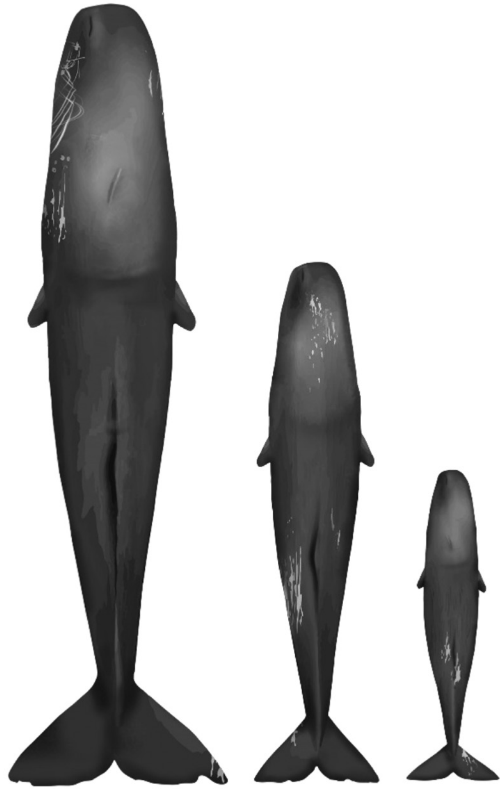

Figure 2. Male, female, and calf sperm whale examples with frequently recorded markings attributed to each sex and age class (Illustration by Myriam El Assil)

Characterization of Markings

To investigate the presence and prevalence of physical features along a sperm whale's dorsal side, images were divided into five sections corresponding to the (1) head, (2) body, (3) tail stock, (4) fluke, and (5) notch. Marks such as scarring, indentations, lacerations, skin blotches/lesions, and parasites were investigated along with the shape of the tail stock, fluke, and fluke notch, as well as any trailing edge markings (Figures 1 & 2; Table 2).

These physical features can be temporary or permanent. Temporary features include lesions, blotches, whale lice (Cyamus, Neocyamus), and stationary parasites (stalked species that are anchored in one position such as *Xenobalanus* and *Pennella* spp.; Hermosilla et al., 2015). These temporary features can change within an encounter depending on a whale's behavior (shedding skin while animals are socializing and making body contact) or between days (e.g., whale lice move slowly around the epidermis layer). Skin lesions and blotches may change between seasons depending on the whale's health status but may also be discarded as the whale sheds its skin. Long lasting and apparently permanent features include color patterns such as speckles, scars, white marks, and rake marks attributed to individual variation in skin color (Hanninger et al., 2023b). Rake marks may appear on sperm whale bodies from social interactions with other whales (e.g., on the head from aggressive intraspecific fighting; Kato, 1984; Clarke & Paliza, 1988; MacLeod, 1998; Eguiguren et al., 2023).

Smaller rake marks may develop on body appendages where smaller dolphin species may be able to bite (e.g., fluke edge or sides, dorsal and pectoral fins) following interactions with other species, such as killer whales, which is most likely related to an attempted unsuccessful predation or harassment event (Pitman et al., 2001; Weir et al., 2010; Dunn & Claridge, 2013; Whitt et al., 2015; Sucunza et al., 2022). Additional harassment from

Table 2. Descriptions of physical features on sperm whale body sections visible in drone images that are useful for identification purposes. *Sources:* *Arnbom & Whitehead, 1989; **Sarano et al., 2022.

