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First Use of Free-Diving Photo-Identification of Porbeagle Shark (*Lamna nasus*) off the Brittany Coast, France

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Abstract: A large number of pelagic shark species have declined significantly in recent decades due to overfishing, bycatch, and habitat degradation. Whereas porbeagle sharks have become scarce due to a reduction in their populations around the world, recent stock evaluations are giving positive signals about the evolution of the North-Eastern Atlantic stock size. The porbeagle shark (*Lamna nasus*), an offshore pelagic species with a wide distribution, is designated by IUCN as Globally Vulnerable and Critically Endangered for Europe and subject to various international conservation conventions. An increasing number of observations are reported off the Brittany coast of Trégor. The ecological role of this area for the species is still unknown and greater knowledge is needed to develop and apply sustainable management measures on a local and international scale. This study represents the first use of photo-identification on porbeagle sharks in order to improve the ecological knowledge of the species in the Trégor area. These results confirm the effectiveness of this method, with 19 of the 131 individuals identified being re-sighted, indicating an interesting degree of site fidelity and showing a sex ratio of 100% females. Observations of individuals over several years allowed the researchers to discuss the relevance of the different types of marks. The findings suggest that the Trégor area off the Brittany coast serves as a seasonal residence for female porbeagle sharks, especially between May and October. This study represents a successful first step in the use of photo-identification for this species. It offers technical support for the sharing of the methodology and provides some biological knowledge allowing researchers to discuss potential sustainable management measures for the conservation of porbeagle sharks in the study area and their habitats while needed.

Keywords: *Lamna nasus*; photo-identification; free-diving; site fidelity; ecology

Citation: Jung, A.; Ory, A.; Abaut, P.; Zaccagnini, L. First Use of Free-Diving Photo-Identification of Porbeagle Shark (*Lamna nasus*) off the Brittany Coast, France. *Diversity* **2024**, *16*, 155. https://doi.org/10.3390/d16030155

Academic Editor: Michael Wink

Received: 31 October 2023
Revised: 6 February 2024
Accepted: 10 February 2024
Published: 29 February 2024

1. Introduction

Porbeagle shark *Lamna nasus* (Bonnaterre, 1788) is a pelagic and neritic species widely distributed among the Northern and Southern Atlantic, the Mediterranean Sea, and the southern Indian and Pacific Oceans [1]. Porbeagle sharks can reach a large body size and perform long seasonal movements [2,3]. *Lamna nasus* mainly feeds on small pelagic fishes and cephalopods [4] although its feeding behavior is considered opportunistic because its diet varies among regions [5,6]. Since the 1930s, porbeagle sharks were subject to commercial fisheries that resulted in a severe decrease in their North Atlantic populations [7,8]. Listed in 2006 as Globally Vulnerable [9] and Critically Endangered for Europe [10] by the IUCN Red list, the porbeagle shark was also included in various international conventions such as the UN Convention on the Law of the Sea (UNCLOS) Annex I, the Convention International Trade of Endangered Species (CITES) Appendix II, the Convention of Migratory Species (CMS) Appendix II, the Barcelona Convention Annex II, and the Bern Convention Appendix II, highlighting its degree of vulnerability and the need of cooperative management. Porbeagle sharks were subject to fishery regulation by the Council of the European Union in 2010 prohibiting

EU vessels in Union waters and in certain non-Union waters to fish for, to retain on board, to transship, and to land these sharks in International European waters [11].

The use of photography to discriminate animals has been broadly used to study large terrestrial species [12–14]. These techniques of photo-identification (Photo-ID) spread in marine research mainly for marine mammals [15–17] or elasmobranch species able to be encountered at the surface such as whale shark (*Rhincodon typus*), basking shark (*Cethorinus maximus*), spotted eagle (*Aetobatus narinari*), or manta rays (*Manta alfredi*) [18–22]. More recently, the use of photo-ID has become much more popular among shark scientists [23]. While extending the species coverage, different parts of the shark body were considered: spots next to the gills for leopard sharks (*Stegostoma fasciatum*) [24], the shape of their fins for white sharks (*Carcharodon carcharias*) [25], basking shark (*Cethorinus maximus*) [20], and nurse shark (*Ginglymostoma cirratum*) [26], fins and body scars for the nurse shark (*Ginglymostoma cirratum*) [27] and basking shark (*Cethorinus maximus*) [20], or the pattern of their body stripes for species such as tiger sharks (*Galeocerdo cuvier*) [28]. These capture-recapture approaches have been described as tools to estimate the abundance of marine megafauna species [29–31]. Whereas porbeagle sharks have become scarce due to a reduction in their populations around the world, recent stock evaluations are giving positive signals about the evolution of the North-Eastern Atlantic stock size [32]. The seasonal presence of porbeagle shark off the Brittany coast of Trégor has been documented since the 1960s [33]; however, the recent increase in sightings reported by locals aroused the interest of our team.

The study area is the Trégor region, located on the northern coast of Brittany (France), in the Côtes d'Armor territory (Figure 1). This area has a particular geological and bathymetric structure, with a steep rocky slope very close to the coast. Trégor is recognized for its marine biodiversity richness which supported the implementation of the marine protected area called National Nature Reserve of Septs Iles in 1976 [34–36], also classified under European Habitat and Bird Directives. This area, also named Pink Granite coast, features a specific magnetic anomaly, linked to the origins of its geological formation [37]. As sharks are very sensitive to electromagnetic fields [38–40], the regular presence of porbeagle sharks so close to the coast could be linked to the presence of this magnetic anomaly.

