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A Novel Technique for Photo-Identification of the Fin Whale, *Balaenoptera physalus*, as Determined by Drone Aerial Images

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Abstract: Drones have become a crucial research tool across marine environments over the past decade, being specifically useful in marine mammal research. Fin whales (*Balaenoptera physalus*) have been monitored feeding along the Catalan coast, Spain (NW Mediterranean), since 2014. To overcome issues such as the distance between a whale and a research vessel or the lack of distinctive dorsal fin features, an aerial identification technique was developed. It uses the fin whales' characteristic central chevron pattern (CCP) and blaze, which are clearly visible from an overhead position. A total of 237 individual whales were identified between 2015–2022 in this study area, of which there were 35 interannual recaptures. While the dorsal fin may undergo modifications over time, the CCP and blaze patterns did not naturally alter over the years, with one whale displaying the same characteristics 8 years apart between the first and the most recent sightings. As such, this coloration pattern provides a reliable identification feature to be used for the interannual identification and population monitoring of fin whales using drones. This novel technique aims to improve and unify this species cataloguing overseas by using the CCP and blaze obtained from UAV (unmanned aerial vehicle) zenithal videos as a robust identification tool.

Keywords: whale identification; UAV; fin whale; central chevron pattern; blaze; dorsal fin; Catalan coast

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1. Introduction

Fin whales (*Balaenoptera physalus* (Linnaeus)) are the second largest whale species found in all the world's major oceans [1]., They are currently considered Vulnerable under the IUCN Red List of Threatened Species [1]. In the Mediterranean Sea, they are the only species of mysticetes present regularly across the entire basin, from the Alboran Sea in the west to the Levantine Sea in the east [2,3]. Two genetically distinct subpopulations of fin whales have been described in the area, the "true" Mediterranean fin whales and the North East North Atlantic (NENA) fin whales [4,5]. In 2021, the Mediterranean subpopulation was classified as Endangered by the IUCN Red List of Threatened Species under criteria C2a(ii), and to date, it shows a continuous decreasing trend [6]. Movement patterns indicated that the NENA fin whales move eastwards through the Straits of Gibraltar during the winter months and westwards out into the Atlantic Ocean in the summer [7–9], while acoustic detections and satellite tagging showed that both populations overlap in range off the Mediterranean coast of Spain [10–13]. Specifically, the Catalan coastline on the northeastern Iberian Peninsula has been identified as a seasonal foraging habitat during the spring–summer months, with sightings peaking in proximity to submarine canyons [14,15].

The most common approach used to evaluate fin whale movement patterns, population size, and dynamics is the photo-identification technique [16,17]. In the Mediterranean Sea, this method has been used since 1990, primarily in the Ligurian Sea [16–18]. Photo-identification uses distinctive features to identify individuals, including the shape of the dorsal fin, any possible markings, scar patterns, and pigmentation. Fin whales are characterized by their diagnostic asymmetrical coloration on their heads [19,20] (Figure 1).

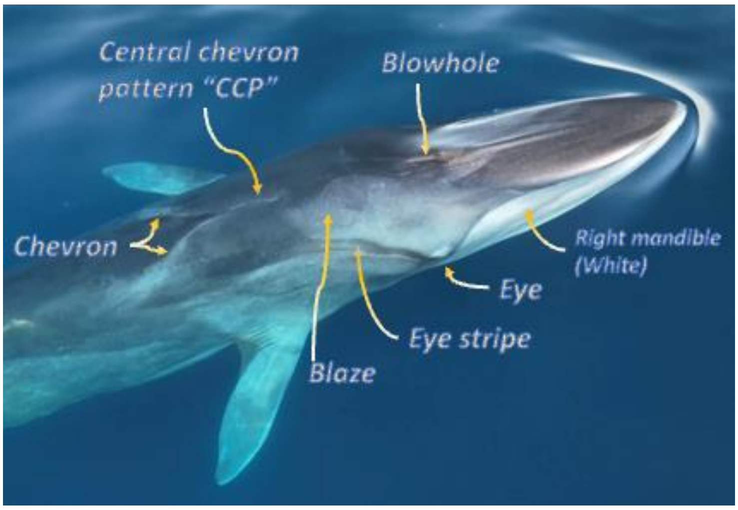

Figure 1. Aerial perspective of a fin whale's (*Balaenoptera physalus*) coloration patterns displaying the central chevron pattern (CCP), left/right chevrons, and blaze. Photograph by EDMAKTUB Association.

