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Post-Release Survival of the Pelagic Stingray (*Pteroplatytrygon violacea*, Bonaparte, 1832) in French Longline Fisheries in the Northwestern Mediterranean Sea

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ABSTRACT

Bycatch remains a critical challenge in global fisheries, even when using selective gears such as longlines. In the French longline fishery targeting Atlantic bluefin tuna (*Thunnus thynnus*) in the Gulf of Lion, the common pelagic stingray (*Pteroplatytrygon violacea*) is the primary bycatch species. This study investigated the post-release survival and behaviour of 38 stingrays (38–75 cm disc width) captured during the spring–summer seasons of 2022 and 2023, using electronic tagging (MRPats, sPats, and PSATLife). A clear seasonal trend was observed, with smaller individuals more frequently caught in summer, likely linked to warmer water conditions that also reduced tag retention time (1–70 days). Survival was estimated using the Kaplan–Meier method, accounting for uncertainty in post-release status determination. The results indicated high survival rates ranging from 73% to 100% (median 87%), demonstrating the species' strong resilience to capture and handling. Tagging data also revealed extensive vertical and horizontal movements, with individuals reaching depths of nearly 700 m and traveling over 20 km per day. This brings new and valuable information on this poorly known species, albeit common in the Mediterranean, for the sustainable management of exploited resources in this area.

1 | Introduction

Bycatch is a major concern for resource management and the conservation of marine ecosystems (Botsford et al. 1997; Lewison et al. 2004; Hazen et al. 2018). Understanding and evaluating bycatch is difficult due to the large area occupied by pelagic animals and fishing gear. Large pelagic fishes are in constant motion; data from many fisheries are insufficient or missing, and some areas are difficult for observers to access (Beddington et al. 2007; Block et al. 2011; Pauly and Zeller 2016). Nevertheless, it has been estimated that bycatch of all species represents more than 10% of global marine catches (Davies et al. 2009; Roda et al. 2019). Each year, almost 10 million tonnes of marine species are considered bycatch and are not landed (Roda et al. 2019). Bottom trawl-type fishing gear generates 45% of this bycatch, while purse seine, mid-water trawl, and nets each account for 10%, and longline generates around 6% (Roda et al. 2019). Dredges and other gear types account for around 18% of the total. Tuna fisheries are among the most selective, with 6% of bycatch, but it still affects elasmobranchs, cetaceans, seabirds, and marine turtle species (Roda et al. 2019). In the western Mediterranean, pelagic longlines are used in tuna fisheries targeting mainly bluefin tuna (*Thunnus thynnus*), albacore tuna (*Thunnus alalunga*), and swordfish (*Xiphias gladius*) (Belda and Sánchez 2001).

In this area, the French longline fishery targeting bluefin tuna started in 2009. In 2024, it was represented by 56 units considered as "small artisanal fishing vessels" (SATHOAN pers. comm. 2024a). The SATHOAN producer organization (responsible for representing and supporting professional fishers) manages 37 of these vessels, which represent 75% of the French quota allocated to the small-scale fishery, with the majority of the activity concentrated in the Gulf of Lion (GOL). Since 2014, this producer organization has been working towards using selective fishing methods and guarantees sustainable and responsible exploitation which has led to the award of several labels ("Peche durable" and MSC). These certifications encourage more selective fishing in order to reduce fishing impacts on marine ecosystems with an active participation of professional fishers into research programs on bycatch issues. Most of the bycatch of French longline fleet of Western Mediterranean is made of sharks and rays, mainly the blue shark (*Prionace glauca*) and the pelagic stingray (*Pteroplatytrygon violacea*, Bonaparte, 1832; Poisson et al. 2017, 2024; SATHOAN pers. comm. 2024a).

The pelagic stingray is the only oceanic-pelagic species of stingrays currently known (Mollet 2002; Neer 2008). Its distribution spans tropical to warm-temperate pelagic waters worldwide, including the Mediterranean Sea (Mollet 2002; Mollet et al. 2002; Ellis 2007; Siqueira and Sant'Anna 2007). There is limited information on its population structure, with no clear evidence of distinct stocks, likely due to its "least concern" status by international wildlife authorities (Kyne et al. 2019). The pelagic stingray is ovoviviparous, giving birth to 4–13 juveniles twice a year in warm waters, such as the equatorial zone or Mediterranean (Hemida et al. 2003; Kyne et al. 2019). Females can store sperm for over a year, allowing gestation to occur under favorable conditions (Ebert 2003). Males reach sexual maturity at 2 years (37–50 cm), and females at 3 years (39–50 cm). The species can live up to 10–12 years (Dulvy et al. 2008).

Pelagic stingrays are found in all oceans, near shelves or in pelagic zones, and are primarily caught by longline fisheries, though nets and trawls also capture them (Wilson and Beckett 1970; Báez et al. 2016). This non-target species of low commercial value is considered bycatch (Domingo et al. 2005; François et al. 2019). In the western Mediterranean, pelagic stingrays are primarily caught as bycatch in longline fisheries targeting swordfish, bluefin tuna, and albacore tuna. Several studies report that pelagic stingrays represent between 8% and 68% (in number of individuals) of spanish longline catch composition and more than 30% for French longline fishery (Macías et al. 2004; Báez et al. 2009; SATHOAN pers. comm. 2024a). Pelagic stingrays are generally released by French fishers following the protocols suggested by best fishing practices manuals (mandatory for MSC fisheries) but the subsequent impact on the ecology of this species, and in particular its survival, are poorly known (Poisson et al. 2016).

Different approaches have been discussed in the literature to characterize post-release survival in longline fisheries. The few studies on ray bycatch in longline fisheries have focused on the types of hooks used, their link to catch rates, and their effect on hook retention and injury recovery (Piovano et al. 2010; Poisson et al. 2024). To date, two studies have reported tagging results on *Pteroplatytrygon violacea*, but did not examine post-release survival, only its vertical and horizontal movements (Weidner et al. 2014; Poisson et al. 2024). One study estimated the post-release survival of *Raja undulata* discarded by trawls in French Atlantic waters; it showed that 49% of tagged individuals survived after 14 days (Morfin et al. 2019). For pelagic stingray, estimates of this parameter remained poorly documented, probably due to several reasons. Little or no commercial interest (in France and Spain, for example), "least concern" qualification by international marine wildlife protection authorities, and dangerous handling due to the venomous stinger can be the reasons for this scientific disinterest (Siqueira and Sant'Anna 2007; Báez et al. 2016; Kyne et al. 2019).