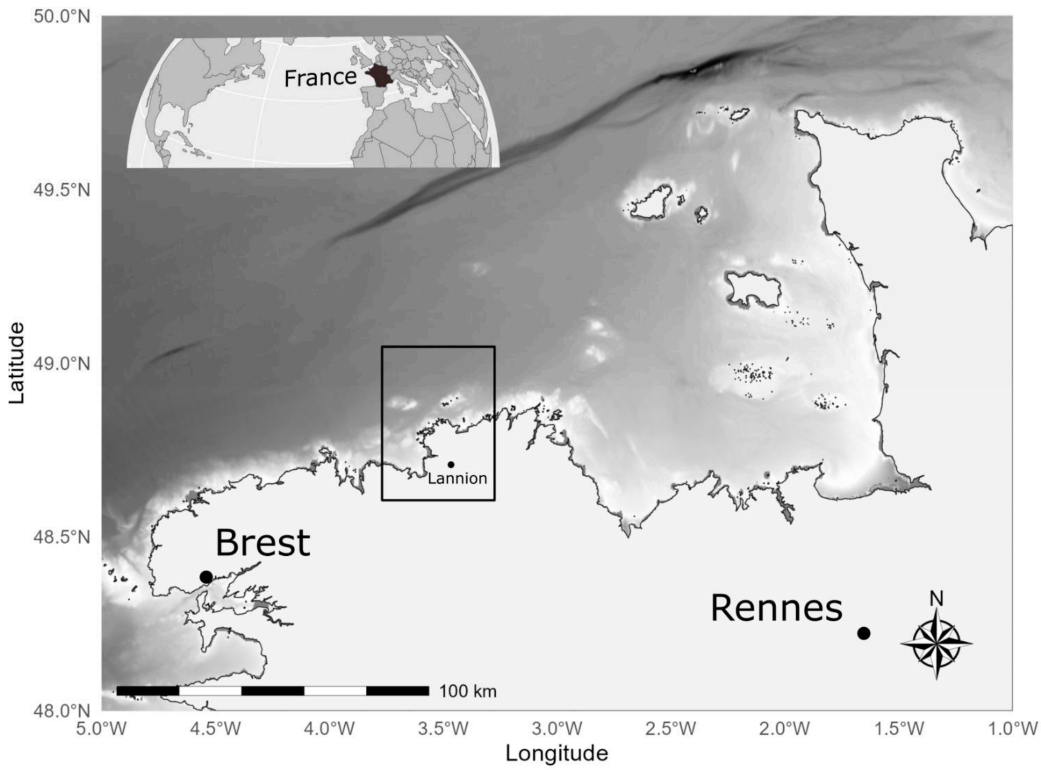

Figure 1. Study area of the porbeagle photo-ID program, DRDH (2021–2023).

In 2021, we started a free-diving protocol based on the methodological recommendations made by Marshall and Pierce [23] for such a photo-ID approach in order to minimize methodological biases. The objectives are (1) to evaluate the presence of porbeagle sharks in the area, (2) to develop an individual shark catalog and assess which phenotypic criteria are most relevant, and (3) to improve the ecological knowledge of the species.

As suggested by the isotopic analysis conducted on individuals coming [41], some degree of intra-population heterogeneity exists between inshore and offshore individuals, and would demand further investigation on their movement behavior. This research allows us to implement a precursory approach to study the use of this very coastal zone for the species and offers a reproducible and collaborative tool to share among research groups working on porbeagles.

2. Materials and Methods

2.1. Field Sampling and Underwater Observations

From June 2021 to September 2023, the DRDH (Des Requins et Des Hommes) team conducted 64 free-diving sessions (corresponding to an estimated 110 h of immersion) following the same protocol. The vessels used to reach the survey area were semi-rigid boats from the professional diving center Joly Plongée (10 m, 250 HP) or DRDH's own boat (Zodiac 5.5 m, 80 HP). For each dive, a group of two to six trained divers used a lead drifting line of 15 m long (stainless steel) equipped with a nylon bag containing 500–1000 g of bait as olfactive attraction only. Bait included sardine (*Sardina pilchardus*) or mackerel (*Scomber scombrus*), fresh or frozen according to the fish market availability. The divers stayed in pairs at the surface and made regular dive checks up to 10 m depth until a shark approached. In order to adhere to our low-intrusive code of conduct, the dive time was limited to 1 h 30 min, and the dive was finalized with or without shark encounter after this period of research.

In the case of an animal coming by, the free divers quietly went down up to 10 m and waited in apnea for the shark to approach in order to film the interaction. Underwater observations were video-recorded with underwater cameras Canon G7x mk2 (Canon, Tokyo, Japan) or GoPro Hero+, 7, 9, 10, and 11 (GoPro, San Mateo, CA, USA). Since 2022, the cameras have been equipped with a mounted pair of underwater lasers (Green Laser 18650 Li-ion 3.6 V, Oceanco Ltd., FL, USA) of 30 cm distance to measure the length of a shark. Before 2022, or when laser measuring was not possible, size estimations were based on in situ observation or videos post-evaluation by comparison to diver size.

2.2. Data from Maritime Stakeholders

In order to increase the geographical and temporal coverage of the shark sightings data, some additional footage taken by professional photographers was collected and included in the photo-ID catalog. Social networks such as Facebook, YouTube, and some dedicated internet forums (spearfishing, recreational fishing, or scuba diving websites) were visited to check some publications of shark sightings. In case the quality of the picture and the detail of information was adequate, the footage owner was contacted to request their permission for the research use of the picture or video. These external data were only used as qualitative data to improve the photo-ID catalog and will not be included in population size analyses or any other analysis requiring a standardized sampling protocol and effort.

2.3. Phenotypic Markers

The identification criteria chosen for the porbeagle shark individual discrimination were as follows: (1) the sex, by checking the presence of the external male reproductive organ; claspers are visible next to the pelvic fin; (2) the size, calculated via laser photometry or via visual estimation; and (3) the body marks (described in Figure 2) as well as the shape and color of the fins and countershading delineation.