The right mandible is white, and a light grey discoloration known as a blaze is positioned posterior to the eye, in contrast to the dark slate coloration on the left side [19]. A light V-shaped pigmentation, the chevron, is present in the dorsal area behind the head. The chevron pattern, mainly on the right side, is also used as a characteristic in conventional photo-ID [19].

Standard vessel-based photo-identification of fin whales mainly focuses on dorsal fin images, as well as side chevron–blaze patterns and the portion of the body that the animals expose during surfacing sequences [19,21]. The quality of the obtained images strongly depends on the whale's position relative to the vessel and on the weather conditions; moreover, the chevron is not always visible from the vessel, due to the water covering the area, and thus it is normally used as complementary information to dorsal fin images [19,22–24]. Additionally, fin whale dorsal fins often do not present recognizable features, such as distinctive notches, as small cetacean species do [25]. Therefore, similarly shaped, indistinctive dorsal fins, smooth and uniform skin, as well as hidden chevron patterns reduce photo-identification efficiency for this species using vessels [19].

To overcome these issues, aircrafts have been extensively used for marine mammal research [26,27]. Traditional platforms include manned aircrafts, such as planes and helicopters, to produce population abundance estimates, document distribution ranges, record behavior, and monitor individuals through the use of photo-identification for some large whale and dolphin species [27,28]. In the Mediterranean Sea, aerial surveys have been conducted infrequently, typically within sectioned study areas across the basin [29–32].

Over the last decade, unmanned aerial vehicles (UAVs, hereafter drones) have become a powerful tool for wildlife research [33,34]. The advantages to using these devices include their affordable prices, their ease to maneuver and deploy, their free movement, and their independence from the launch platform, as well as the possibility to conduct close-up views of the animals in a noninvasive and less disturbing way than with the use of manned aircrafts [28,34–38].

Drones are now widely used in marine mammal research for photogrammetry studies [35,39,40], population assessments [41], blow-sample collection [42,43], behavioural and social structure studies, photo-identification of individuals [44–46], and anthropogenic interactions analysis [21]. To date, baleen whales have not displayed disturbance reactions to drone noise [35,47–49]. The aforementioned arguments suggests that the employment of drones for baleen whale research is safe and effective.

Several studies have demonstrated drone usefulness in photo-identification research on various cetaceans, such as bottlenose dolphins (*Tursiops truncatus* (Montagu, 1821)), Risso's dolphins (*Grampus griseus* (G. Cuvier, 1812)), belugas (*Delphinapterus leucas* (Pallas, 1776)), killer whales (*Orcinus orca* (Linnaeus, 1758)), bowhead whales (*Balaena mysticetus* (Linaeus, 1758)), humpback whales (*Megaptera novaeangliae* (Borowski, 1781)), and North Atlantic right whales (*Eubalaena glacialis* (Müller, 1776)) [44,45,50–54]; however, similar studies on fin whales are lacking [21,55].

The aim of this work was to describe a novel photo-identification technique for fin whales, *Balaenoptera* physalus, as determined by drone aerial images in the NW Mediterranean Sea.

2. Materials and Methods

2.1. Study Area

The study area was based off the Garraf coast, primarily between Tarragona and Barcelona. It extended approximately 37 km offshore within 40.9492° N, 2.0757° E in the north and 40.8407° N, 1.4603° E in the south (Figure S1), and occasionally expanded to the Balearic basin, Denia, and off the coast of Barcelona, Blanes, and Palamós, in the northeast of Catalonia. Data collection took place annually from February to June between 2015–2022 (excluding 2020 due to the COVID-19 pandemic). Random transects during daily surveys within the study area were carried out using the 14.15 m Catana 471 catamaran RV Maktub when the weather conditions allowed (<10 m/s wind, <2 m swell). Fin whales were located while surfacing thanks to visual inspection of the area and commercial fishermen's and sailors' real-time reports. This area is an oligotrophic area with a 7 to 9 km continental shelf and with a significant input of nutrients from the coast, especially from the Llobregat River, where springtime becomes a more productive period. There are also two submarine canyons: the Foix Canyon and the Cunit-Cubelles Canyon. The dynamics of these canyons, together with the nutrients supply from shore, generate highly productive areas along the edge of the continental shelf and at the heads of these canyons [56,57] (Figure S1).