Electronic tagging is a widely used method that allows researchers to monitor large pelagic species in their natural environment by recording parameters such as depth, temperature, and light intensity, which can later be used to reconstruct behavior and infer survival (Moyes et al. 2006; Nielsen et al. 2009; Hussey et al. 2015; Jepsen et al. 2015). This technique is applied to assess post-interaction survival by analyzing depth and temperature profiles (Moyes et al. 2006; Campana et al. 2009; Bowlby et al. 2021) and to improve management and conservation by tracking migratory routes and ecological dynamics, as demonstrated in studies of bluefin tuna and cetaceans (Evans and Hammond 2004; Block et al. 2005; Rouyer et al. 2020). Electronic tags differ in the type of data they record and in how those data are retrieved, with some requiring physical recovery and others detaching automatically and transmitting data via satellite. This study uses tags with automatic release and satellite transmission to estimate the post-release survival of pelagic stingrays due to the challenges in recapturing individuals once released.

None of the market tags incorporate a function that can accurately identify the moment of an animal's death. However, some models are designed for survival studies, but interpreting sensor data to determine post-release survival is not always straightforward (Moyes et al. 2006; Musyl et al. 2009; Jepsen et al. 2015). The main objective of post-release survival studies is to assess the impact of fishing gear on the animal and estimate its survival rate over time. The Kaplan–Meier method is commonly used to create survival curves, considering the animal's status and follow-up time (Bland and Altman 1998; Goel et al. 2010; Guyot et al. 2012). Based on this method, several studies make different decisions that may have an impact on the interpretation of the results, such as the time after which death is no longer considered to be a consequence of interaction with fishing gear (Campana et al. 2009; Hutchinson and Bigelow 2019; Benoît et al. 2020; Bowlby et al. 2021). These decisions, some based on data and others poorly explained, lack consensus. As a result, there is no standardized approach to defining the time after which death is no longer attributed to fishing gear interaction.

In this study, we present data on post-release survival of pelagic stingray caught as bycatch by the French longline fishery targeting Atlantic bluefin tuna (LLBFT) in the Gulf of Lion using an electronic tagging approach. The data collected by the electronic tags deployed on the animals were analyzed to assess whether individuals survived or died during the tag deployment period. The Kaplan–Meier method was implemented and several thresholds presented in the literature were tested in this study in order to provide the most plausible results for post-release survival linked to interaction with fishing gear for pelagic stingrays. The electronic tagging data also provide a better understanding of the ecology and habitat of this species that is still poorly known. These results contribute to understanding the impact of fishing on the species and to predicting future interactions that may influence the sustainable management of resources.

2 | Materials and Methods

2.1 | Data Collection

This study deployed three PSATLife tags (Lotek Inc.; 131 × 42 mm, 87 g), three sPat tags (Wildlife Computers; 118 × 41 mm, 68 g), and 35 MRPat tags (Wildlife Computers; 118 × 28 mm, 44 g; Table 1). In total, 41 electronic tags were deployed during commercial pelagic longline operations conducted on the continental shelf of the Gulf of Lion (southeastern France) between 14 April 2022 and 27 September 2023 (Figure 1). All participating vessels were dual-certified ("Pêche durable" and Marine Stewardship Council, MSC).

All tag models were pop-up satellite archival tags programmed to detach after a predefined deployment period. Multiple tag types were used to accommodate differences in size, cost, and data resolution. Upon release, the positively buoyant tags surfaced and transmitted stored data via satellite. PSATLife tags recorded light level, depth, and temperature for 28 days at 5-min intervals. sPat tags recorded the same parameters for 60 days but transmitted only the final 5 days of depth data at 10-min intervals, along with daily minimum and maximum temperatures for the full deployment. Both PSATLife and sPat tags included conditional release mechanisms triggered by prolonged inactivity or depth thresholds. PSATLife tags detached if a constant depth of 5 m was maintained for more than 3 days or if a depth of 2000 m was reached, whereas sPat tags detached after 1 day at a constant depth of 4 m or upon reaching 1700 m. MRPat tags recorded daily minimum and maximum temperatures and tilt over a 100-day period but did not include an inactivity-based release mechanism. As the smallest model used, MRPat tags were well suited to the slender morphology of pelagic stingrays. In the absence of conditional release, premature detachment of these tags required post hoc interpretation to determine whether release was attributable to mortality.

To evaluate the effects of capture on post-release survival, the study replicated commercial fishing conditions. All vessels used standardized gear and procedures, including circular hooks with 8 m leaders. Longlines were set for approximately 3.5 h, soaked for 4–5 h, and hauled according to catch volume. Pelagic stingrays were tagged without selection based on size, sex, or apparent condition. Individual condition and hook position were recorded, with no observed differences among individuals. All stingrays were landed alive and in good condition, with hooks located in the lower lip. Fishers applied established best practices by cutting the monofilament line close to the hook (Poisson et al. 2016). As tagging imposes additional handling stress relative to standard release, stingrays were continuously oxygenated during processing. Individuals were placed in a seawater tank, with eyes and stinger covered using wet cloths. Tagging was conducted by two operators, one restraining the stinger and the other attaching the tag. Disc width, sex, deployment site, vessel, and tagging method were recorded for each individual. Age was estimated using the von Bertalanffy curve presented by Neer (2008).

Selecting an appropriate tagging method is critical, as it can strongly influence both post-release survival and premature tag loss. Although no standardized tagging protocol exists for pelagic stingrays, several methods have been applied to other ray species (Brewster et al. 2021; Poisson et al. 2024; Orrell et al. 2025). A stepwise approach was therefore adopted to develop an effective tagging technique. An initial method, involving a cable tie and surgical tubing passed through the tail using a hollow needle, showed satisfactory tag retention for approximately 2 weeks in two individuals tagged in April 2022 (Table 1). However, subsequent trials on ten individuals in August 2022 resulted in premature tag loss after 1–4 days (Table 1). A modified technique was then implemented, using a 2 mm monofilament line inserted through the dorsal musculature with hollow needles to secure the tag at two attachment points, thereby limiting movement and improving retention. Petersen discs were added to minimize tissue damage and further enhance tag stability (Figure S8).

2.2 | Analysis

Tagging data were analyzed using the Kaplan–Meier survival method to assess post-release survival based on a binomial alive-or-dead response following fishing gear interaction (Campana et al. 2009; Bowlby et al. 2021). This time-to-event approach analyzes the probability of survival of a subject from start of monitoring (tag deployment) to end point (release of the tag).

Tag retention time can be influenced by factors such as sex, size, and environmental conditions. Studies suggest tags last longer on larger fish, with less impact on swimming ability (Steinhausen et al. 2006; Jepsen et al. 2015). To investigate potential effects on pelagic stingrays, retention time was compared with sex, disc width, deployment date, and sea surface temperature (SST). SST data from the Copernicus Monitoring Environment Marine Service (CMEMS) was used to obtain the surface temperature at the deployment point and avoid any measurement bias caused by the tag sensor upon launch. This made it possible to study the possible link between short retention time and high surface temperature at the moment of release. It covered the area from 43.15° N to 43.4° N latitude and 3.05° E to 4.9° E longitude, between 14/04/2022 and 27/09/2023 (space–time limit for deployment and pop-off) (Clementi et al. 2021). The physical model grid resolution was 1/24° (ca. 4 km).