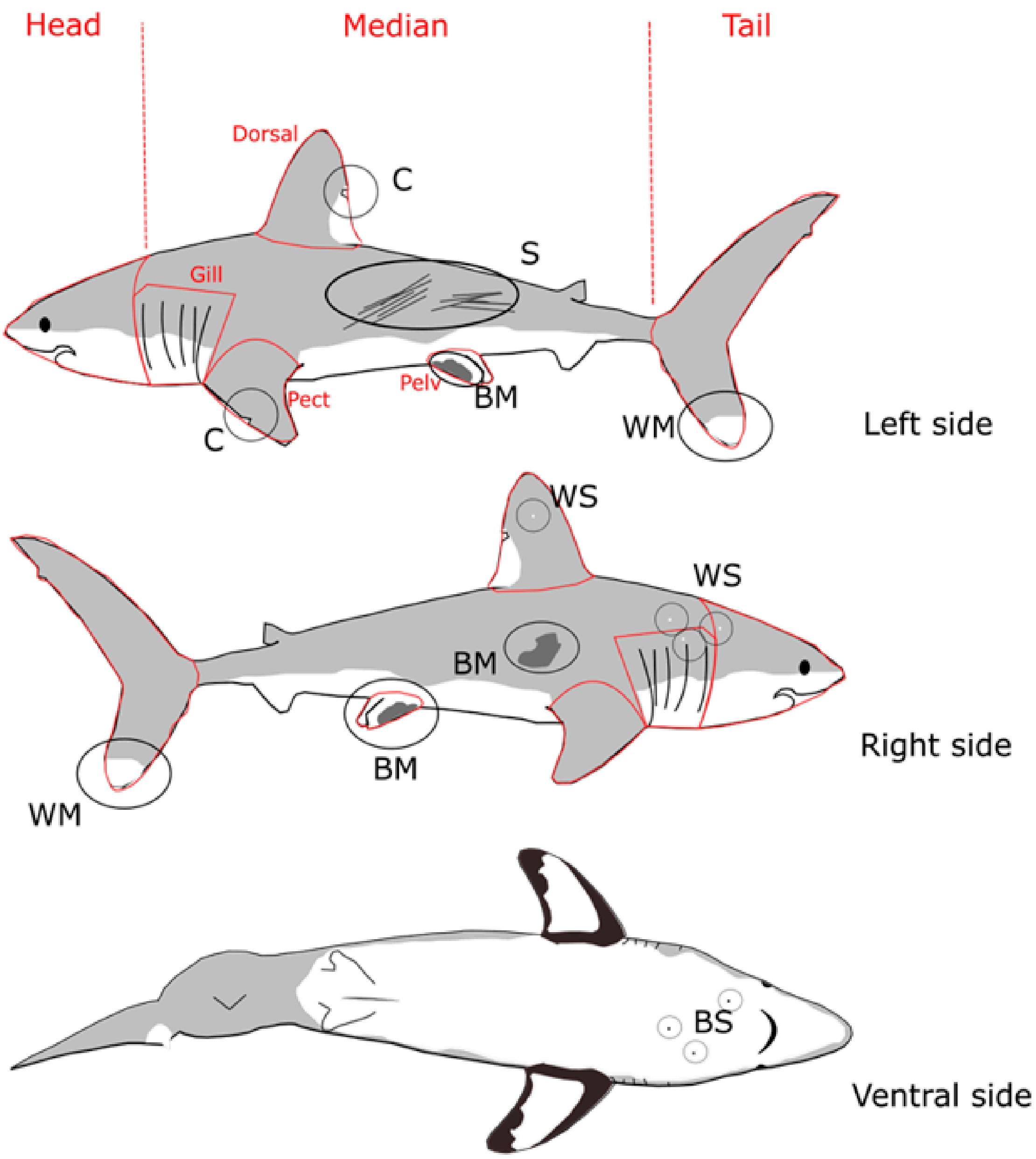

Figure 2. Body parts and marks used for porbeagle shark individual discrimination: Tail, Median, Gill, Head, Pelvic Fin, Pectoral Fin, Dorsal Fin. S = Scar, BM = Black Mark, C = Clip, WM = White Mark, WS = White Spot, BS = Black Spots, presented on the Left, Right, or Ventral sides.

These marks are used in many other shark photo-identification studies, especially for tiger sharks (*Galeocerdo cuvier*) [28], great white sharks (*Carcharodon carcharias*) [42,43], and basking sharks (*Cethorinus maximus*) [20].

2.4. Additional Data

In order to improve the ecological knowledge of the species, other parameters were collected during the fieldwork for future analyses and were therefore not used in this study. We used a hand sensor to collect sea surface temperature (SST) and salinity (Mettler Toledo, Greifensee, Suisse). Additional environmental parameters such as tide coefficient, cloud cover, wave height, moon phase, and the number of divers were also collected for each dive. We also checked and documented the presence of macro parasites such as copepods while checking the photos. Some additional elements were also recorded such as anthropogenic remains: net entangle cicatrix, hook lines hanging, tagging devices, relics, or evidence of interaction with boats (e.g., propeller scars).