The study area is home to high biodiversity, where, apart from fin whales, seven species of cetaceans occur on a regular basis in addition to more than 22 different species of seabirds, some of which are in a critical state of conservation [15,57].

2.2. Equipment

Five DJI drone models were used over the course of the fieldwork seasons: a customized DJI F550 (2014), Phantom 3 Pro (2015–2019), Mavic Pro (2018–2019), Mavic 2 Pro (2019–2022), and Mavic 3 (2022). The DJI drones were operated using the DJI app corresponding to the drone model used on an Apple iPad Air. Each drone model had an up to 30 min battery lifespan, depending on the model and weather conditions, and the recording quality was high definition, up to 4K 120 fps. Two digital SLR cameras (two Nikon D7100 models with an AF-S 75-300 VR Nikon lens and a 150–600 Sigma lens) were used to photograph each individual whale when possible.

2.3. Photo-Identification

The sighted whales were approached by the RV Maktub (14.15 m Catana 471 sailing catamaran), sails-down and under engine power <5 knots, in compliance with the regulation on vessel behavior in proximity of cetaceans (Real Decreto 1727/2007). The vessel was kept parallel to the animals within the range of 100–300 m, and the engine was placed in neutral gear and stopped in close proximity to the whales.

The drones were flown whenever the weather conditions allowed for it (swell <2 m and wind speed <10 m/s). Each whale's diving duration was recorded by visual observers on the research vessel and the surfacing expectation time was used as an indicator for launching the drone to gather identification data.

Photographs targeted the chevron–blaze patterns, the dorsal fin, and any identifiable distinctive features, such as parasites, notches, and body lesions, photographing each individual, preferably on both flanks. Suitable images were obtained from whales positioned at an angle between 90° and 60° from the observer, and images of other distinctive body marks at less optimum angles were also opportunistically collected.

2.4. Flying Procedure

To avoid any risk of collision with the rigging, the drone was mainly launched from the vessel stern and flown towards a whale at the maximum speed of 72 kph. The orientation of the drone was altered in order to have a clear image of the whale's chevron, depending on the light condition (i.e., sun glare, waves). The device was positioned directly overhead, when possible, at between 5–30 m relative altitude (Figure 2) and was kept upwind of the whale's 6 m blow to avoid water damage and camera lens obscuring caused by water or blow spray. Video footage was taken during the entire surfacing sequence until the whale dived down, in an effort to document its behavior and to maximize the opportunities to record clear identification patterns. The location of the drone, together with the description of the whale's behavior performed by the drone operator, were used as key aids to orient the vessel and, thus, facilitate the collection of photographs.

Figure 2. The drone (DJI Mavic 3) positioned overhead of a surfacing fin whale; the yellow arrow is pointing at the drone. Photograph by EDMAKTUB Association.

2.5. Central Chevron Pattern and Video Processing Procedure

Drone zenith view perspective allowed to develop a new methodology to identify fin whale individuals through the pattern observed where the left and right chevron branches join in the dorsal midline of the animal, denominated by the authors as the central chevron pattern (henceforth: CCP) (Figure 1).

Drone videos were uploaded, cataloged, and processed using the Adobe Lightroom Classic software (11.2 version). For each video, still images with a sharp view of the CCP, right/left chevron patterns, blaze, and eye stripe were extracted (Figure 1). The quality of the images was assessed based on the light, the focus of the image, and the distinctiveness of the chevron and blaze patterns. Images were then classified by the clarity of the identification patterns and the presence of additional useful identification features, such as deformities, scarring, or permanent marks visible along the whale's dorsal surface.

