Title: Shedding rates and retention performance of conventional dart tags in large pelagic sharks: insights from a double-tagging experiment on blue shark (*Prionace glauca*)

Authors: Federico Mas [a,*], Enric Cortés [b], Rui Coelho [c], Omar Defeo [d], Rodrigo Forselledo [a], Sebastián Jiménez [a], Philip Miller [a] and Andrés Domingo [a]

[a] Dirección Nacional de Recursos Acuáticos, Laboratorio de Recursos Pelágicos, Montevideo, Uruguay. [b] National Marine Fisheries Service, Southeast Fisheries Science Center, Panama City, FL, United States. [c] Instituto Português do Mar e da Atmosfera, Olhão, Portugal, [d] Facultad de Ciencias, Montevideo, Uruguay.

*__Corresponding Author at:__ Dirección Nacional de Recursos Acuáticos, Constituyente 1497, CP11200, Montevideo, Uruguay. E-mail address: f.masbervejillo@gmail.com (F. Mas)

Abstract

Tagging studies are a fundamental tool for understanding fish population dynamics. Choosing the right tag type, however, is of major importance, as properties such as shedding rate can affect estimates of mortality, abundance, and movement rates. Here, we provide tag-specific recapture rates for blue sharks (*Prionace glauca*) and assess the retention performance of plastic and stainless-steel dart tags based on shedding rates from a double-tagging experiment. In total, 4,648 sharks were tagged, of which 67 were recaptured. Single-barb (SB) and double-barb (DB) plastic tags yielded similar recapture rates, which were almost eight times lower compared to stainless-steel dart tags (M). Shedding rates from recaptured double-tagged sharks were 54, 8 and 0% for SB, DB and M tags, respectively, with the shedding probability of SB tags positively correlated with time. Double-tagging results provided critical insight into the potential loss of information through tag shedding: the overall recapture rate from this study would drop from 1.4 to 1.0%, and above half of all long-term (≥ 1 year) and large-scale (≥ 1,000 km) recaptures would have been lost through shedding of SB tags. This study showcases the utility of double-tagging experiments to assess the performance of different tag types. We conclude that M tags outperform SB tags in retention performance and ease of application, and recommend that future conventional tagging studies focused on large pelagic sharks implement the use of this tag type, as they minimize tag loss through shedding and maximize the probability of obtaining long-term and large-scale recaptures.

Keywords: Conventional tagging; Double-tagging; Dart tag; Tag shedding; Shark

1. Introduction

The use of a wide array of marks and tags has become a fundamental tool for studying fish population dynamics, providing information on stock identity and connectivity, abundance, mortality rates, movement patterns, and age and growth (Fonteneau and Hallier, 2015; McFarlane et al., 1990; Pine et al., 2012). Tagging studies on sharks date back to the 1940s (Kohler and Turner, 2001) and although electronic tags (*i.e.* acoustic and satellite telemetry) over the past 50 years have expanded the horizon of shark research (Simpfendorfer and Heupel, 2012; Sims, 2010), conventional tagging is still the most cost-effective and widely used methodology to address ecological aspects at both individual and population scales (Bartes et al., 2021; Dunlop et al., 2013; Kohler and Turner, 2019; Latour, 2005). The effectiveness of a tagging study, however, largely depends on the type of tag used (McFarlane et al., 1990). Shedding rate, ease of application, conspicuousness, and tag effects on fish behavior and survival can vary largely among and within different tag types depending on the species, body size and tagging procedure (Latour, 2005; Pine et al., 2012).

Tag shedding rates (instantaneous and long-term) can lead to underestimations of return rates, and if not properly accounted for, can bias abundance and mortality estimates and movement patterns (Pine et al., 2012, 2003). Double-tagging is a straightforward method to inform on tag shedding, having the benefit of providing a specific estimate for the species under study, location and tag type (Gaertner et al., 2022; Latour, 2005; Pine et al., 2012). This method can also be used to compare the performance and shedding rate of different tags (Barrowman and Myers, 1996; Prince et al., 2002), hence informing on the suitability of specific tag types depending on the objectives of the study. In sharks, double-tagging experiments have been carried out to assess shedding rates of a single tag type (Dicken et al., 2006; Francis, 1989; Xiao et al., 1999) and to compare shedding rates between different types (Hansen, 1963; McFarlane and Beamish, 1986; Olsen, 1953; Stevens et al., 2000; Talwar et al., 2022; Xiao, 1996; Xiao et al., 1999). However, these tag comparisons were conducted between very similar tags with slight modifications, or between fin tags (*i.e.* Petersen discs, rototags, cattle tags) and dart tags (*i.e.* T-bar tags, plastic or stainless-steel darts). Moreover, most of these experiments were conducted on small to medium-sized sharks, and none of them were focused on large, oceanic migratory species.