Body section	Category	Longevity	Description
Head	Rake markings	Variable	Tooth scar markings appearing either white as scar damage or sliced into the animal's skin. Most prevalent on the left or right side of adult male's head, likely due to intraspecific conflict.
	Speckles	Apparently permanent	A series of small white markings clustered together starting at the anterior of the head moving posterior in various quantities.
	Laceration	Permanent	A deep, straight cut on the animal, often into the blubber layer. Likely caused by a vessel collision.
	Indent	Permanent	A superficial to deep blunt area of damage to the sperm whale's head causing an impression to occur in its epidermis/blubber layer.
	Shedding skin	Temporary	Skin patches that appear to be a lighter color to adjacent areas of darker skin, often in sections indicating the skin layer is being shed.
	Whale lice	Temporary	Small white lice present on female and young sperm whales that change position occasionally while moving on the sperm whale's epidermis.
	Lesion	Temporary	Whale pox or skin disease that causes localized skin discoloration.
	Scarring	Variable	Damaged areas of skin appearing white where previous wounds have healed.
	Blotches	Temporary	Wide areas where the skin has changed color to grey or black.
Body	White marks	Permanent	A linear or slightly curved white line along the animal, often parallel to the dorsal fin along its flank or patches of white present around the dorsal fin.
	Body blotch	Variable	An often circular-shaped area around the dorsal fin where coloration may vary from white, grey, or tinged with orange and yellow.
	Dorsal indent	Permanent	A localized area anterior to the dorsal fin where an indentation has been made into the animal.
	Parasites	Temporary	Stalked parasites attached to the sperm whale, often along its flanks and sometimes fluke. Whale lice may also occasionally occur.
	Scarring	Variable	An area of bright white indicating tissue damage from a past physical trauma that may originate from natural or anthropogenic (e.g., entanglements, ship strikes) sources.
	Calluses	Permanent	Greyish deformity on the dorsal fin related to female whales.*
	Shed skin	Temporary	Lighter-colored skin patches indicating the skin was coming off.
Tail stock	Scarring	Variable	White area of tissue indicating an area where tissue healed from a past physical trauma.
	Indent	Permanent	A divot into the tailstock.
	Knuckle shape	Likely temporary	The roundness or pointiness of the knuckles on their trailing edge which likely changes with age.
Fluke	Triangular	N/A	Overall fluke shape appears triangular.
	Curled	N/A	One or both of the tail fluke tips are curled inwards on itself.**
	Damaged	N/A	Section of the fluke's tip is missing.*
	Raked	Variable	Prevalent rake marks from harassment or predation attempts by smaller cetacean species—likely killer whales, pilot whales, false killer whales, or Risso's dolphins.
Fluke notch	Line	N/A	Tail notch is straight when they meet at the centre.
	V shaped	N/A	The tail notch does not touch on both sides; it sharply meets in the middle.
	U shaped	N/A	Horseshoe-shaped notch.
	Overlapping	N/A	Both sides of the notch meet, but one overlaps on top of another either on the left or right sides.
	Open	N/A	Notch does not join in the centre of the fluke and leans on one side of the fluke's trailing edge.

short-finned pilot whales (*Globicephala macrorhynchus*), long-finned pilot whales, false killer whales (*Pseudorca crassidens*), and Risso's dolphins may also cause rake marks on sperm whale bodies (Palacios & Mate, 1996; Weller et al., 1996; Smultea et al., 2014; Fernández et al., 2022; Hanninger et al., 2023b).

Permanent physical markings include indents, lacerations, damaged flukes, and calluses. Indents may have a natural cause but may also relate to blunt trauma associated with ship strikes (Hanninger et al., 2023a). Lacerations show a deep cut and likely stem from ship strike injuries (Hanninger et al., 2023a). Calluses on the dorsal fin are believed to be from physical contact between females over their lifetime (Arnbom & Whitehead, 1989).

Fluke shape, from an overhead perspective, was used as identification criteria to differentiate between sperm whales in addition to marks along the fluke's trailing edge, which is widely used in the literature to identify individuals. Four categories were used: (1) triangular, (2) curled, (3) damaged, and (4) raked (Figure S2). Fluke notch types were an additional secondary identification feature when using the fluke shape and trailing edge for identification purposes—for example, line, V-shaped, overlapping, U-shaped, and open notches (Figure S3). Head types and body marks for sperm whales were differentiated from one another to determine the number of sperm whales flown over within and between seasons (Table 2; Figure 3). Calf and juvenile sperm whales were distinguished from one another using indents; whale lice; presence of shed skin; and permanent white markings on heads, dorsal fins, and flukes (Figure 4).