An individual is characterized by the retention time of its tag (serial time) and its status at the end of serial time (Rich et al. 2010). The status can either be "dead" or "censored". As explained in Prinja et al. (2010), a participant is said to be censored when information on time to event is not available due to loss to follow-up or non-occurrence of outcome event before the trial end. In this study, this refers to pelagic stingrays whose tags detached before the scheduled programming, or for which data are unavailable. Therefore, the status is represented numerically (dead = 1, censored = 0) (Rich et al. 2010). While an animal can generally be assumed alive if the tag reaches the end of its deployment, tags often release prematurely due to attachment failure or the premature death of the animal. In the latter case the body generally sinks to the ocean floor, where its tissues and flesh decompose (Moore

TABLE 1 | Morphometric and deployment metadata for the pelagic stingrays tagged for this study.

Id	Tag type	Deployment date	RT (days)	DLAT (°)	DLON (°)	PLAT (°)	PLON (°)	DW (cm)	Sex	Vessel	TD (km)	DD (km)	TP
R3	MRPat	14/04/2022	1	43.26	3.99	43.1	4.11	52	F	Trois Frères II	21	21	Method 1
R4	MRPat	14/04/2022	14	43.26	3.99	42.98	3.83	48	M	Trois Frères II	34	2	Method 1
R5	MRPat	03/08/2022	1	43.16	3.68	43.09	3.67	50	F	Thoyan III	7	7	Method 1
R6	MRPat	03/08/2022	2	43.16	3.68	43.02	3.94	50	F	Thoyan III	26	13	Method 1
R7	MRPat	03/08/2022	2	43.16	3.68	42.84	3.73	45	M	Thoyan III	36	18	Method 1
R16	MRPat	03/08/2022	3	43.16	3.68	42.63	4.16	45	M	Thoyan III	71	24	Method 1
R24	MRPat	03/08/2022	1	43.16	3.68	43.24	3.68	40	M	Thoyan III	10	10	Method 1
R29	MRPat	03/08/2022	4	43.16	3.68	42.37	3.8	40	M	Thoyan III	88	22	Method 1
R10	MRPat	04/08/2022	3	43.16	3.68	43.19	3.33	40	M	Thoyan III	28	9	Method 1
R14	MRPat	04/08/2022	2	43.16	3.68	42.98	3.61	45	M	Thoyan III	20	10	Method 1
R20	MRPat	04/08/2022	1	43.16	3.68	43.1	3.74	50	F	Thoyan III	8	8	Method 1
R23	MRPat	04/08/2022	1	43.16	3.68	43.15	3.56	45	M	Thoyan III	9	9	Method 1
R8	MRPat	27/08/2022	12	43.17	4.04	43.29	4.9	55	F	Trois Frères II	71	6	Method 2
R11	MRPat	27/08/2022	9	43.17	4.04	42.7	4.11	41	F	Trois Frères II	53	6	Method 2
R19	MRPat	27/08/2022	1	43.17	4.04	43.08	4.15	40	M	Trois Frères II	14	14	Method 2
R28	MRPat	27/08/2022	7	43.17	4.04	43.39	4.43	38	M	Trois Frères II	40	6	Method 2
R30	MRPat	27/08/2022	65	43.17	4.09	—	—	49	F	Trois Frères II	—	—	Method 2
R39	MRPat	27/08/2022	28	—	—	—	—	51	F	Trois Frères II	—	—	Method 2
R40	MRPat	18/04/2023	—	43.12	3.94	—	—	50	F	Trois Frères II	—	—	Method 2
R1	sPat	19/04/2023	13	43.27	3.81	42.66	4.4	57	F	Trois Frères II	83	6	Method 2
R2	sPat	19/04/2023	14	43.18	3.96	42.72	4.06	47	F	Trois Frères II	52	4	Method 2
R41	sPat	19/04/2023	—	43.15	4.02	—	—	47	F	Trois Frères II	—	—	Method 2
R36	PsatLife	24/04/2023	18	43.18	3.74	41.24	4.57	75	F	Trois Frères II	226	13	Method 2
R37	PsatLife	27/04/2023	24	43.23	3.82	41.45	3.96	46	F	Olga	199	8	Method 2
R38	PsatLife	27/04/2023	7	43.16	3.87	42.81	4.19	45	F	Olga	47	7	Method 2
R12	MRPat	23/08/2023	3	43.25	3.74	42.88	3.89	40	M	Thoyan III	44	15	Method 2

(Continues)

TABLE 1 | (Continued)

Id	Tag type	Deployment date	RT (days)	DLAT (°)	DLON (°)	PLAT (°)	PLON (°)	DW (cm)	Sex	Vessel	TD (km)	DD (km)	TP
R17	MRPat	23/08/2023	13	43.24	3.77	42.5	3.83	45	F	Thoyan III	83	6	Method 2
R18	MRPat	23/08/2023	2	43.24	3.78	43.02	3.78	40	F	Thoyan III	24	12	Method 2
R22	MRPat	23/08/2023	4	43.24	3.77	42.27	3.76	47	F	Thoyan III	108	27	Method 2
R31	MRPat	06/09/2023	7	43.31	3.97	42.64	3.19	52	F	Olga	98	14	Method 2
R9	MRPat	19/09/2023	5	43.23	3.76	42.79	3.68	36	M	Olga	50	10	Method 2
R21	MRPat	19/09/2023	13	43.22	3.85	42.75	3.77	49	F	Olga	53	4	Method 2
R33	MRPat	19/09/2023	1	43.23	3.78	43.23	3.76	43	M	Olga	2	2	Method 2
R34	MRPat	19/09/2023	1	43.23	3.8	43.17	3.92	47	F	Olga	11	11	Method 2
R13	MRPat	20/09/2023	22	43.26	3.7	42.77	3.06	53	F	Olga	75	3	Method 2
R35	MRPat	20/09/2023	12	43.24	3.74	41.8	3.59	43	F	Olga	160	13	Method 2
R15	MRPat	27/09/2023	6	43.21	3.9	42.49	3.21	41	F	Olga	97	16	Method 2
R25	MRPat	27/09/2023	16	43.25	3.88	41.91	3.43	41	M	Olga	153	10	Method 2
R26	MRPat	27/09/2023	17	43.26	3.86	42.44	3.24	46	F	Olga	103	6	Method 2
R27	MRPat	27/09/2023	70	43.22	3.9	41.92	3.25	55	F	Olga	153	2	Method 2
R32	MRPat	27/09/2023	7	43.25	3.85	43.04	3.76	52	F	Olga	25	4	Method 2

Abbreviations: DD, Daily Distance traveled (TD/RT); DLAT, Deploy Latitude; DLON, Deploy Longitude; DW, Disc Width; PLAT, Pop-off Latitude; PLON, Pop-off Longitude; RT, Retention Time; TD, Total Distance traveled (considering the route as a straight line between deploy and pop-off locations); TP, Tagging Protocol.