2.5. Data Treatment and Analysis

To distinguish the animals, the videos were meticulously analyzed via VLC player (OpenSource, France) or Movie & TV (Microsoft, WA, USA), especially using the slow-motion facility. Screenshots of each side of the shark and details of specific criteria were taken and stored in an individual folder by date. To facilitate the data analysis, the body was divided into seven different parts (Head, Median, Tail, Gill, Dorsal Fin, Pectoral Fin, and Pelvic Fin) for each side of the shark and assigned to six types of marks (Scar (S), Black Mark (BM), Clip (C), White Mark (WM), White Spot (WS), and Black Spot (BS)) as described in Figure 2. Retained criteria were entered both in the Excel folder catalog and in a corresponding single ID paper form; a single ID-code was allocated to each shark—for practical reasons, an additional nickname was also used for animals we used to encounter. The maturity stage of the females was estimated based on the maturity size observed by Jensen et al. [44] in the North Atlantic. As no males were observed during this study, no visual method for estimating the maturity stage of males was developed. Because this study is the first to use photo identification on this species, all the marks were considered at the same level. When a new observation was included in the database, a simple R function was used to assist potential assignment to an individual which had already been observed. Basically, the function searches in our database for all observations corresponding to individuals showing a minimum number of similar common criteria (the same type of mark on the same area and side of the body). This number of criteria is chosen according to the number of available visible criteria of the new observation and adjusted in order to have up to 20 potential matches found by the function. All the potential matches are then compared visually with the new observation to check if the marks are considered the same or not, allowing the new observation to be assigned or not to an individual already recorded in the database. If the observation is not assigned to an individual already registered, a new individual code is created in the database. To avoid reading discrepancies, all assignments were made by the same observer; in cases of uncertainty, other members of the team were consulted for double reading.

3. Results

3.1. Porbeagle Photo-ID Catalog

The porbeagle photo-ID program, in three years of field seasons, was successful in making 183 shark sightings which correspond to 131 different individuals (100% females) ranging from 1.5 m to 2.5 m fork length (Lf) observed between 2015 and 2023 in the study area. The majority of the sightings came from DRDH diving sessions (60%), contributions from professional photographers represented 28%, and underwater online publications 12%. No particular trend is visible in the time series so far; from the three years of free-diving seasons performed by DRDH, 2023 is the year with the most porbeagle sighting events whereas external sighting data are the most important for 2020 (Figure 3).

Some obvious phenotypic marks such as large fin clips or massive body scars allowed us to easily recognize some of the sharks. However, in most cases, identification was possible due to a combination of morphological marks associated with body size. All assignments were made using a minimum of two and a maximum of eleven criteria (an average of six criteria). As illustrated for the shark n°20LAMNA#13 ("Mylene"), the white marks (WM) discerned on the dorsal fin are well recognizable (Figure 4A), as highlighted by the red circles drawn as post-treatment. Three white spots (WS) visible on the left side upper gill are also clear over time (Figure 4A) although they require careful screenshot analysis and good light exposure. The white mark (WM) present on the lower caudal fin is also very characteristic and constitutes a good criterium to recognize "Mylene", even when in the water (Figure 4C). Finally, the observation of the countershading delineation (Figure 4D) is very efficient for photo-recapture criteria because this pattern is unique for each individual and persists for several years (Figure 4D).

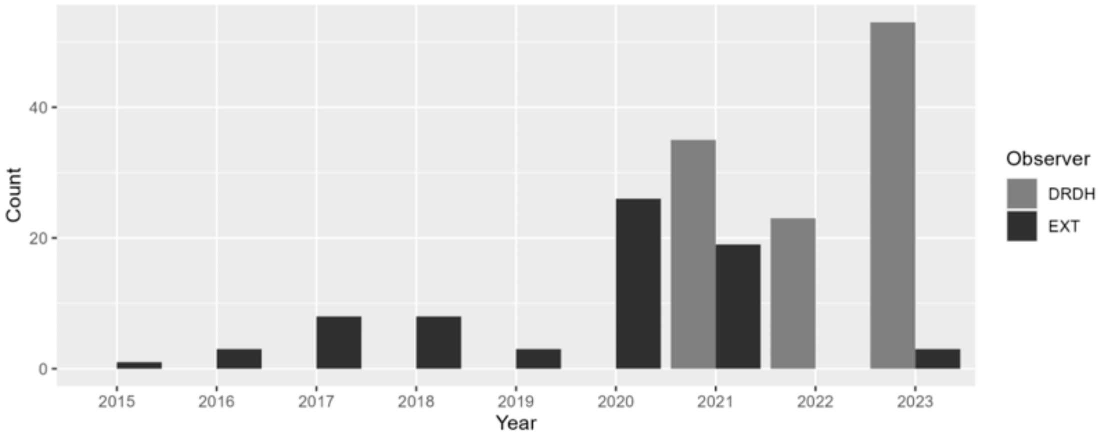

Figure 3. Total number of porbeagle shark sightings between 2015 and 2023 by DRDH and other marine stakeholders (EXT).