Oceanic species such as the blue shark, *Prionace glauca,* have been tagged for decades by major cooperative tagging programs (CTP) across the world (e.g. Holdsworth et al., 2016; Kohler and Turner, 2019; NSW-GFTP, 2021; ORI-CFTP, 2021a; Wögerbauer et al., 2016), many of which are still active. Combined, thousands of individuals have been tagged with different tag types, including fin and dart tags, and although substantial information has been gained regarding short- and long-term movements and stock structure, direct information on relative retention performances or shedding rates between different tags is still lacking. Beckett (1970) and Burnett et al. (1987) might be the only precedent of opportunistic double-tagging of large pelagic sharks with different plastic and stainless-steel dart tags, but returns were too scarce to compare their performance.

In 2012, Uruguay started a double-tagging experiment to address the retention performance of different types of conventional dart tags commonly used by CTPs for pelagic sharks (Domingo et al., 2016). Here, we provide tag-specific recapture rates for blue sharks, assess the retention performance of plastic and stainless-steel dart tags based on shedding rates from double-tagged individuals, and discuss the implications for tagging studies on large pelagic sharks.

2. Materials and methods

Sharks were captured using pelagic longlines and opportunistically tagged by biologists or trained scientific observers from the Uruguayan National Observer Program on Board the Tuna Fishing Fleet ('Programa Nacional de Observadores a bordo de la Flota Atunera', PNOFA) of the National Directorate of Aquatic Resources ('Dirección Nacional de Recursos Acuáticos', DINARA, Uruguay). Tagging effort took place during pelagic surveys carried out on board DINARA's *R/V Aldebarán* within the Uruguayan Exclusive Economic Zone (UEEZ), and on board commercial longline fishing vessels within the UEEZ and in international waters of the southwestern Atlantic Ocean. Tagging activities were carried out in collaboration with two major CTPs from the Atlantic: the International Cooperative Tagging Program from the International Commission for the Conservation of Atlantic Tunas (ICCAT-CTP), since 2007; and the National Marine Fisheries Service Cooperative Shark Tagging Program (NMFS-CSTP) from the United States, since 2012.

Four types of dart tags were used during this study, three of which were provided by the ICCAT-CTP and one by the NMFS-CSTP (Fig. 1). Tags from the ICCAT-CTP included a single-barb plastic dart tag (SB, anchor dimensions: ~16 mm long x 9 mm wide), and two types of intramuscular double-barb plastic dart tags, one with a small dart head (DB-S, ~15 mm x 12 mm) and another with an enlarged dart head (DB-L, ~23 mm x 18 mm). The SB tag is the type used for pelagic sharks by the ICCAT-CTP and was the main focus of this study, whereas DB-S and DB-L tags are used mainly for billfishes. The tag provided by the NMFS-CSTP was a stainless-steel dart tag (M, ~34 mm x 8 mm) with a plastic capsule at the rear end, commonly known as M-type (Kohler and Turner, 2019).

Tagging procedure lasted less than three minutes, including bringing the shark to the deck, removing the hook (if possible), recording size and sex, tagging, and releasing the animal. Fork length (FL) was measured over the curvature of the body with a measuring tape. All tags were applied using a tag applicator (Fig. 1), with DB-S, DB-L, and M tags implanted in the dorsal musculature and close to the first dorsal fin, and SB implanted at the base of the first dorsal fin to secure the dart head to the pterygiophores beneath the base of the fin. In all double-tagged sharks, both tags were implanted on the same side of the trunk but separated enough to avoid contact between them. As the main objective was to assess the performance of SB tags, double-tagging was almost exclusively performed using this tag in combination with any of the other three types.