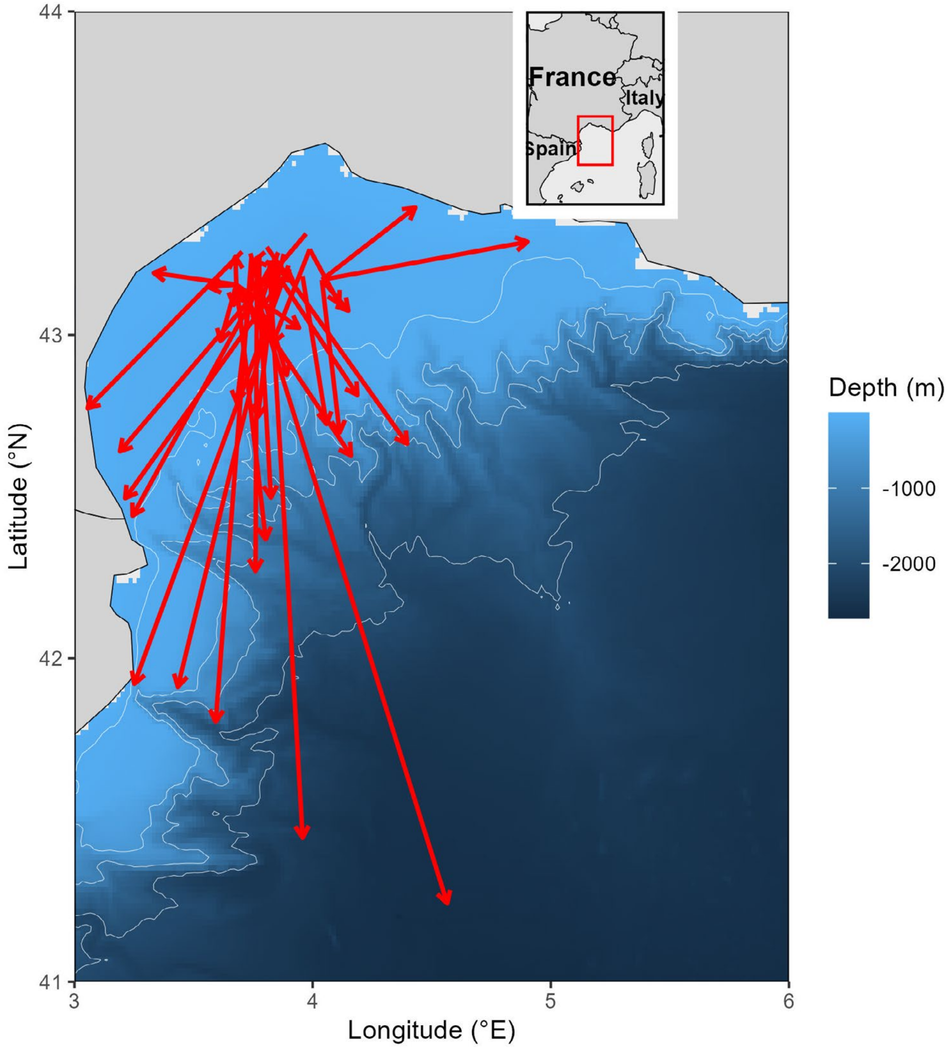

FIGURE 1 | Topographic map indicating straight trajectory between deployment and pop-off locations. The continuous white line represents isobath of 100, 500, 1000 and 2000 m depth.

et al. 2020). The decomposition time of large pelagic species on the seabed is not well studied but, for instance, the body of a pig at 300 m depth may skeletonize in 3–4 days (Anderson and Bell 2016). If the pelagic stingray dies and the body sinks, the PSATLife and sPat tag models identify periods of inactivity and trigger their conditional release mechanism. In the case of MRPats, the tag detaches only when the tissue has decomposed sufficiently to release the anchoring system or if it is mechanically pulled out of the flesh. In this case, the interpretation of the data provided by the tag allows the status of the individual to be defined.

Tags do not directly provide survival status but instead offer depth and temperature data, from which behavior and fate can be inferred. Prolonged inactivity, indicated by a constant depth, often follows a long dive, helping to identify the moment of death, as observed in several studies on elasmobranch post-release survival (Campana et al. 2009; Musyl et al. 2009; Bowlby et al. 2021).

Campana et al. (2009) clearly shows a canonical death for a tagged individual. After release, the animal's depth increases until it sinks, followed by a constant depth for 5 days. The tag's constant-depth warning function then triggers release, allowing it to transmit data (Campana et al. 2009). In this study, a pelagic stingray was considered dead if a prolonged inactivity period (less than 0.5°C or 5 m in depth) was followed by tag detachment. For MRPat tags, without a conditional release system, 3 days of inactivity indicates death, reflecting the time it takes for the body to enter the skeletonization phase. This is consistent with the PSATLife tag's conditional release period, while the sPat tag activates release after 1 day of inactivity. A substantial and sudden discontinuity in diving behavior, for instance substantially deeper than previously recorded, may be interpreted as an additional sign of death. To date, there is no consensus in the literature on when death due to fishing gear interaction can be distinguished from natural mortality in rays species. However, a period of 30 days has been determined to be the minimum and sufficient deployment period to observe fishing mortality (SPC 2017; Francis et al. 2023). This specific threshold for sharks remains debated in some survival studies, but it was considered and tested in this study (Marçalo et al. 2018; Bowlby et al. 2021). Furthermore, the results of over 90 studies on the post-release survival rate of large pelagic species show that 80%–85% die within 7–14 days after capture (Musyl and Gilman 2019). This study tests three threshold values (7,