Four categories were developed to describe the CCP based on its junction shape (Table 1, Figure 3): (1) the CCP branches are joined in the central area with a straight line; (2) the junction area forms a curved pattern, with different shapes; (3) the formed shape is unique and distinctive or a mix of other pattern categories; (4) the CCP branches do not join in the central area or are absent/undistinguishable. Furthermore, the blaze was also used as a secondary aerial identification aid based on its shape (pointed or rounded) and on its position in relation to the CCP and blowhole, to confirm CCP identifications when the identity was difficult to determine. Each new whale identified was then attributed a unique drone ID code (e.g., Dr_0XX). To complete the identification process, the two catalogues were visually compared to each other, and a general catalogue was eventually created by merging both datasets.

Table 1. Central chevron pattern (CCP) categorization based on the junction area pattern.

Category		CCP Junction Shape Description
1		**Straight**
	A	Short line or no line
	B	Long line, centered
	C	Short or long line towards one side, accent
2		**Curved**
	A	"C", "7" right or "¿" shape
	B	"D", "inverted C", "7", "?" shape
	C	"h" shape
	D	"Z" or "S" shape
3		**Distinct**
	A	Circle, flower, leaf (clover)
	B	Flame, triangle
	C	Others/mix of different categories
4		**Unjoined or Absent**
	A	Unjoined
	B	Absent or undistinguishable

2.6. Dorsal Fin Photo Processing Procedure

For each observed individual, photographs were processed by image quality and categorized as (a) chevron–blaze, (b) left flank and dorsal fin side, (c) right flank and dorsal fin side, and (d) peduncle. The quality of the images was assessed by the angle at which the animal was captured, the image focus, the light exposure, the portion of the body shown by the animal, the presence of any distinctive features on the fin or the body, and the presence of external parasites. Photos that did not satisfy the quality criteria were discarded. The dorsal fin shapes were categorized into types A–F and 0, where 0 referred to the dorsal fins that did not fit any other categories [19], and used as the base identification criteria (Figure 4). The matching of good-quality pictures was conducted using the naked eye while analyzing digital images on a computer screen. The matching procedure was carried out by two researchers in order to double-check matches, avoid mismatching individuals, and maintain a high level of reliability in the catalogue. Suitable photos were manually compared to one another within the catalogue, starting from the current season and proceeding backwards in time. All the recapture events were annotated and, if no match was found, a new identification code (e.g., Bp_0XX) was assigned to each new individual sighted.

Figure 3. The CCP category types used for identification purposes. The numerical legend in the lower right-hand corner of the photographs refers to Table 1 categories and subcategories. Photograph by EDMAKTUB Association.

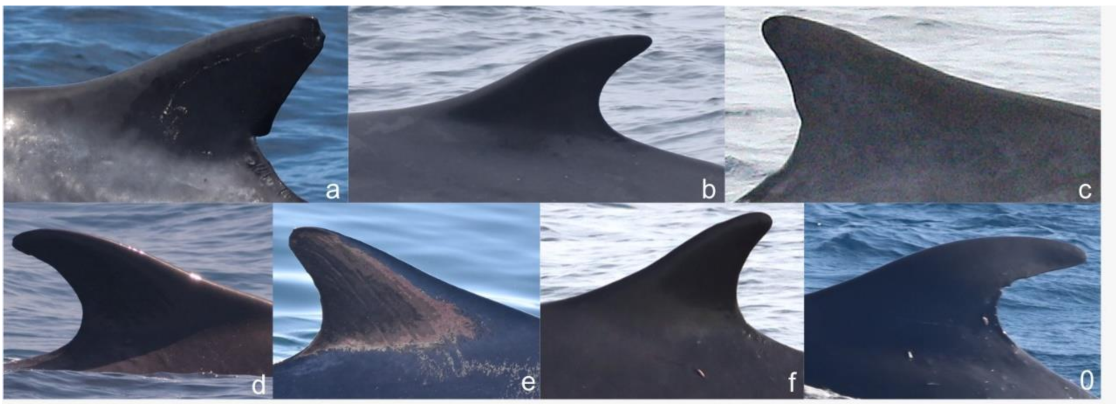

Figure 4. Dorsal fin type categorization: (**a**) broad, (**b**) long, pointed and thin, (**c**) triangular, (**d**) hooked, (**e**) short and broad, (**f**) humps on the basal leading edge, (**0**) all remaining fins [19]. The alphabetical legend in the lower right-hand corner of the photographs refers to the categorization types [19]. Photographs by EDMAKTUB Association.