Results of this study were focused on blue sharks, as this species accounted for most of the tagging and recapture data; however, occasional recaptures from other double-tagged shark species were also considered. Relative retention rates (RRR) of SB tags were calculated for each tag-type combination as:

$$RRR = ((R_{Both} + R_{SB})/(R_{Both} + R_O))$$

Where R_{Both} is the total number of recaptured sharks with both tags, R_{SB} the total number of recaptured sharks with only the SB tag, and R_O the total number of recaptured sharks with only DB-S, BD-L or M tags. Shedding events for each tag type were also addressed in terms of time at liberty (elapsed time between tagging and recapture) and minimum distances covered (geodesic distance between tagging and recapture locations).

Statistical analyses were carried out using the R language (R Core Team, 2021). Minimum geodesic distances between tag and recapture locations were calculated using the library "*geosphere*" (Hijmans et al., 2021).

3. Results

A total of 4,648 blue sharks were tagged over a 12-year period (2007–2018), of which 1,827 were double-tagged (39.3%). Single-barb tags accounted for 95.9% of all blue sharks single- or double-tagged combined (n = 4,458). The total number of single-tagged sharks and of double-tagged sharks with every tag-type combination is summarized for each sex in Table 1. Size range of single- (56–245 cm FL) and double-tagged (59–243 cm FL) sharks was almost identical, although on average, smaller sharks were tagged with single tags (122 vs 139 cm FL, Exact Permutation Test, $p < 0.01$).

Sixty-seven recaptures (44 males and 23 females) were reported during the study period, including 32 single-tagged and 35 double-tagged blue sharks. The overall recapture rate (all tag-types combined) was 1.4%, with tag-type specific rates of 1.0, 0.8, 0.3 and 7.1% for SB, DB-S, DB-L and M tags, respectively. Although not included as a recapture event, a male blue shark (93 cm FL) was double-tagged and found three days later in the stomach content of another blue shark (unknown size) caught by the same fishing vessel (Fig. S1).

Tag shedding was evident from recaptures of double-tagged sharks, with only 15 of 35 individuals retaining both tags (42.9%). Although sample size was limited, shedding rates appeared to be tag-specific, with SB tags missing in 18 out of 33 cases (54.5%), DB-L in one out of two (50.0%), DB-S in one out of 12 (8.3%), and M in zero out of 23 (0.0%). Most shedding events were observed in sharks recaptured after 6 months or more, although this varied among tag types (Fig. 2). The RRR of SB tags was 28.6% of M tags, and 70.0% of DB-S tags (Table 2); hence, assuming that all additional factors affecting retention rates remain constant, M and DB-S had better retention performance than SB tags, attaining values 3.5 and 1.43 times higher than the latter, respectively. Only two SB+DB-L double-tagged sharks were recaptured during the study period, which prevented any meaningful calculation of RRR: one shark was recaptured the day after release (both tags still attached) and the other after 392 days (DB-L tag lost).

Average time at liberty of sharks which had lost the SB tag (mean: 529 days, range: 139–1,530 days, $n = 17$) was significantly longer (Wilcoxon rank sum test, $W = 63.5$, $p = 0.01647$) than that of sharks retaining the tag (mean: 269 days, range: 1–1,133 days, $n = 15$), suggesting that shedding probability of SB tags increases with time. Considering times at liberty of <0.5, 0.5–1, and > 1 year, seven out 10 (70.0%), five out of nine (55.6%), and three out of 13 (23.1%) sharks still had the SB tag when recaptured (Fig. 2). Time at liberty was positively correlated with minimum distances covered (Spearman's rank correlation test, $r = 0.44$, $p < 0.01$, all recaptures considered), which is consistent with the significantly larger ($W = 75$, $p = 0.03$) average minimum distances observed in sharks that lost the SB tag (mean: 1,679 km, range: 131–5,724 km) compared to those that did not (mean: 865 km, range: 10–4,657 km). Only three of 11 double-tagged blue sharks (27.3%) recaptured at ≥1,000 km from their tagging location (time at liberty range: 142–1,530 days) retained the SB tag (Fig. 2, 3).

Recaptures of other double-tagged shark species were available for one bronze whaler (*Carcharhinus brachyurus,* from 23 sharks double-tagged), two night sharks (*Carcharhinus signatus,* from 89 sharks double-tagged), and two shortfin makos (*I. oxyrinchus,* from 47 sharks double-tagged). Two of these sharks retained both tags when recaptured, whereas the other three had lost the SB tag. The bronze whaler, one shortfin mako and one night shark, all double-tagged with SB+M, were missing the SB tag after 1,129, 128 and 13 days, respectively. The other night shark (SB+M) and shortfin mako (SB+DB-S) retained both tags after 1,148 and 11 days, respectively.