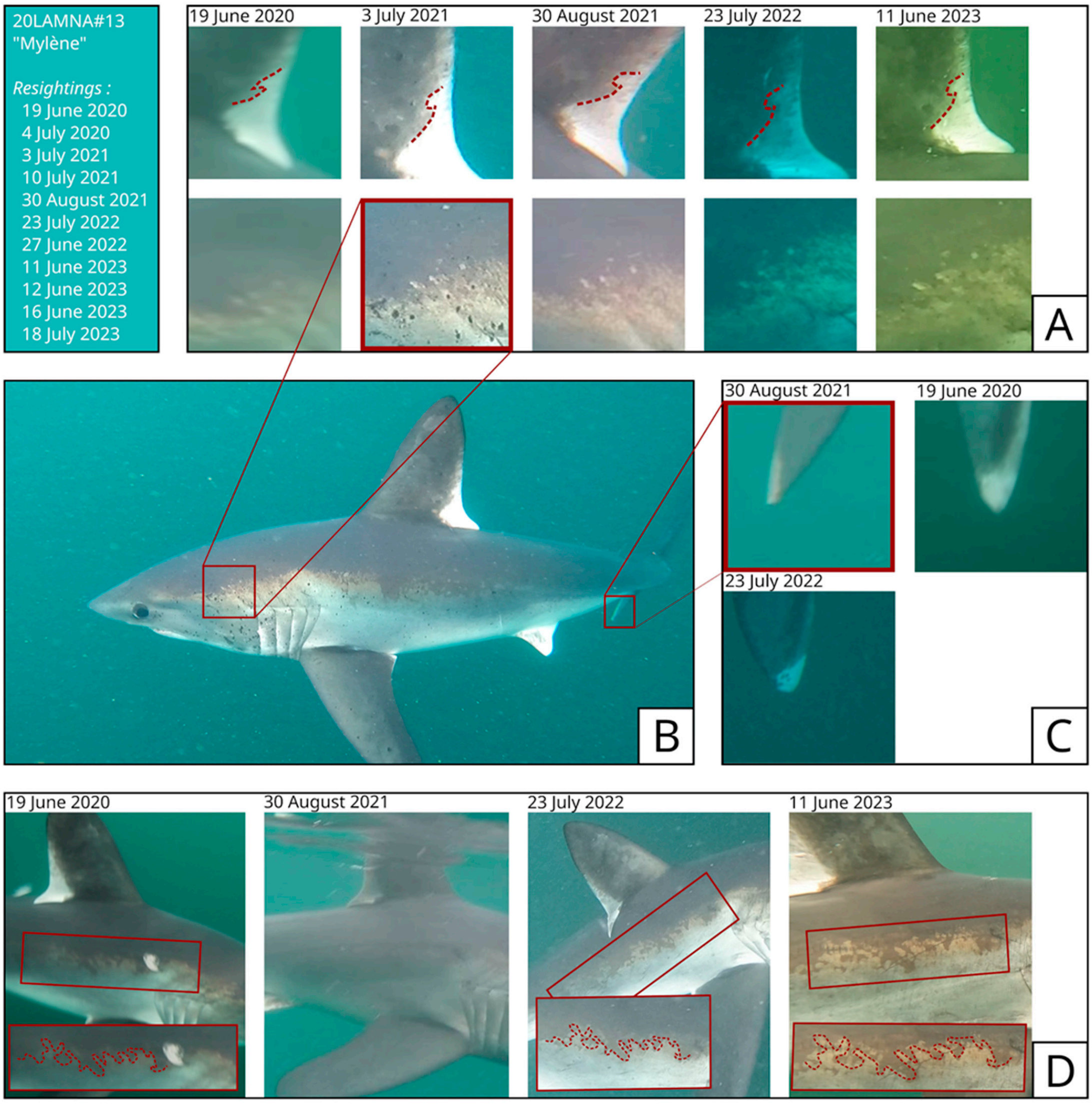

Figure 4. Example of the major persistent body marks for porbeagle sharks for individual n°20LAMNA#13 ("Mylene"): (**A**) Dorsal fin and upper gills, (**B**) general body view from left side, (**C**) tail, and (**D**) countershading delineation from 2020 to 2023. Red dashed lines are representing the color contrasts delineations post-added manually.

3.2. Seasonal Variations

Sightings occurred between March and September. For the dives performed by DRDH, no significant difference can be observed within the months while weighed by the effort of research ($p > 0.05$, Tukey test). However, July is the month showing the highest variability in the number of animals observed per dive (cf. Figure A1, additional material).

3.3. Re-Sighting Rate and Site Fidelity

Over the 131 individual sharks identified, from 2015 to 2023, the photo-ID techniques allowed 19 different animal re-sightings corresponding to 51 re-sighting events (Figure 5). Re-sightings occurred from 1 to 10 times maximum for the shark n°20LAMNA#13 ("Mylene"), 57% of re-sighted sharks were observed twice, 15% were observed three times, and 25% were observed more than four times. Most of the sharks were photo-recaptured during the same year (68%), with the longest time series of four consecutive years for four animals. The longest period between two re-sightings was four years, and this event occurred once for a mature female shark n°17LAMNA#07 between 2017 and 2021. We observed a maximum of five re-sightings during the same season in 2023 for "Yvette", the porbeagle shark n°20LAMNA#18. The large majority of the re-sightings involved mature porbeagle sharks (82% of the sightings events and 58% of the number of individuals).

Shark Code	Nick Name	Estimated Size LF (m)	Sex	Maturity stage	Year of observation									Total Nb of resighting
					2015	2016	2017	2018	2019	2020	2021	2022	2023	
20LAMNA#13	Mylene	2.3	F	Mature						2	3	2	4	10
20LAMNA#17	Fanny	2.3	F	Mature						2	3	1*	4*	9
20LAMNA#18	Yvette	2.3	F	Mature						1	2	1	5	8
21LAMNA#03	Armelita	2.3	F	Mature							1*	2	3	5
23LAMNA#19	Allana	2.1	F	Mature									4	3
21LAMNA#08	Elisabeth	2.0	F	Sub-adult							3			2
21LAMNA#10	Monique	2.0	F	Mature							2		1	2
21LAMNA#15	Nikita	1.9	F	Sub-adult							3			2
15LAMNA#01	Jumpa	2.1	F	Sub-adult	1	1								1
17LAMNA#07	-	2.0	F	Mature			1				1			1
18LAMNA#01	-	2.0	F	Mature				1		1*				1
18LAMNA#03	-	2.1	F	Mature				2						1
19LAMNA#03	-	2.2	F	Mature					1		1			1
20LAMNA#05	Didy	1.9	F	Sub-adult						1	1			1
21LAMNA#06	-	1.7	F	Juvenile							2			1
21LAMNA#33	Anne	2.2	F	Mature							2			1
22LAMNA#15	-	1.8	F	Juvenile								2		1
23LAMNA#08	-	1.8	F	Sub-adult									2	1
23LAMNA#15	-	1.8	F	Juvenile									2	1
Total														**51**

Figure 5. Total number of re-sighting events for porbeagle sharks observed by the DRDH team and marine stakeholders between 2015 and 2023. Maturity scale ($\leq$1.8 m = Juvenile, 1.8–2.2 m = Sub-Adult, $\geq$2.2 m = Mature—all measures are fork length); (*) Gravid individuals.