3. Results

From 2015 to 2022, a CCP-based catalogue was created, including 237 identifiable whales. A total of 35 interannual recaptures were obtained, with 26 over two years, seven over three, one over four, and one over five years. Among these recaptured individuals, no natural alteration in the CCP was evident. The fin whale (Dr_004/Bp_057), "Silver", was regularly sighted (seven times) over a 6-year period, from April 2015 to April 2021. The whale displayed a 1A CCP category, and in each recapture, the drone footage revealed that the CCP remained unaltered between observations (Figure 5).

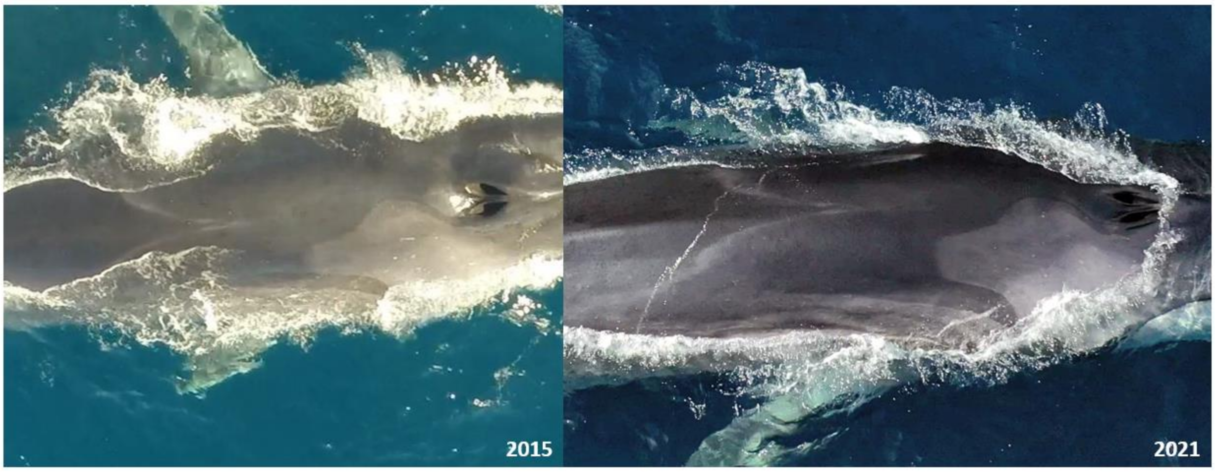

Figure 5. Examples of CCP and blaze non-alteration of Dr_004/Bp_057 "Silver" over a period of 6 years, from April 2015 to April 2021. Photographs by EDMAKTUB Association.

The rejection of drone identification images was mainly caused by the distance of the drone to the animals and the light conditions, such as severe sun glare covering the whale's distinctive features and poor lighting corresponding to dawn or dusk fieldwork.

From 2011 to 2022, a previous catalogue, based on dorsal photo-identification, was created, with 244 whales identified. The rejection of camera dorsal fin identification photos was mainly dependent on the image quality, which was affected by the distance of the animal from the vessel, the exposure, the focus, the angle of the whale, and the absence of any distinctive features on the dorsal fins. Type A fins were discarded more than the other fin types because their broad and large shapes could lead to possible identification biases.

Fin whale dorsal fin changes over time were evident, but the chevrons did not show any change, which allowed whales to be identified over different seasons successfully. This was the case of a female whale (sex determined by a biopsy sample) (Dr_010/Bp_045), "Clover", with a 3A CCP category type, which was also reidentified using the CCP over a 6-year period, from May 2016 to April 2022. The animal's dorsal fin presented some peculiar features, such as a pointy and limp tip when sighted in 2014 and 2016, and did not show any notch until 2021, when one appeared on the upper trailing edge (Figure 6a). Despite the first visual inspection of the fin suggesting the animal's recapture, its identity was confirmed only by the CCP and blaze pattern images, obtained using the drone. Similarly, another male individual (Dr_060/Bp_012), "Hook", which was first sighted in April 2013 and identified using the CCP in 2018, presented a notch on the trailing edge of the dorsal fin when sighted in 2019; this individual was recaptured on two more occasions before the notch appeared, so the CCP was required to confirm that it was the same individual. Otherwise, it would have been considered a "new" whale. This whale's CCP remained the same for three years (Figure 6b).