Data Processing

The number of sperm whales identified in Norway and the Azores were totaled within each field season at each location. Whale age classes were attributed to individuals by their physical characteristics and in relation to the size of nearby whales to gauge the group composition from aerial data. Individuals were also differentiated into adult, juvenile, and calf categories. To determine the suitability of using aerial photographs to identify sperm whales, the whale recapture rate between seasons in Norway and the Azores was assessed by comparing catalogues created at both locations to determine if marks used for identification purposes persisted between years. The number of sperm whales with flukes captured above water or as subsurface flukes was also totaled in Norway and the Azores to gauge how aerial images can help gather photo-identification data on flukes. The prevalence of marks observed with aerial images was compiled with tallies of mark types per individual sperm whale on their first sighting to evaluate how common they were within the two study areas: (1) a high-latitude foraging ground and (2) a lower-latitude nursery ground.

Results

The number of individual identifications made in Norway ranged from 21 (2020) to 60 (2024) and totaled 160 individual sperm whales across four field seasons. In the Azores, 11 sperm whales were identified off Faial in 2017, while four to 67 were identified in São Miguel between 2021 and 2024, which tallied to 163 individual sperm whales in four field seasons there but, when combined, 174 sperm whales were identified in the Azores overall. Opportunistic data were collected from live sperm whales that came into coves and bays in Scotland and Ireland in 2022, representing two separate individuals. In total, 336 individual sperm whales were documented during this study across all areas. Of these, in the Azores, 75 adults, 25 juveniles, and 40 calves comprised the dataset. The male whales in Norway, Scotland, and Ireland were deemed to be subadult to adult in age class.

Aerial Fluke Photo-Identification

From aerial footage, fluke ups from 129 individuals in Norway and 46 in the Azores were recorded above the water; these enabled the identification of individual sperm whales from an overhead dorsal perspective. More subsurface flukes were recorded (when possible) in the Azores—94 individuals compared to 40 in Norway. The lone male sperm whales in Scotland and Ireland did not fluke up but were in relatively shallow water when recorded.

Socializing females often remained at the surface for prolonged periods of time (> 2 h), while juveniles and calves either did not fluke up or there were no distinguishing features present on the fluke. Subsurface images of flukes that were held flat just beneath the surface, in the processes of diving, or if flicked above the surface during biopsy sampling or satellite tagging enabled identification confirmation because the animals that were disturbed often did not fluke up when diving after being sampled or tagged (Figure 5). The white-water runoff from a fluke that was lifted before a dive offered additional contrast to the trailing edge and assisted with identification.

Prevalent Aerial Identification Features

Indentation marks on the head and white marks on whale bodies were the most frequently recorded categories in both the Azores and in Norway (Table 3). Rake marks on the head were also more prevalent

Figure 3. Frequent distinguishable head and body marking categories for female/juvenile sperm whales (top row) from São Miguel, Azores, and male sperm whales (bottom row) from Andenes, Norway (Aerial stills taken by Seán A. O'Callaghan at 25 m and cropped accordingly for demonstration purposes)

in Norway than the Azores where only one confirmed adult male was flown on the nursery grounds (Table 3). A summary percentage of feature occurrence useful for aerial identification purposes in the Azores and Norway are presented in Table 3. The triangle-shaped fluke was the most common shape in both the Azores and Norway followed by damaged flukes being equally prevalent at both locations (Table 3). Flukes with rake marks were the third most prevalent type but were only recorded in Norway, while curled flukes were the rarest type, also only noted in Norway (Table 3). The V-shaped fluke notch was the most frequently recorded type in the Azores and Norway followed by the line type and then overlapping, respectively (Table 3).