4. Discussion

To the best of our knowledge, this is the first study to conduct a double-tagging experiment to assess the retention performance of different types of conventional dart tags in a large oceanic shark species. Our results strongly suggest that shedding rates are tag type-specific, with the SB tag having the highest percentage of shedding (54.5%), followed by the DB-S (8.3%) and M tags (0%). Due to the extremely low sample size, conclusions regarding the DB-L tag cannot be drawn and will not be further discussed.

The double-tagging experiment provided critical insight into the information that would have been lost if only SB tags were used. Considering all blue sharks tagged with SB tags (n = 4,458; single- or double-tagged), more than 28% of all the reported recaptures (18 out of 63) would have been lost if not for the double-tagging. In other words, the recapture rate from this study would drop from 1.4% to 1.0% if other tags had not been used. The shedding probability of SB tags also tended to increase with time at liberty, and given the positive correlation between time at liberty and minimum distance covered, SB tags would be less effective for long-term recaptures and less likely to reveal large-scale displacements (Fig. 2). In fact, 52.6% of all recaptures with times at liberty ≥ 1 year (n = 19) and 57.1% of all recaptures at ≥1,000 km (n = 14) from the tagging location would have been lost through shedding of SB tags.

Recapture rates from SB tags (1.0%) were substantially lower than those from M tags (7.1%), and slightly higher than those from DB-S tags (0.8%). However, given that SB tags have been used since 2007 and that tagging with M and DB-S tags only started in 2012, the recapture rate from SB tags could be inflated as tagged sharks prior to 2012 would have had more time to be recaptured. If only sharks tagged since 2012 are considered, the recapture rate of SB tags would drop to 0.9%, similar to the recapture rate from DB-S tags and almost eight times lower than that from M tags.

The blue shark is undoubtedly one of the most extensively tagged shark species around the globe (e.g. Holdsworth et al., 2016; Kohler and Turner, 2019; Stevens 1990; Wögerbauer et al., 2016). However, many studies used more than one tag type and recapture rates are often reported as a whole, precluding comparisons between different types. Among 15 tagging studies on blue sharks that either used only one tag type or reported recapture rates separately for each type, recapture rates from our M, SB and DB-S tags fell at the higher end, middle and lower end of the range, respectively (Table 3). Tag types used in these studies included rototags, SB tags, M tags, and a second type of stainless-steel dart tag that, unlike the M tag, is attached to a plastic streamer (H-, C- and N-types *sensu* Mather et al., 1974). We found no other study that used DB-S tags on blue sharks. M tags and rototags rendered the highest recapture rates among all studies, with our results from M tags closely in line with those from the NMFS-CSTP, albeit based on a substantially lower number of sharks tagged. Stainless-steel dart tags with plastic streamers showed relatively lower recapture rates, ranging between 0.7 and 2.5%, except for one study (5.8%; Table 3). Single-barb plastic tags yielded the lowest recapture rates, with the only study reporting a recapture rate above 1% being based on a single shark recaptured 29 days after release.