On the other hand, there were some individuals, such as the male (Dr_003/Bp_005), "Bruixa", that had a low pigmented chevron pattern which was difficult to observe in poor light conditions. This whale was the most regularly sighted individual (28 times) over an 11-year period between 2011–2022 with its distinctive dorsal fin but, identified through the CCP from 2015 to 2022. The whale displayed a 2A CCP category, even though it was classified as 4A until 2021. After reviewing the images, the 2A CCP category was noted in most pictures, indicating an unaltered chevron, but with a different visualization due to its light whitish mark. A white line on the whale's dorsal edge, right behind the chevron, additionally aided in its identification (Figure 7). As such, more than one category may be needed in order to be sure not to miss recaptured animals due to image quality.

Figure 6. Examples of CCP and blaze non-alteration compared to dorsal fin modification over the years. (**a**) Bp_045 "Clover" in 2018 and 2022; (**b**) Bp_012 "Hook" in 2018 and 2019. Photographs by EDMAKTUB Association.

Figure 7. Examples of CCP and blaze visualization depending on light exposure in the individual Dr_003/Bp_005 "Bruixa". The dorsal fin remained unaltered. The black arrow in the drone images points to the light whitish mark on the whale's dorsal edge right behind the chevron. Photographs by EDMAKTUB Association.

The CCP identification rate using drone images has increased over seasons, with 2022 being the year with the highest identification rate (sighted/identified), 74.7% (Table 2). The number of drone identifications increased each season (with the exception of 2019, when fin whale abundance was low in the study area) as the methodology developed and increasing the effort to capture CCP identification images was made the primary research objective (Table 2). On the other hand, dorsal fin ID has been maintained around 65% for most of the years, with 2017 being the year with the highest dorsal fin identification rate of 73.8% (Table 2). More drone identifications than dorsal fin identifications were made in 2018, 2021, and 2022 (Table 2).

Table 2. Summary for the number of fin whales identified per year (including intraannual recaptures), the number of whales sighted per season (including intraannual recaptures), and rate for identification success (sighted/identified) based on drone photo-identification and dorsal fin identification.

	2015	2016	2017	2018	2019	2021	2022
N° animals sighted	29	100	103	99	5	204	166
N° animals identified by CCP (drone)	4	18	50	60	3	145	124
N° animals identified by dorsal fin	17	45	76	48	3	138	118
N° of different individuals identified by CCP (drone)	4	13	44	41	3	76	102
N° of different individuals identified by dorsal fin	11	29	56	29	3	66	86
Identification rate by CCP (drone)	13.8%	18.0%	45.5%	60.6%	60.0%	71.0%	74.7%
Identification rate by dorsal fin	58.6%	45.0%	73.8%	48.5%	60.0%	67.6%	61.4%

No behavioural reaction was observed in relation to the presence of any drone used while collecting data, which is similar to previous studies using drones on baleen whale species, given that the sound output from the drone was likely too high a frequency to be detected by fin whales.

4. Discussion

While studies focusing on fin whale CCP aerial inspection are lacking [21,58], our observations strongly suggest the persistence of the CCP pattern between years for at least 7 years; the whale (Dr_003/Bp_005) "Bruixa" was seen in 5 different years, but its CCP did not change between successive skin molts [59,60]. To date, the photo-identification of fin whales in the Mediterranean has used dorsal fin and lateral images of surfacing individuals to recognize and monitor their presence over prolonged periods of time [17].

From 1990 until 2007, 507 individuals were recorded within the Pelagos Sanctuary between France and Italy, and the inclusion of the CCP in the future monitoring efforts may reveal further insights into the whales that use that region and the wider Mediterranean Basin [17]. CCP consistency may thus prove to play a key role in future fin whale identification studies, especially due to the fact that dorsal fins have been observed to be modified over time naturally or due to anthropogenic impacts [25,61–63].