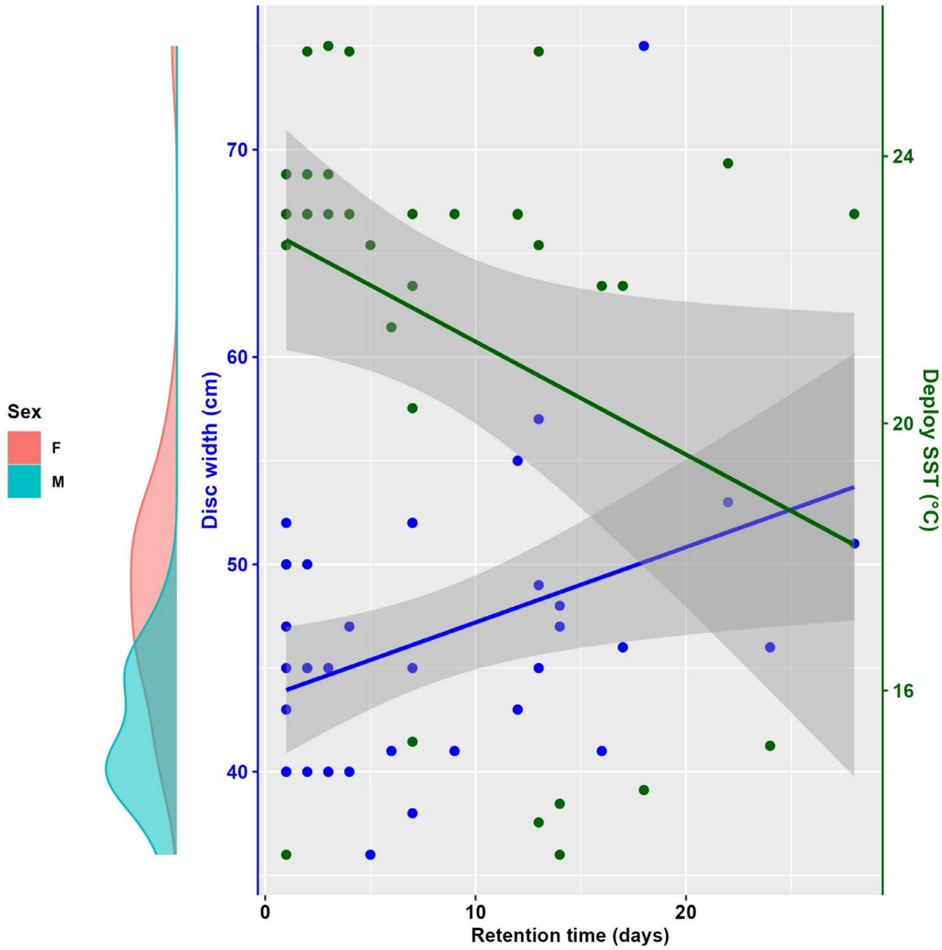

FIGURE 2 | Relationship between tag retention time and stingray disc width (blue) and sea surface temperature (SST) at the deployment location (green). Solid line represents a linear model fitted to the data and the gray area represents the 95% confidence interval. The disc width density distribution of pelagic stingrays by sex (male = blue, female = red) are represented in the left panel.

14, and 30 days) to compare findings with different assumptions about gear impact on mortality. Survival curves for each threshold are presented, with results potentially providing further insights into this time threshold.

In some cases, it is difficult to determine an individual's survival status with certainty, which can affect Kaplan–Meier analysis outcomes. For example, a sudden change in depth or temperature followed by a shorter inactivity period may not align with canonical mortality signs. To address this uncertainty, a probabilistic approach was used. Each ray was assigned a survival probability based on temperature and depth data. If no mortality signs were observed, the ray was considered alive with a survival probability of 1. If mortality signs were observed but the status remained uncertain, a probability of 0.5 was assigned. If death was clearly indicated, the probability was 0. These probabilities fed into the Kaplan–Meier model, which assigned survival status accordingly. Numerous simulated datasets were created to account for all possible combinations of probabilities. For example, if a ray had a 0.5 survival probability, it was considered alive in half of the simulations. For each simulated dataset, an estimated survival rate was calculated and a Kaplan–Meier curve estimated using the Surv and survfit2 functions implemented in the "survival" package in R (Therneau 2024). The distribution of all survival curves obtained through this process was merged to build a final survival curve with its associated confidence interval.

3 | Results

In 2022 and 2023, 41 pelagic stingrays were tagged, with data from 38 used in this study. Three tags (2 MRPats and 1 sPat) failed to transmit due to technical issues. Tagging occurred in April, August, and September on three vessels: "Trois Frères II" (ST916523), "Olga" (ST859056), and "Thoyan III" (ST781490), all from the same fishing ground. The disc width of individuals ranged from 38 cm to 75 cm, corresponding to ages 2–10 years. The sex ratio was M:F (1:2), with 14 males and 25 females. The ratio varied seasonally, with a lower male-to-female ratio in April (1:6) compared to August (1:1) and September (1:3). Males were smaller than females, with median disc widths of 40.5 cm and 49 cm, respectively (Figure 2).

Retention times varied substantially, ranging from 1 to 70 days, with an average of 11 days (Table 1). Seventeen tags lasted less than 5 days, especially the 11 out of 12 from the first protocol, highlighting the need for protocol changes, leading to protocol 2. Retention times were longer for larger individuals (*t*-test, $p < 0.05$) and were associated with lower sea surface