Recaptures Between Years

Resightings were made for eight individual whales in Norway during this study: one individual was sighted 2 y apart (2020 to 2022) while seven individuals were 3 y apart (2020 to 2023) (Table 3). Scars and back blotch marks remained

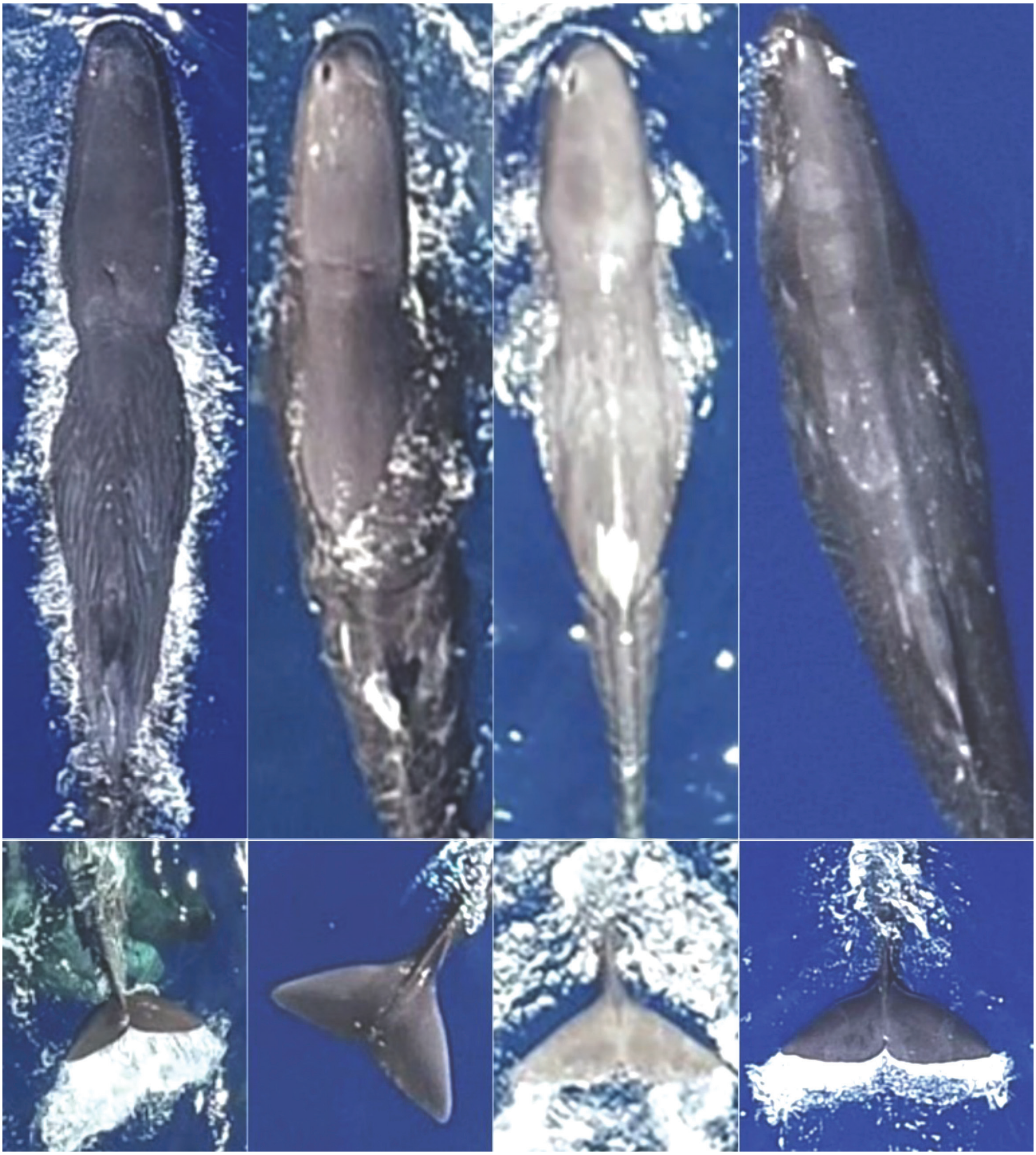

Figure 4. Sperm whale calf and juveniles displaying identifiable markings along their heads, bodies, and tail flukes off São Miguel, Azores (Aerial stills taken by Seán A. O'Callaghan at different altitudes and cropped accordingly for demonstration purposes)

the same for resighted sperm whales in addition to the fluke's trailing edge. Additional rake marks were noticed on two sperm whales, while the development of speckles and a new indent on the skull crest of two other sperm whales were also noted (Table 4). Resightings were also made for four sperm whales at São Miguel in the Azores: two were 1 y apart (2022 to 2023) and two were 2 y apart (2022 to 2024). These animals retained their head/body scars, indentation(s), and white markings along with some dorsal markings on their flukes (Figure 6).