There may be some circumstances where the CCP is not visible due to diatom masking, but this variable would only occur in cold, high-latitude waters where some fin whale populations migrate to feed [59]. Additionally, the CCP visibility may be affected by light conditions, the angle at which the drone is flown over the whale, and the resolution of the camera used. Thus, a single flight over repeated breathing sequences maximized the drones presence over animals in order to reduce discarding of unsuitable CCP footage. The use of drones to study fin whales also provides additional benefits. In the case of our study area, the majority of the whales sighted off the Catalan coast were engaged in feeding behaviours and their surfacing period was relatively short (1–4 breaths), with unpredictable underwater movements. Having an aerial perspective helped to direct the research vessel to approach them at the right surfacing direction and at acceptable distance for dorsal fin photo-identification, maximizing the opportunities to obtain useful photographs of the dorsal fin and lateral chevron patterns.

Once a whale was visually spotted from the research vessel (and weather conditions allowed), the drone could be quickly flown hundreds of meters away to reach the whale faster than the vessel and also before its deep dive (on occasions, the whale may not be resighted by the research vessel). The footage obtained during these scouting flights was downloaded and viewed on a big screen on the research vessel when the drone returned from the flight, to quickly determine the whale's identity and if additional data or samples should be gathered from it. This information proved critical when whales were not easily approachable with the research vessel, when multiple individuals were present in the same area, to differentiate between dorsal fins and to select whales to be biopsy-sampled and/or tagged.

Drone identification footage also enabled the simultaneous capture of data on behaviour, health status, photogrammetry, and for anthropogenic assessment studies [21,35,43,47], as well as minimized the potential disturbance from the research vessel.

The use of drones provides access to the whole CCP and blaze of fin whales, which were otherwise not visible with the traditional camera photo-identification methodologies from a vessel. However, it does have some considerable limitations, mainly dictated by the weather conditions. Drone models of the Phantom Pro and Mavic Pro DJI series could be safely launched and retrieved to the research vessel with wind strength less than 10 m/s and swell less than 2 m, although in certain regions, characterized by harsh weather conditions, the use of drones could be more limited.

The CCP categorization proposed in this paper was designed through the experience of researchers engaged in the identification of fin whales and is intended to be a useful tool to create an organized and intuitive catalogue in order to be able to compare and recognize new individuals by filtering categorization. This is not a universal and fixed system, but rather an open system that might be modified by adding or changing categories. The categories represent the most common patterns observed in the study area during years of research.

Given that the CCP categorization can be subjective, the use of subcategories can further help to distinguish different types of chevrons within the same category, especially in the case of chevrons that present more than one categorized feature.

Although this paper has been based primarily on CCP-based identification, the blaze shape can also be a determining factor for fin whale identification. It has been particularly useful in animals with similar CCPs or during moments when there was more than one animal and the CCP was not clearly visible due to light conditions and/or CCP pigmentation intensity. This was the case of Dr_061 and Dr_106, in which, at first sight, the chevron, and especially the CCP, could lead to confusion, but in which, thanks to the distinctive shape of the blaze, it was possible to determine that they were actually different animals (Figure 8).

In future work related to this fin whale identification technique, it may be interesting to include a characterization of the blaze. In addition, to gain efficiency, an artificial intelligence model could be programmed to identify the animals through drone videos, as it was done with dorsal fin [64–68] and caudal fin [67,69] photographs. Thus, analyzing fin whale drone images using AI would allow researchers to save time and effort on image processing and analysis, as well as to focus on research on an individual level, increasing fin whale knowledge.