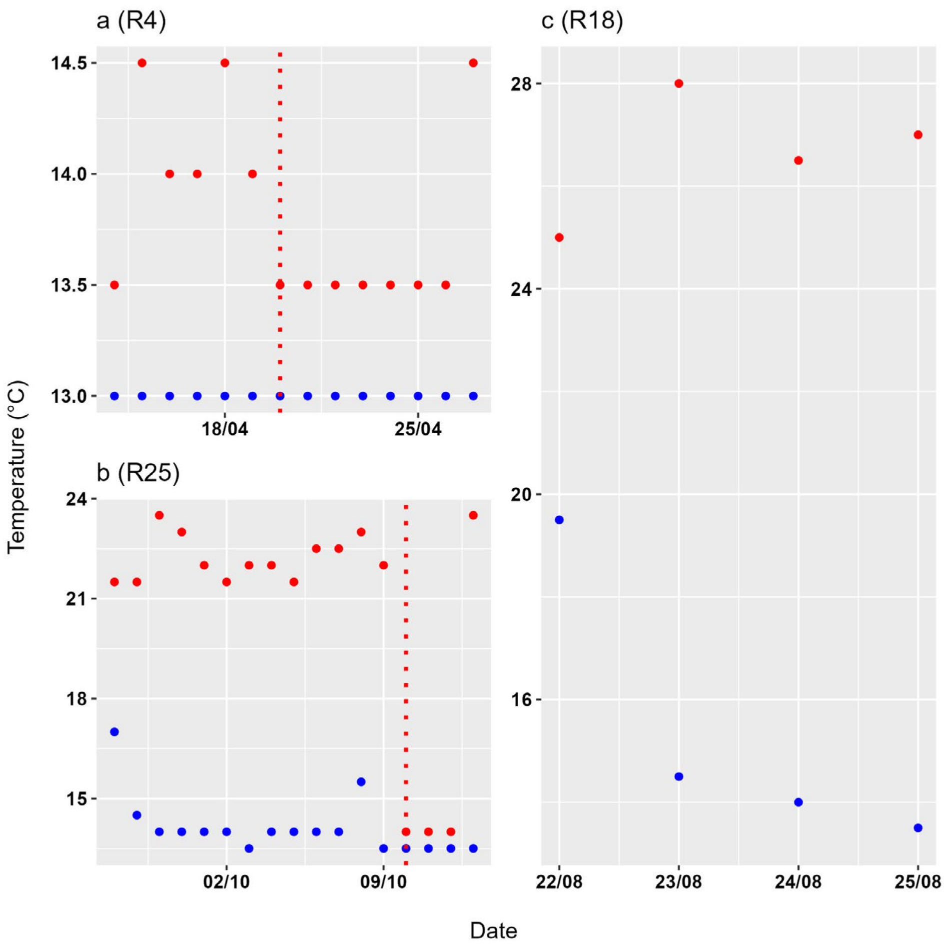

FIGURE 3 | Observed daily minimum (blue) and maximum (red) temperature recorded by the tag deployed on R4 (a), R25 (b) and R18 (c). Red dashed lines indicate the moment of canonical death.

temperatures (*t*-test, $p < 0.05$), suggesting a confounding effect between size and temperature, with larger rays, often females, in colder waters. Horizontal movements between the deployment and pop-up locations ranged between 2 and 226 km (Table 1). The daily distance traveled by individuals varied between 2 and 27 km.

Unequivocal signs of mortality, such as prolonged inactivity indicated by constant parameters, were only found for two individuals. Substantial temperature differences were recorded over 6 days for R4 and 13 days for R25 (Figure 3a,b). These temperatures suddenly became very similar or identical for 7 consecutive days for R4 and 3 consecutive days for R25, before the release of the tag. As a result, a survival probability of 0 was assigned to these two pelagic stingrays. For the 35 other individuals, no signs of death were observed, as they showed substantial variation in depth and temperature, such as individual R18 (Figure 3c; Figures S2–S7). A survival probability of 1 was assigned to these 35 individuals.

Five datasets provided high resolution pressure data that could be inspected in more detail (Figure 4). Individuals tagged with sPats and PSATLife models showed substantial successive dives during deployments (Figure 4a–d). R36 displayed multiple deep dives, with the deepest reaching 685 m (Figure 4d). Despite these deep dives, temperatures remained constant between 18°C and 13.8°C below 100 m due to water column stratification. None of these individuals exhibited signs of mortality, and a survival probability of 1 was assigned to each.

For pelagic stingray R37, two distinct phases were observed (Figure 4e). The first 11 days showed successive dives to 220 m, with temperature fluctuations between 13.5°C and 18°C, similar to other spring-tagged individuals. Substantial variations in depth (over 600 m) were observed from the twelfth day onwards after a dive and a period of inactivity at 750 m, deeper and longer than the dives and inactivity observed for the four other individuals (R1, R2, R36 and R38; Figure S1). In contrast, 95% of dives for these individuals were below 400 m, and inactivity lasted less than 200 min (3h22). Although the deep dive and inactivity raised doubts about survival, they were not definitive signs of mortality. The second phase added further uncertainty, so the survival probability for R37 was assigned a value of 0.5.

Survival probabilities assigned to each pelagic stingray were used to calculate survival curves using the Kaplan–Meier method (Figure 5). The curve drops each time an individual is declared dead. Temporal thresholds (7, 14, and 30 days) from the literature were applied to the survival data. Only R4 and R25 had a survival probability of 0 (dead), and R37 had a probability

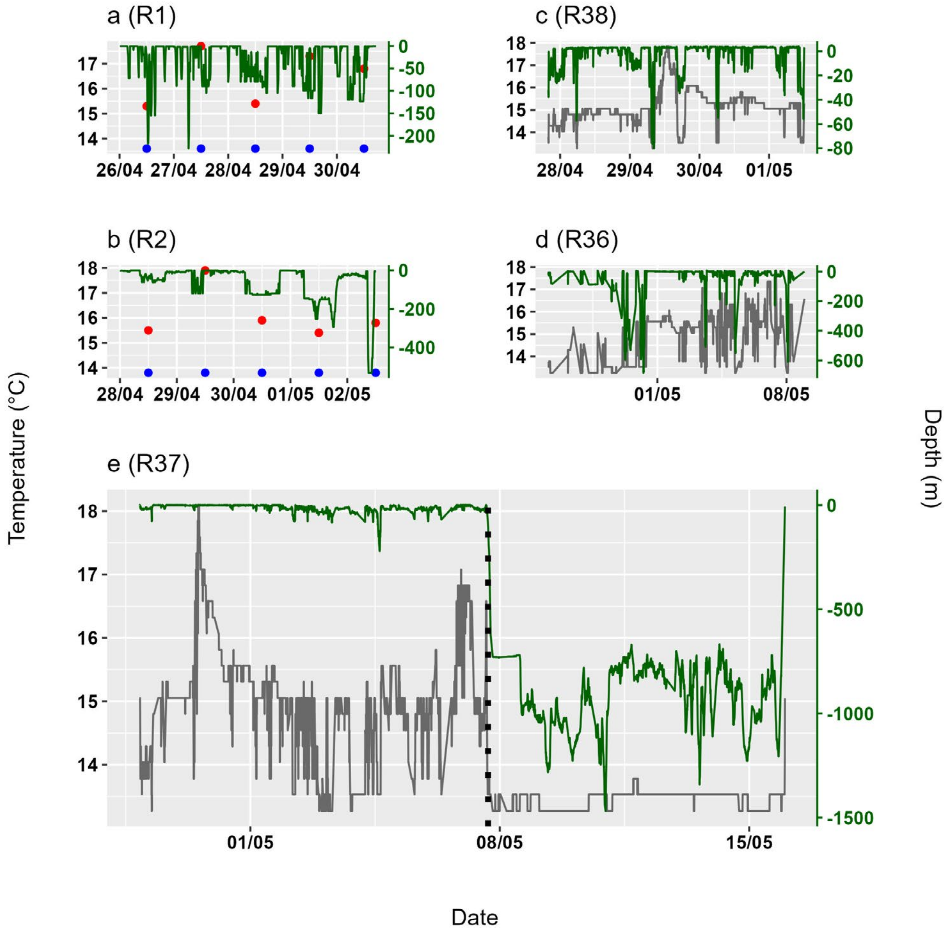

FIGURE 4 | Observed daily minimum (blue) and maximum (red) temperature recorded by the tag. Observed temperature (gray line) and depth (green line) recorded by the tag. Ray 1 (a), ray 2 (b), ray 38 (c), ray 36 (d) and ray 37 (e). Vertical black dashed lines indicate the moment of potential death.