3.4. Biological Information

Underwater observation allows us to document some elements on the maturity of the sharks visiting the area (Figure 5). We encountered four gravid females including one n°20LAMNA#17 ("Fanny") twice in consecutive years: in June 2022 and June 2023. The same individual was observed in the postpartum stage in August 2023, with an evident reduction in the belly volume between the two final observations (cf. Figure A2, additional material).

While scrutinizing the Photo-ID catalog, we realized that some phenotypic criteria were less constant than others over time, for the porbeagle sharks we encountered; for instance, scars tend to reduce in size over time. For the porbeagle shark n°21LAMNA#15

("Nikita"), we estimated a reduction of 75% in the scar surface within 62 days, as presented in Figure 5.

Moreover, we noticed an interesting phenomenon for the porbeagle shark "Mylene": black spots (BS) were present around the gills on both sides of this animal during the encounter that occurred in July 2021, but they were not visible one year before (Figure 6). When "Mylene" was photo-recaptured two months later in August 2021, these BS were no longer present.

Figure 6. Example of the non-persistence of certain scars (S) for the porbeagle shark n°21LAMNA#1.5 ("Nikita").

4. Discussion

4.1. Effectiveness of the Methodology

This study shows for the first time the feasibility and efficiency of using photo identification to distinguish and study individual porbeagle sharks over several years. The re-sighting rate of porbeagle sharks in this study is 15%. As this is the first study using photo identification on this species, comparison with other sites or populations is not yet possible. However, comparable photo-ID methodologies with similar temporal coverage have shown highly variable re-sighting rates among species. For instance, a re-sighting rate of only 5% has been observed for basking sharks [20], whereas such rate is 61% for tiger sharks [28] and 47% for nurse sharks [27]. The re-sighting rate can also vary depending on the study area. For the great white shark, Domeier and Nasby Lucas [42] observed a re-sighting rate of 78% at Guadalupe Island in Mexico, while Hewitt et al. [25] observed a rate of 29% at Seal Island in South Africa. Finally, re-sighting rates are also linked to the methodology of observation (e.g., at sea survey, BRUV, citizen sciences, or drone) but also depend on the ecology of the studied species. Considering the scarcity of porbeagle sightings underwater, the re-sighting rate in this study can be considered satisfactory and adequate to continue the implementation of the methodology. As the photo-identification protocol has only been used for three years and the sampling effort has increased, it is expected that this rate will increase in the coming years.

The variety of distinctive marks as well as the multiple re-sightings of some individuals will make it possible to determine which types of marks are the most relevant for long-term identification. Countershading delineation, black marks on the belly and pelvic fins, white marks on the caudal and dorsal fins, and white spots seem practical for long-term identification (Figures 2 and 3). However, countershading delineation requires time-consuming post-treatment and good exposure in terms of light and orientation of the body; for instance, the screenshot available for 30 August 2021 (Figure 4D) does not allow the use of this phenotypic mark. It is therefore not always possible to use this mark to confirm an identification. These kinds of marks are also used for the long-term identification of tiger sharks (*Galeocerdo cuvier*) [28] and great white sharks (*Carcharodon carcharias*) [42]. In this study, scars on the body and the gills and fin clips were used to identify individuals in the short term. But it is important to be aware that these marks can change over time, with small scars reducing over the years or being replaced by a new, larger scar, leading to serious problems for long-term identification (Figure 6). This has already been observed for great white sharks (*Carcharodon carcharias*) [43], tiger sharks (*Galeocerdo cuvier*) [28], and basking sharks (*Cethorinus maximus*) [20]. However, the use of multiple marks can increase the accuracy of individual identification, thereby reducing observer bias and the probability of false identification due to changes in some marks [28,42,45]. Graham and Roberts [21] even considered that photo identification based on multiple marks is more efficient than traditional visual tagging methods. Indeed, despite a significant change in the general appearance of some of the sharks identified (Figures 6 and 7), the use of several markings enabled them to be properly identified. In addition, this study observed for the first time changes in darker pigmentation spots on porbeagle sharks over a short period of time (Figure 7). Domeier and Nasby-Lucas [42] have already observed a similar phenomenon on the great white shark (*Carcharodon carcharias*). Black spots are thus not used to identify individuals in this study as standalone, but combined with other criteria.

Figure 7. Pigmentation variations observed on the same porbeagle shark n°20LAMNA#13 ("Mylene") observed in June 2020, July, and August 2021.

Furthermore, this underwater photo-ID approach can be considered as an asset in comparison to traditional recapture methodology such as tagging protocols. Free diving allows approaching the shark in a silent and smooth way, avoiding disturbance and reducing potential behavioral modification (attraction or avoidance) although a long-term study on shark behavior is required. Moreover, photo-ID is considered as a less impactful method by preventing capture or shark manipulation that affect animal fitness through metabolic stress [23] or potential epizootic events.

4.2. Ecology

The seasonality observed with the first results of this study is consistent with current knowledge. Porbeagle shark landing data from the French targeted fishery [46] indicate a strong presence of porbeagle sharks in spring and summer in shallow waters on the north-east Atlantic continental shelf, and tagging studies suggest autumn and winter migration behavior in offshore deep water [2,47]. [7] observed the same pattern along the Canadian coast, based on data from inshore and offshore fisheries.

The life cycle of the species is also an element that this methodology has allowed us to document. Porbeagle shark n°20LAMNA#17 ("Fanny") was observed gravid twice, within a 12-month interval. Current knowledge estimates the gestation period for porbeagle sharks around 8 to 9 months probably on an annual or potentially biennial period [44,48], which suggests that this female gave birth twice in two consecutive years. Furthermore, the observations suggest that "Fanny"'s parturition occurred between June and August 2023, potentially in the study area. Although additional research is required to state the ecological functionality of this area for the species, the overall findings suggest that the Tregor area, and the seven islands MPA in particular, could play a major role in the life cycle of this group of porbeagle. This non-invasive biological information, which is difficult to obtain using traditional methods, such as scientific fisheries, electronic tagging, or ultrasound technologies [49,50], can benefit the global understanding of the species' ecology.