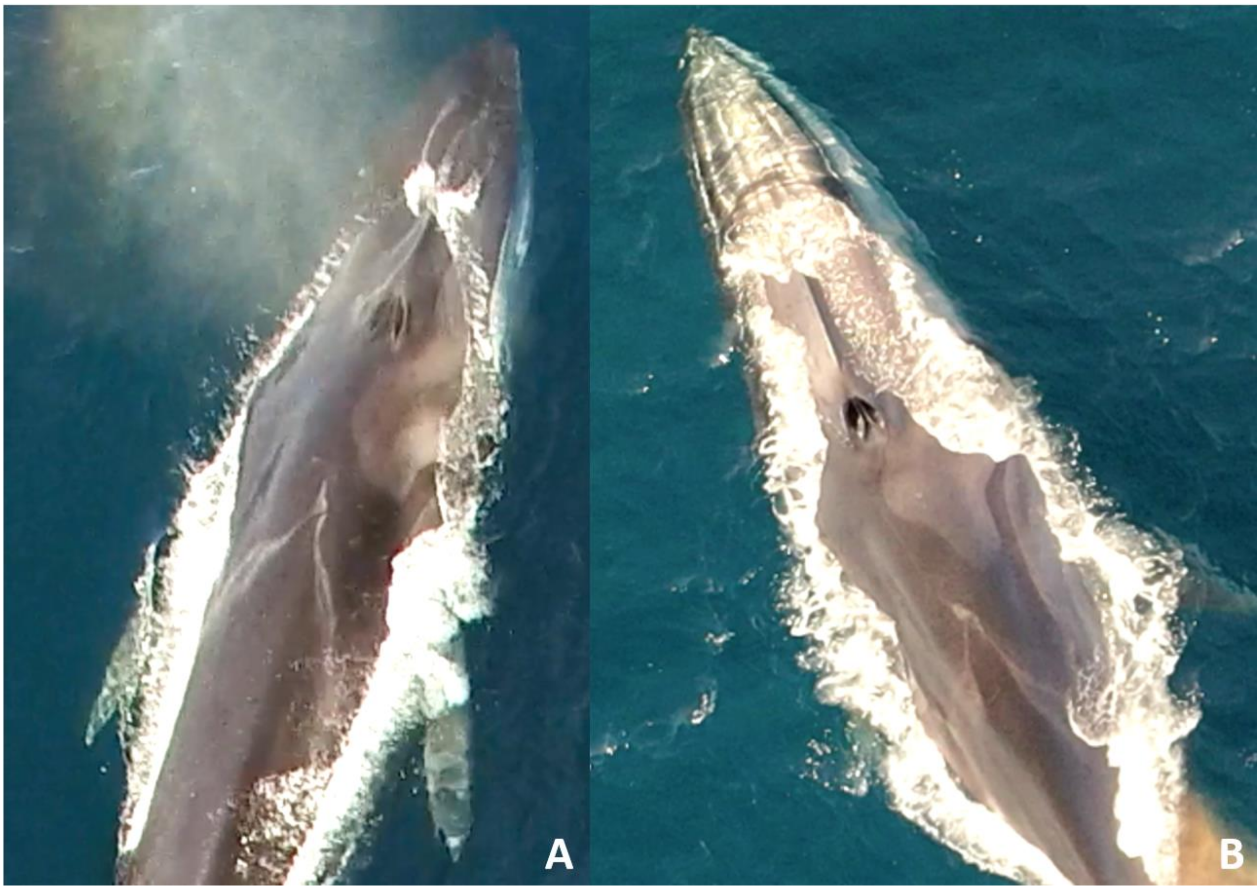

Figure 8. Examples of CCP and blaze visualization of Dr_061 (**A**) and Dr_106 (**B**), two fin whales with similar CCP patterns, but with distinctive blazes. Photographs by EDMAKTUB Association.

5. Conclusions

The use of drones for fin whale identification is a relatively new method. In our work, its application for CCP cataloguing was fast, easy, efficient, and consistent, maximizing whale recognition in recaptures. In addition, this approach represents an evolution from the old camera-based photo-identification system, ensuring a success rate of almost 80% for individual sighting identification, including the sightings in which the drone could not be launched due to weather conditions or whale behaviour, while the common dorsal fin identification success rate is usually around 65%. A consistent and widespread use of this methodology will allow the researchers to improve fin whale cataloguing, to compare populations, and to increase the knowledge of the movement of this species.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/drones7030220/s1, Figure S1: Study area.

Author Contributions: E.D.: Conceptualization, methodology, validation, investigation, data curation, writing—review and editing, and supervision. N.A.: Conceptualization, methodology, formal analysis, and writing—review and editing. S.A.O.: Conceptualization, methodology, writing—original draft preparation, and writing—review and editing. M.V.: Formal analysis and writing—review and editing. K.R.: Formal analysis and writing—review and editing. B.T.: Validation, data curation, writing—review and editing, visualization, and supervision. All authors have read and agreed to the published version of the manuscript.

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