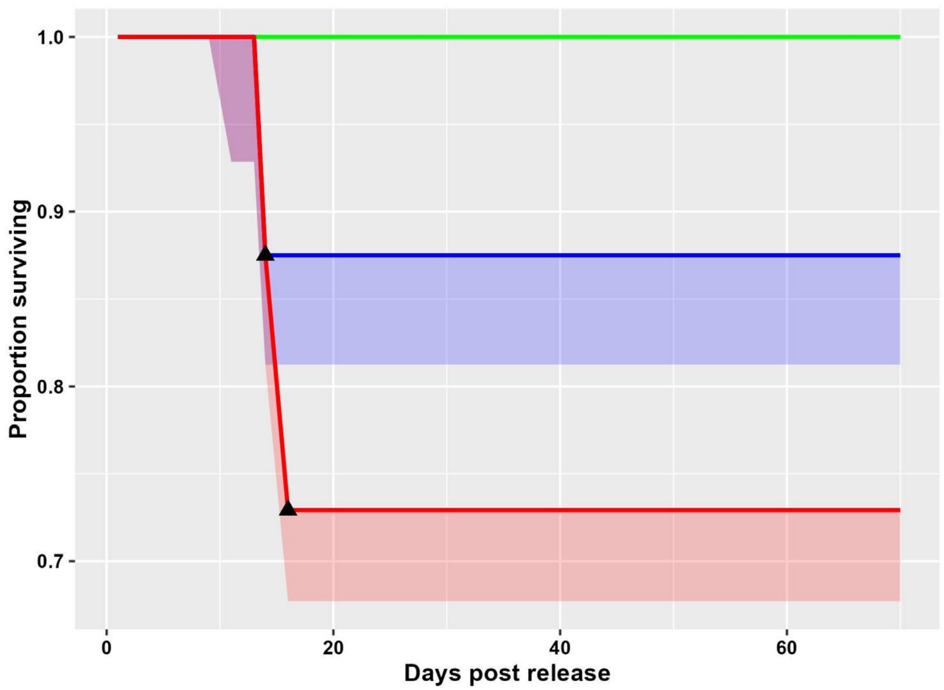

FIGURE 5 | Estimated survivorship (with uncertainty) of pelagic stingray, based on the non-parametric Kaplan–Meier (KM) estimator considering the temporal thresholds of non-consequential death of fishing after 7 days (green), 14 days (blue) and 30 days (red). Black triangles represent the death of an individual.

of 0.5 (doubtful survival). R4 and R25 had retention times of 14 and 16 days, respectively. For R37, the questionable event occurred after 11 days. With the 7-day threshold, no individual was considered dead. If one assumed a threshold at 14 days, R4 was considered dead as a result of fishing gear interaction. R37 was considered alive but with a 0.5 probability, which explains the shaded area starting at 11 days. For the worst-case scenario curve, the 30-day threshold, the three events could be considered the consequence of an interaction with fishing gear. R4 and R25 were therefore considered dead and R37 alive (with 0.5 probability). Median survival rates were 1, 0.87, and 0.73 for the 7, 14, and 30-day thresholds, respectively.

4 | Discussion

Little is known about the post-release survival of pelagic stingrays caught in the Mediterranean by longline fleets targeting bluefin tuna. This study proposes a first estimate of the proportion of individuals surviving after their release from a fishing event and documents an approach to account for uncertainty in survival determination using electronic tagging data. It remains to be discussed whether the findings of this study can be generalized to the entire fishery, but it is a first attempt to get a general picture with a rational approach.

Tagging techniques for marine animals are evolving, directly affecting tag retention time and the quality of behavioral data. In post-release survival studies, interpreting tag data is necessary to determine survival. While some studies have examined pelagic stingray recovery in tanks, no research has used electronic tags to estimate post-release survival, despite its bycatch in some fisheries (Poisson et al. 2017; François et al. 2019). Various methods for tagging pelagic rays are described in the literature, but none stood out as a clear reference (Le Port et al. 2008; Poisson et al. 2017; Morfin et al. 2019; Orrell et al. 2025). These methods were often too complex, imprecise, or invasive for smaller pelagic stingrays, prompting the testing of two protocols in this study. The first tagging protocol showed disappointing retention time results. The second protocol, although faster and easier to deploy, resulted in more variable retention times (1–70 days). It was still possible to interpret these data while taking into account a certain degree of uncertainty. Although the average retention time remained low (11 days), it falls within the range reported by the only two other studies conducted on this species, both of which selected rays in good condition: retention times ranged from 2 to 60 days in Poisson et al. (2017) and averaged 13 days in Weidner et al. (2014). More generally, several post-release survival studies have shown relatively heterogeneous and low retention times. Nevertheless, survival estimates can still be derived (Campana et al. 2009; Jensen and Graves 2020).

The low retention times in this study are probably due to the tagging protocol, as handling appears to be substantially more traumatic than the simple release method usually practiced by fishers. Individuals are kept immobile, the application of the tag to the body is probably not painless, and the stress caused by handling must be considered. Improving the protocol to reduce stress and enhance retention would allow for a more accurate assessment of post-release survival of this species in future studies (Poisson et al. 2016).

Interpreting the raw data from the tags is complex. Out of 38 tags, 35 showed no clear signs of fishing-related mortality. These 35 pelagic stingrays moved through waters with daily temperature variations up to 15°C. However, two individuals (R4 and R25) displayed temperature patterns indicating canonical mortality. After more than a week of fluctuating temperatures, the variations stabilized between 0°C and 0.5°C for several days, suggesting the animal had died and sunk to the bottom. The tag detached later, likely due to tissue decomposition. Apart from decomposing whale corpses that are buoyant due to intracorporeal fermentation, all pelagic species sink after death (Reisdorf et al. 2012; Moore et al. 2020). In post-release survival studies, inactivity and lack of movement, reflected by constant temperature and/or depth values, may indicate death (Hussey et al. 2018; Benoît et al. 2020; Stahl 2023). Individual R37, tagged with a PSATLife, exhibited unusual behavior. After 11 days, it made a substantial dive to 750 m, followed by 8 h of inactivity at that depth (Figure 4e). This inactivity was longer than the typical recovery times observed in other individuals but too short to be classified as canonical death (Figure S2). The dive to 750 m is unprecedented for this species, raising doubts about the animal's survival. If tagged with an MRPat, this inactivity would likely have been interpreted as death. This justifies the use of an alternative probabilistic method to consider this uncertainty. The significant fluctuations in depth after the period of inactivity make it impossible to classify the individual as dead, but may suggest predation. Additionally, constant temperature values could indicate the tag was inside a non-mammalian predator. Cases of tags being ingested or torn off by predators have been reported (Lennox et al. 2023; Rouyer et al. 2024; Rudd et al. 2024).