It is well established that shark species can exhibit sex-specific segregation and resident areas, and their migration patterns can be dependent on their sex [51–53]. As mentioned above, a wide range of porbeagle shark sizes is observed in this study (1.5 m to 2.5 m LF) and it appears that this particular area serves as a seasonal aggregation zone where exclusively females were able to be detected. This finding is consistent with the study of Hulbert et al. [54] on salmon sharks (*Lamna ditropis*) which reports a concentration of females (95% sex ratio) with a similar size range in Prince William Sound (Alaska). Similar findings have been described on blue sharks (*Prionace glauca*) by Druon et al. [55], who observed that large females' habitats tend to overlap with juveniles. Nevertheless, further studies are needed to assess potential variations in ecological behavior based on size or sex, such as whether males or juveniles exhibit deeper, offshore habitats with reduced coastal or exploratory movements, or simply show less interest in the "scent trail". Hennache and Jung [56] have documented variation in the sex ratio of porbeagle sharks in the Bay of Biscay based on fishery-dependent information, ranging from 1 female for every 0.74 males in the South Irish region to 1 female for every 1.19 males in the Canal St. Georges. But until now, no other area occupied exclusively by porbeagle shark females had been identified in the Northeast Atlantic. This situation has already been observed for the great white shark (*Carcharodon carcharias*), as published for Southern Australia by Bradford et al. [57], where only females are encountered in winter time. The existence of these sex-specific aggregation sites is increasingly well identified, but remains difficult to interpret.

4.3. Caveats and Limitations

Underwater methodologies are known to present some limits such as the visibility or sea conditions; this parameter can be of particular concern in Brittany waters (high tides, strong current, and low temperatures). This can affect both the detection of the animal and the possibility to acquire good quality footage. Given that the bottom depth in the study area was mainly around 40 m, with visibility varying from 2 to 15 m, some porbeagle sharks may have visited our team without possible detection. Additionally, the performance of the methodology is reduced in the case of high turbidity (in the case of plankton blooms, for instance).

Furthermore, a correct approach of the animal is crucial to obtain good footage and measurements. It requires the training of good free divers, accustomed to difficult sea conditions and able to interpret and predict shark movement in order to be in the right position while the animal will pass by them.

Nevertheless, with more than 130 individuals identified, the database has reached a considerable size, resulting in a significant increase in the time required to assign an observation to an individual, already recorded or not. The use of automatic or semi-automatic identification methods such as collaborative multi-user software (Wildbook for shark, Microsoft, WA, USA) or the mapping of pigmentation patterns with specific software such as "I3S" [26,58] could be a relevant solution. However, these methods require a standard identification protocol and good-quality images taken from the right angle [45,59]. Conditions of high turbidity and low visibility, as well as the use of small sports cameras, could reduce the efficiency of these methods for this study. Efficiency tests are therefore required before applying these methods in future years of monitoring.

4.4. Perspectives

Additional years of photo-identification monitoring coupled with other methods are needed to better understand the porbeagle shark's use of this area. The validation of the photo-identification method by genetic identification, the estimation of the size of the group present in the area, and the study of family relationships between individuals observed [60] would provide a better understanding of the importance of this area in the porbeagle shark's life cycle and ecology. The analysis of the relationships between the various environmental factors and the number of shark sightings will also be carried out once more data have been collected to ensure the accuracy of the subsequent modeling process. Additionally, systematic laser measurements will be conducted in the future and will enable a more comprehensive description of the size distribution as well as the growth rate estimation for re-sighted animals.

Moreover, the individual underwater identification may complement the ecological knowledge of the species as it allows the collection of multiple additional samples such as the experiment in summer 2023 with skin biopsy and eDNA water filtration. In the meantime, the team dives for individual-specific recordings, which are key elements for research on the group structure and connectivity [50,61].

Finally, estimating anthropic pressures on a local population is complementary to understanding ecology [62], and relevant to implementing appropriate local management adapted to the area. Because the study area is on the border of an MPA (Marine Protected Area), the recent touristic interest for this species and the increase in human interactions, particularly bycatch and depredation (personal communication C. Mangin 17 July 2023—Recreational fishery committee president), also highlight the need for a thorough study of the behavior and ecology of the porbeagle shark in this area, in order to adopt concerted management methods. In addition, the significant proportion of our database obtained from local stakeholders (40%) highlights the importance and relevance of citizen science for the study of marine predators ranging from sharks [63] to marine mammals [64].

5. Conclusions

This study enabled us to establish the first photo-identification catalog for porbeagle sharks. The method proved effective, as 19 of the 131 females identified were re-sighted, indicating a certain degree of site fidelity. Given that sightings are most frequent between May and October, the Trégor area seems to serve as a seasonal residence for female porbeagle sharks, although the specific ecological importance of this site remains to be determined. It should be noted that males may also be present at the site, but their presence may not have been detected. Future research using alternative methods will be essential to better understand porbeagle shark ecology in this area and beyond, enabling the implementation of management measures adapted to the well-being of porbeagle sharks and their ecosystem.

Author Contributions: Conceptualization, A.J.; methodology, A.J., A.O. and L.Z.; software, A.O.; validation, A.J. and L.Z.; formal analysis, A.J., A.O. and P.A.; investigation, A.J., A.O., P.A. and L.Z.; resources, L.Z.; data curation, A.J., A.O. and L.Z.; writing—original draft preparation, A.J.; writing—review and editing, A.J., A.O. and L.Z.; visualization, A.O. and L.Z.; supervision, A.J.; project administration, A.J.; funding acquisition, A.J. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by Des Requins et Des Hommes (DRDH), Technopôle Brest-Iroise, 29280 Plouzané, France and the French Ministry for Ecological Transition and Territorial Cohesion, Arche de la Defense, 92055 Paris la Defense, France.