Several factors could be affecting the retention performance of SB tags. Compared to the other types used in this study, SB tags are arguably the most difficult to apply and secure correctly, as they need to be carefully inserted near the base of the first dorsal fin so that the dart head interlocks with the pterygiophores beneath the base of the fin (Kohler and Turner, 2001; Pine et al., 2012). If not inserted correctly, the tag may end up loosely attached to the shark's dorsal musculature and prone to be dislodged (Xiao et al., 1999), as this type of anchor was not designed for intramuscular attachment. This can become an issue particularly when tagging from small boats, where sharks cannot be hauled on board and must be tagged while alongside the boat. Securing the tag correctly under these circumstances can be challenging due to the movement of the struggling shark and the boat itself, and even more so if using a tagging pole. In contrast, sharks captured by anglers from the coast, or caught by scientific vessels, can be handled directly once brought to the shore or deck, making the tagging procedure easier and more effective, but also allowing the tagger to ensure the tag was properly secured. Tagger experience could also play a role, as more experienced taggers are expected to secure the tags more consistently than unexperienced ones (Gaertner et al., 2022; Pine et al., 2012). Tagging efficiency may also improve when tagging effort is carried out during scientific surveys in comparison to when tagging is carried out on board commercial fishing vessels. In the former case, several technicians can cooperate in the tagging procedure (handling, tag insertion, data collection, and release) which could translate into a higher probability of securing the tag correctly and safely. In contrast, scientific observers on board commercial fishing vessel usually perform the tagging procedure on their own, which could affect the overall tagging efficiency, especially when tagging larger individuals and/or if the observer has limited experience. In addition, handling practices on board commercial fishing vessels can result in physical trauma and/or internal injuries that could negatively affect post-release survival of tagged sharks. The recapture rate from SB-tagged sharks from this study appeared to be higher for sharks tagged during scientific surveys (1.2%) than onboard commercial fishing vessels (0.9%), and similar results were reported by Mejuto et al., (2005), although in this case more than one type of dart tag was used and no tag-specific information was available. Another factor affecting SB tag performance is the maintenance of the tag applicator, as its sharpness will gradually decrease with repeated use (Mather, 1963; ORI-CFTP, 2021b). If not sharpened enough, punching a hole through the thick-abrasive skin of a shark can damage the plastic barb or even cut it off completely, compromising the retention performance (Beckett, 1970). During our scientific surveys this issue was observed on several occasions, especially when tagging large-sized sharks, and was later avoided by first making a small incision in the skin, as in Mejuto et al. (2005) and ORI-CFTP (2021b). A damaged tag can easily go unnoticed when tagging alongside the boat or with a tagging pole. Despite all these factors, SB tags can drastically improve their retention performance if correctly inserted and secured. Results from the Oceanographic Research Institute's Cooperative Fish Tagging Project from South Africa have shown that SB-tagged sharks can be recovered after extensive periods of time and yield satisfactory recapture rates for several large pelagic sharks (ORI-CFTP, 2021a), and some of our SB-tagged sharks were recaptured after periods of up to 3.1 years and at distances of up to 4,657 km. However, our double-tagging results suggest that even if short- and long-term recaptures are obtained and recapture rates are satisfactory, a considerable amount of information is likely being lost by shedding, which could be significantly reduced by using stainless-steel dart tags. Especially on CTPs where sharks are tagged on a variety of modalities (scientific surveys, commercial fishing, coast sport-fishing, boat sport-fishing, free-diving) and by taggers with different levels of experience, the use of a tag that can be easily implanted and secured is likely to yield better results.

Although DB-S tags are easier to secure and had higher relative retention performance compared to SB tags, the former did not yield better recapture rates than latter. This might not be related to the anchor type but rather to the long-term durability of the connecting nylon threads (Fig. 1). Even if the anchor is firmly secured to the dorsal musculature, the friction with the shark skin may end up severing one of the threads causing the eventual detachment of the plastic streamer.

Beckett (1970) and Burnett et al. (1987) reported higher recapture rates for several pelagic fish, including blue sharks, when using plastic streamer stainless-steel dart tags instead of M tags, and argued that the capsule of the latter (Fig. 1) could reduce retention performance by generating more drag and turbulence (Beckett, 1970). Similar results were reported by Mejuto et al., (2005) based on the recapture rate of several pelagic shark species combined.

Although our experimental design cannot confirm nor reject this hypothesis, we failed to observe any shedding of M tags in the 23 double-tagged blue sharks recaptured after times at liberty of up to 4.2 years, nor in the double-tagged bronze whaler, night, and shortfin mako sharks recaptured after up to 3.1 years. Rather than structural differences among both tag types, recapture rates could be affected by reporting rate (Mejuto et al., 2005; Pine et al., 2012), especially in wide-ranging migratory species that are likely to be caught at large distances from the tagging location and by a variety of fishing fleets and nations. The NMFS-CSTP has been active for almost 6 decades and it is arguably the most well-known shark CTP from the Atlantic Ocean, with fishermen from 32 countries having tagged sharks for the program and recaptures reported from 59 countries (Kohler and Turner, 2019). A widespread and well-known tagging program has better chances of obtaining recapture reports from distant commercial fishing fleets, especially if no scientific observer is onboard, or by anglers from distant countries, than more local and lesser-known programs.

A spatially structured tagging model of the blue shark in the North Atlantic Ocean showed that although mortality estimates were fairly robust, movement rate estimates were sensitive to assumptions of different shedding rates, and especially when shedding rates were high (Aires-da-Silva et al., 2009). Our results suggest that M tags have a significantly better retention performance than SB or DB-S tags, and most likely to have a very low instantaneous shedding rate. However, the long-term shedding rate from our double-tagging experiment is more complex to interpret. Given the worse retention performance of SB tags compared to M tags, the former type is much more likely to be lost first, therefore significantly reducing the probability of observing shedding events on M tags. Double-tagging sharks with M tags could allow the estimation of long-term shedding rate of this tag type.