The survival rate after capture by fishing gear and release was calculated using the Kaplan–Meier method. However, for rays there is no consensus on when death can no longer be attributed to fishing gear interaction. Three time thresholds mentioned and used in the literature were tested using the results of this study (Figure 5). These thresholds provided three different survival rates for pelagic stingrays, each with uncertainty due to the probabilistic approach. The 30-day threshold, defined by an expert workshop on sharks post-release survival, is the most conservative and identified two pelagic stingrays (R4 and R25) as dead, with R37 potentially dead, yielding a survival rate of 73%. This threshold establishes a minimum deployment period of 30 days to observe immediate mortality after release due to fishing gear interaction (SPC 2017; Francis et al. 2023). Nevertheless, several studies have questioned the consensus surrounding this threshold (Marçalo et al. 2018; Musyl and Gilman 2019; Bowlby et al. 2021). Musyl and Gilman (2019) analyzed the distribution of time-to-event for tagged individuals, observing that 80% of post-release fishing mortality occurred within 7 days and 83% within 14 days. These two thresholds were tested with the results. The first, most optimistic assumption is that no individuals died as a result of fishing. The second (14 days) assumes that only the individual R4 died after interacting with the gear, resulting in an 87% survival rate. However, these thresholds seem insufficient, as several studies indicate that recovery periods for elasmobranchs can last up to 38 days (Campana et al. 2009; Bowlby et al. 2021). Recovery time likely depends on the animal's condition upon release and environmental factors (Hoolihan et al. 2011; Whitney et al. 2016). A plausible and conservative interpretation would suggest considering the 30-day threshold mentioned in Francis et al. (2023), and defined by the tag manufacturer (Wildlife Computers).

Regardless of the threshold and assigned survival probabilities, it is crucial to note that the impact of tagging is substantial and causes extra trauma compared to standard release used by fishers following best fishing practice guidelines (Holm et al. 1999; Cooke et al. 2011; Poisson et al. 2016).

Recovery after release is influenced by size, health, and environmental conditions (Moyes et al. 2006; Whitney et al. 2016; Cope et al. 2022). Larger pelagic stingrays, often found in spring with cooler sea surface temperatures, had higher tag retention times. High water temperatures negatively affect recovery and survival, impacting ventilation and heart rate (Musyl et al. 2009; French et al. 2015; Rouyer et al. 2023). Studies using electronic tagging have shown better tag retention on larger individuals, as the tag is less intrusive, allowing for easier mobility (Steinhausen et al. 2006; Jepsen et al. 2015). According to several direct observations during the release, smaller pelagic stingrays may experience greater stress and swimming effort in warmer waters, leading to longer recovery times (at the surface) and increased vulnerability to predators like seabirds. Post-release survival studies have identified stationary periods at the surface, with little depth variation, which can precede death in some cases (Campana et al. 2009; Hoolihan et al. 2011; Bowlby et al. 2021). Although several studies have demonstrated a link between post-release survival and various factors such as individual size, environmental conditions, stress levels, and animal condition, the uncertainty surrounding survival and the low number of animals considered dead in this study prevented detection of these links (Musyl et al. 2009; Massey et al. 2022).

The electronic tagging approach used in this study also provided valuable information on the ecology of this poorly documented species in the Western Mediterranean. Data revealed the presence of larger, mostly female individuals in spring, while smaller males appeared in warmer summer waters. These findings align with local catch data (Landreau et al. 2024; SATHOAN pers. comm. 2024b). Pelagic stingrays inhabit temperate and tropical waters and reproduce in warm equatorial or Mediterranean zones (Hemida et al. 2003; Kyne et al. 2019). No gonad observations were conducted in this study, but the presence of individuals of both sexes in the waters of the Gulf of Lion in summer may suggest reproductive behavior. Using deployment and pop-off locations, the distance traveled by pelagic stingrays was estimated. On average, an individual can travel up to 10 km per day, which aligns with findings from Poisson et al. (2024) and is still about 10 times less than the travel of adult bluefin tuna which is the target species of the fishery and emblematic of the area (Teo et al. 2007; Block et al. 2011; Rouyer et al. 2020). Three individuals tagged with PSATLife tags and two with sPat tags exhibited significant movements, with some dives reaching over 480 m, the deepest recorded for this species (Poisson et al. 2017, 2024). The maximum depth reached was 684 m, and R37's movements beyond 750 m likely indicate predation, as tag ingestion by predators is a plausible explanation (Francis et al. 2023; Rouyer et al. 2024; Rudd et al. 2024). The horizontal displacements observed in this study appear to correspond to the values presented in the literature. A comparison shows that the largest individuals cover the longest distances (Weidner et al. 2014).

In 2024, pelagic stingrays represented substantially 3% of the catch volume and 30% of the number of individuals captured in the French longline fishery targeting bluefin tuna in the Gulf of Lion (Poisson et al. 2020; SATHOAN pers. comm. 2024a, 2024b).

The deployment of electronic tags in this study provides valuable information as (1) it provides a first estimate of the post-release survival rate of this bycatch species, and (2) it sheds light on the phenology, habitat, and ecology of this species. Marine species' movements are increasingly influenced by climate change, with shifts in species presence and migratory routes observed (Occhipinti-Ambrogi 2007; Poloczanska et al. 2013; Cheung et al. 2016; Duarte et al. 2020). The characterization of bycatch will help anticipate future interactions of these species with humans and improve the sustainable management of exploited resources in the context of an ecosystem approach to fisheries.

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Ethics Statement

The care and use of the animals complied with EU animal welfare laws, guidelines, and policies.

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

Data publicly available via Zenodo (https://doi.org/10.5281/zenodo.17601713).

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. **Figure S1:** Density distributions of dives (a) and (inactivity period) recorded by the tag of ray number 1, 2, 36 and 38. Vertical black dashed lines indicate quantile 95. **Figure S2:** Observed daily minimum (blue) and maximum (red) temperature recorded by the tag deployed on ray number 3, 5, 6, 7, 8 and 9. **Figure S3:** Observed daily minimum (blue) and maximum (red) temperature recorded by the tag deployed on ray number 10, 11, 12, 13, 14 and 15. **Figure S4:** Observed daily minimum (blue) and maximum (red) temperature recorded by the tag deployed on ray number 16, 17, 18, 19, 20 and 21. **Figure S5:** Observed daily minimum (blue) and maximum (red) temperature recorded by the tag deployed on ray number 22, 23, 24, 26, 27 and 28. **Figure S6:** Observed daily minimum (blue) and maximum (red) temperature recorded by the tag deployed on ray number 29, 30, 31, 32, 33 and 34. **Figure S7:** Observed daily minimum (blue) and maximum (red) temperature recorded by the tag deployed on ray number 35. **Figure S8:** Picture of a pelagic stingray tagged with sPat model according to protocol 2.