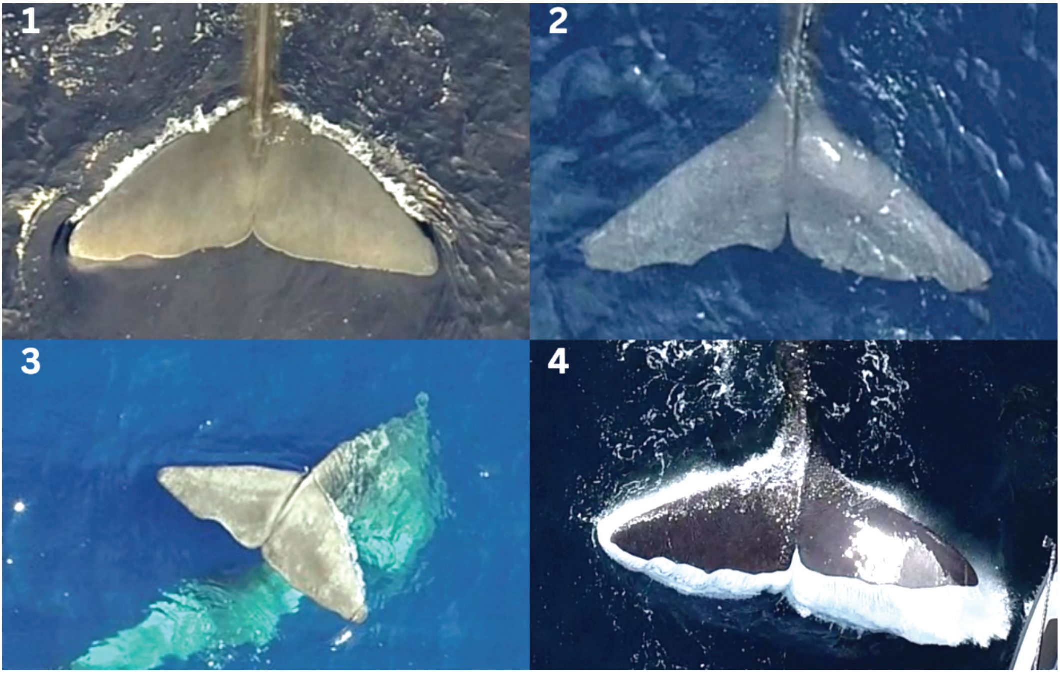

Figure 5. Tail fluke trailing edges visible just beneath the surface before diving (1), while swimming just below the surface (2), when diving without showing the tail fluke above water (3), and when a sperm whale reacted to being biopsy sampled (4). (Aerial stills taken by Seán A. O'Callaghan at 25 m and cropped accordingly for demonstration purposes)

Table 3. Prevalent aerial identification categories for sperm whales in the Azores and Norway using permanent and variable markings on the body and the fluke. *Fluke shales and notches tallied independent to one another and summed based on the available data.

Body section	Category	Azores % (n = 142)	Norway % (n = 161)
Head	Rake markings	1.4	4.34
	Speckles	9.15	7.45
	Laceration	2.11	6.83
	Indent	19.0	29.81
	Scarring	17.6	21.11
Body	White marks	35.9	23.6
	Dorsal indent	0.7	3.1
	Scarring	7.74	1.24
	Calluses	2.1	0.00
Tail stock	Scarring	1.4	1.24
	Indent	1.4	0.00
	Knuckle shape	2.1	1.24
		Azores % (n = 197)*	Norway % (n = 288)*
Fluke	Triangular	53.0	41.9
	Curled	0.0	1.3
	Damaged	5.1	3.4
	Raked	0.0	3.1
Fluke notch	Line	14.7	17.8
	V shaped	20.4	23.7
	U shaped	0.0	0.6
	Overlapping	6.6	7.6
	Open	0.5	0.6