Institutional Review Board Statement: The study was conducted in accordance with. The French Charter on the Ethic of Animal Experimentation from both the Ministries of Research and Agriculture (Paris, France). A specific research permit for biopsy was attributed by the Direction Inter-Régionale de la Mer Nord-Atlantique, Manche-Ouest (DIRM NAMO, Rennes, France), n°: 708/2023 delivered the 6 June 2023.

Data Availability Statement: Updated of this project will be available on the https://www.researchgate.net/profile/Armelle-Jung.

Acknowledgments: We are grateful to the professional photographers who kindly accepted to share their videos: Didier Brémont, Yannick Cherel, Jérome Delafosse, Stéphane Granzotto, Yves Lefèvre, Andy Murch, Armel Ruy, the Ocean Collective team, and all the marine stakeholders websites contributors. We address a sincere thanks to Pascal Provost, director of the Nature Reserve of the Seven Islands and his whole team; as well as to the Conservatoire du Littoral, Lannion Community, and Perros Guirec harbor managers. All this work would not have been possible without the help of DRDH members (divers, drivers, and technical assistance), and the active contribution of Joly Plongée diving club and Didier Brémont to the ethical code of conduct and their facilitation of the field research. The authors are grateful for the comments provided by reviewers as well as colleagues' proofreading and advice.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

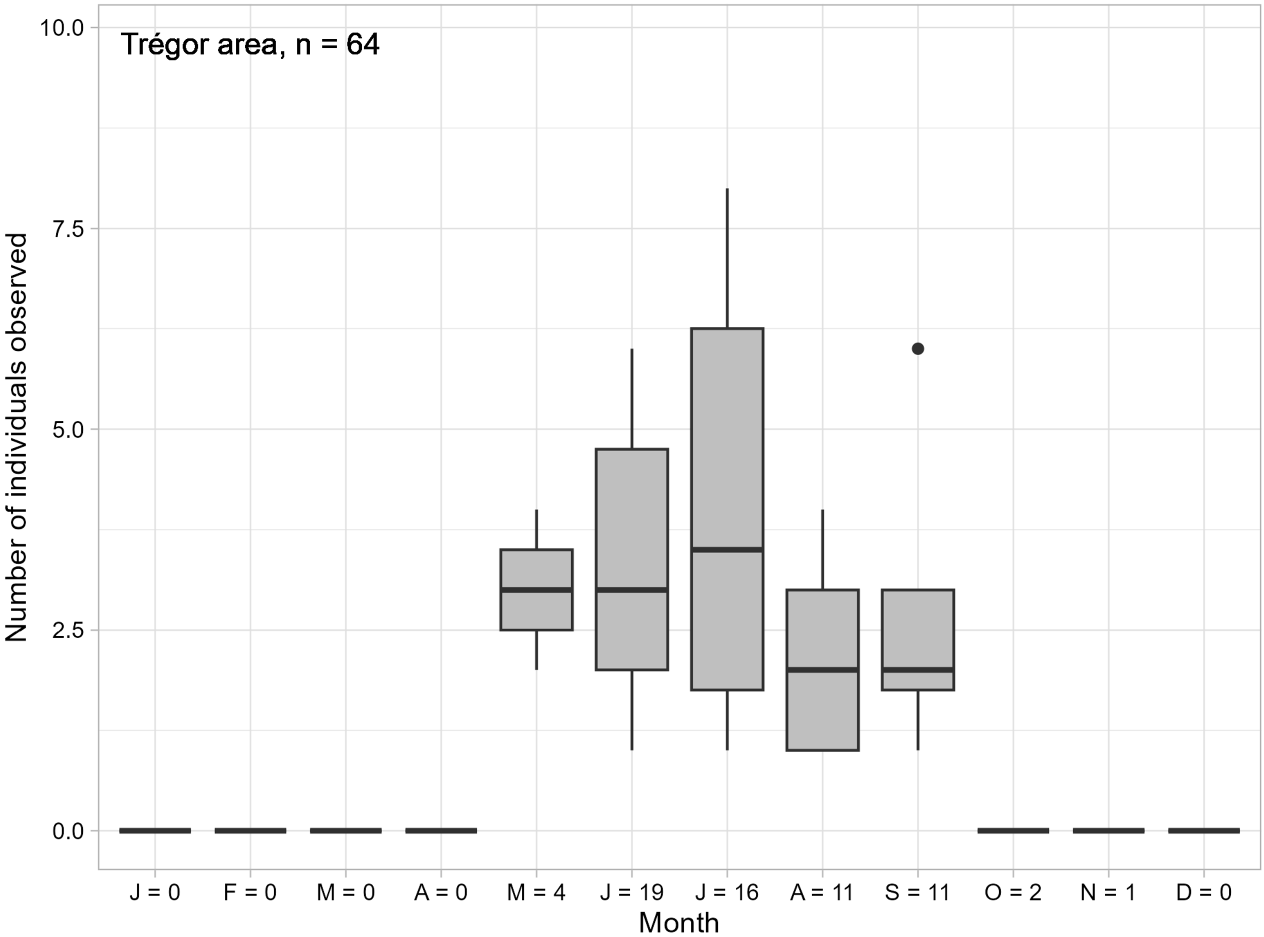

Figure A1. Distribution of the number of porbeagle shark sightings by dive per month between 2021 and 2023 (observed by DRDH), with the accumulated number of dives per month on the *x*-axis.

Figure A2. Example of maturity stage identification for the porbeagle shark 20LAMNA17 "Fanny" observed by DRDH in June 2023 (gravid) and August 2023 (postpartum).

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