Table 4. Resighting rates for aerial photo-identified sperm whales in Norway and the Azores, 2020-2024

Year	Location	No. of identifications	No. of recaptures
2020	Andenes, Norway	21	0
2022	Andenes, Norway	32	1
2023	Andenes, Norway	55	7
2024	Andenes, Norway	60	0
2021	São Miguel, Azores	4	0
2022	São Miguel, Azores	67	0
2023	São Miguel, Azores	64	2
2024	São Miguel, Azores	32	2

Discussion

Boat-based photo-identification studies have limitations where vessel proximity to animals, the behavior of animals being grouped together or widely spaced apart, in addition to boat maneuverability when close to animals, reduces the ability to identify whales farther away from the vessel (Würsig & Jefferson, 1990). The use of a drone allows for the surfacing animal to be approached from greater distances as well as offers the ability to target multiple animals in a single flight in comparison to a boat that may focus attention on one sperm whale or groups that have a tight cohesion that can affect the photographer's ability to capture identifiable shots. Additionally, drone use enables the collection of a variety of data from a multidisciplinary perspective when a drone is the primary research tool for behavioural, photogrammetry, blow sampling, and faecal sample collection projects (Costa et al., 2022; Glarou et al., 2022; Álvarez-González et al., 2023). Using a drone to gather data for individual identification is especially useful in more intense research situations when the angle at which animals show identifiable features cannot be easily photographed from a boat (e.g., during biopsy sampling and tagging operations).

Sperm whales did not appear to react to the drone's presence unless it was flown in very close proximities (5 to 25 m) at which point their reaction was to roll to one side, potentially trying to visually look for the drone. The drone's acoustic output may be detected by sperm whales, but it depends on the drone model and how it was flown around the animals (Christiansen et al., 2016; Laute et al., 2023). Dickson et al. (2021) noted no noticeable reaction to the use of a DJI Inspire 1 Pro quadcopter when flown over sperm whales between 25 and 30 m in altitude.

Our results demonstrate that several sperm whale features can be seen in images obtained by UASs and can reliably facilitate the identification of individual animals. All population segments (adult males and females, juveniles, and calves) presented markings along their bodies that can be used for photo-identification (Clarke & Paliza, 1988; Frantzis et al., 2014; Rødland & Bjørge, 2015; van der Linde & Eriksson, 2019). Aerial photo-identification enables the collection of fluke images from a dorsal perspective that allows for the augmentation and merging of aerial images with existing photo-identification catalogues to more readily confirm the shape of fluke trailing edge(s) that might be visible both ventrally (for boat-based photo-identification) and dorsally (for aerial photo-identification) but from different collection platforms (Rødland & Bjørge, 2015; van der Linde & Eriksson, 2019). Taking fluke images from an aerial perspective helps account for a tilt that may affect the visibility of a fluke's trailing edge as a sperm whale dives (Figure 7).

Young sperm whales often do not fluke up when diving or their flukes may be unmarked. Thus, the use of other body marks is required to differentiate between different whales (Gero et al., 2009; Frantzis et al., 2014). The use of aerial images increases the chances of capturing recognizable features and evaluating their prevalence over time as an individual grows—for example, white markings remained in sperm whales resighted during this study, suggesting some features may be more permanent than previously assumed. Physical marks on sperm whales may originate from anthropogenic activities such as entanglement in fishing gear and ship strikes (Hanninger et al., 2023a); these interactions may result in thin body scars from long-line hooks or deep lacerations and indents (Ramp et al., 2021; Hanninger et al., 2023a) as were noted on animals in this study. These marks appear to become permanent and, thus, they represent an opportunity to use them as identification criteria over prolonged periods of time (up to at least 3 y in this study).

Whale lice, such as *Neocyamus*, that are present on primarily female and young sperm whales are white in colour, which contrasts with the skin of surfacing sperm whales, making them more visible from an aerial perspective (Hermosilla et al., 2015). In this study, their occurrence and slow movements on the host's body allowed for some reidentifications within short timespans during the same season for sperm whales in the Azores. Additionally, skin marks that may be piebaldism, where greyish-white patches or hypopigmented skin patches may develop on sperm whale bodies,

Figure 6. Recaptured sperm whales between years using aerial photo-identification categories with the body (Azores) and tail fluke (Norway) between 2020 and 2024 (Aerial stills taken by Seán A. O'Callaghan at 25 m and cropped accordingly for demonstration purposes)

Figure 7. Tail fluke photos that were identifiable from both the aerial photographs and those taken from a boat for a female (left) and male (right) (*Photo credits:* Top left photo provided by Francisco Garcia and top right photo provided by Marten Bril, Whale2Sea; aerial stills taken by Seán A. O'Callaghan at 25 m and cropped accordingly for demonstration purposes)

particularly on the flanks adjacent to the dorsal fin and the fluke, were useful long-term markings to reidentify sperm whales (Hanninger et al., 2023b).

While shedding skin, lesions, blotches, and parasites were recorded with some frequency in our study, their adequacy for photo-identification must be considered carefully, as well as how they are related to the purpose of the study. Such temporary marks (like shedding skin and parasites) have been noted elsewhere but are often excluded from long-term photo-identification catalogues (Sarano et al., 2022). Sperm whales are thought to shed their skin frequently in warmer (19° to 26°C) seawater temperatures and less frequently in cooler temperatures (14° to 18°C) whereby skin lesions or blotches may naturally be lost over time to maintain the sperm whale's health, which limits their usefulness for reidentification purposes to within-season periods (Pitman et al., 2019).

Likewise, verifying the presence of skin lesions, blotches, and parasites represents a tool that is mainly useful for reidentifying sperm whales within a season rather than between seasons depending on skin shedding rate and on whale health as they can be visible from above and provide a secondary identification characteristic to help establish a known sperm whale's identity or verify that it previously was not known. That said, Gaydos et al. (2023) used skin lesions successfully to re-identify killer whales from the Southern Resident population between Canada and the United States, so these marks may be a useful future tool for species such as sperm whales given that such lesions may reflect health status. Still, further long-term monitoring of such marks on sperm whales is required to assess their usefulness.

The advancement of technology to support cetacean photo-identification projects has not only been confirmed through the development of new equipment to capture large volumes of data from the sea's surface (digital cameras) and from the air (drones), but also from a data processing perspective. Artificial intelligence (AI) and machine learning has enabled the creation of platforms such as Happy Whale and Flukebook to receive, process, and match whales using identifiable features sourced from submissions made by both the general public and researchers (Levenson et al., 2015; Cheeseman et al., 2017; Patton et al., 2023). This approach has been especially successful in monitoring the movements and life histories of humpback whales across entire populations (Cheeseman et al., 2023) and may also prove powerful in monitoring sperm whales when combining all available photo-identification resources.

Overall, the incorporation of aerial drone images for photo-identification purposes shows potential to monitor sperm whale populations using the head, body, and flukes from an overhead perspective. Long-term monitoring of cetacean species through the use of photo-identification forms the basis from which population monitoring and movement patterns of animals can be extracted. Utilizing drones for the minimal to non-invasive gathering of identifiable imagery while simultaneously supporting other data collection methods will help to assess the species and, in turn, inform protection measures and policies for sperm whales. Aerial photo-identification complements the traditional, boat-based photo-identification methods used on sperm whales by obtaining flukes and dorsal fin shots both above and below the water's surface along with the entire dorsal side of surfacing animals. This maximizes the possibility of identifying individuals at various stages of their life cycles and can yield additional opportunities for monitoring some individuals across their life spans.

Note: The supplemental figures and video footage for this article are available in the "Supplemental Material" section of the *Aquatic Mammals* website: https://www.aquaticmammalsjournal.org/supplemental-material.

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