Plastic and stainless-steel dart tags can cause localized wounds on sharks, although without being detrimental to survival (Dicken et al., 2006; Heupel and Bennett, 1997). Stainless-steel darts, however, have been shown to compromise growth at least in small juvenile lemon sharks, *Negaprion brevirostris* (Manire and Gruber, 1991), and may affect survival in small-sized sharks. In this study, only five sharks ≤100 cm FL were M-tagged and none of them have been recaptured. However, in the northeast Atlantic several small blue sharks have been tagged with these tags and recaptured, including three individuals <70 cm FL recaptured after 180–635 days (Queiroz et al., 2005). These results suggest that M tags are unlikely to affect the survival of small juveniles, although the effect on growth rate remains unknown. Similarly, the predation by another blue shark of one small shark tagged in this study represents direct evidence of cannibalistic behavior in the species, but whether this event was prompted by the tagging itself cannot be ascertained.

5. Concluding remarks

This study showcases the strength of double-tagging experiments as an effective way to assess the performance of different conventional tag types. Based on our results for blue sharks, we conclude that the M tag outperforms the common SB tag both in shedding rate and ease of application, which will ultimately translate into improved long-term results. Occasional recaptures from other double-tagged shark species suggest that M tags are a good option for large pelagic sharks in general. However, SB tags are still the most used tag type for sharks within the ICCAT-CTP and also commonly used in other tagging studies (Bartes et al., 2021; Dunlop et al., 2013; ORI-CFTP, 2021b). Ongoing tagging of large pelagic sharks using SB tags will benefit from switching to stainless-steel dart tags by minimizing tag loss and maximizing the probability of obtaining long-term and large-scale recaptures. Future efforts should focus on double-tagging experiments designed to estimate shedding rates of stainless-steel dart tags on pelagic sharks as a better understanding of this parameter will likely improve the robustness of mortality, population size, and movement rate estimates.

CRediT authorship contribution statement

Federico Mas: Methodology, Formal analysis, Investigation, Data Curation, Writing - Original Draft, Writing - Review & Editing, Visualization. **Enric Cortés:** Conceptualization, Methodology, Resources, Writing - Review & Editing. **Rui Coelho:** Writing - Review & Editing.

Omar Defeo: Writing - Review & Editing. **Rodrigo Forselledo:** Methodology, Investigation, Data Curation, Writing - Review & Editing. **Sebastián Jiménez:** Investigation, Writing - Review & Editing. **Philip Miller:** Methodology, Investigation, Writing - Review & Editing. **Andrés Domingo:** Conceptualization, Methodology, Investigation, Resources, Writing - Review & Editing

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Tables

Table 1. Summary of total male and female blue sharks (*Prionace glauca*) tagged with conventional tags in the southwestern Atlantic Ocean according to tag type and whether the shark was single- or double-tagged. SB: Single-barb dart tag; DB-S: small double-barb dart tag; DB-L: large double-barb dart tag; M: Stainless steel dart tag. Single- (n = 52) and double-tagged (n = 6) sharks of unknown sex are not shown.

	Males (n = 2,459)					**Females (n = 2,131)**				
Tag Type	**Single-tagged**	**Double-tagged (n = 1,127)**				**Single-tagged**	**Double-tagged (n = 694)**			
	(n = 1,332)	SB	DB-S	DB-L	M	**(n = 1,437)**	SB	DB-S	DB-L	M
SB	1188		616	230	273	1407		551	81	54
DB-S	111				8	23				8
DB-L	25					7				
M	8									

Table 2. Comparative tagging study for blue sharks (*Prionace glauca*) tagged in the southwestern Atlantic Ocean using plastic single-barb dart tags (SB) and either plastic double-barb (DB-S) or stainless-steel dart tags (M). Total numbers of recaptured sharks retaining both tags, only the SB tag, or only the M or DB-S tag are given. The relative retention rate (RRR) is calculated as the number of SB tags retained over the number of DB-S or M tags retained (see Methods).

Sharks double-tagged		**Recaptures**				RRR (%)
N	Tag combination	SB	M or DB-S	Both	Total	
328	SB + M	0	15	6	21	28.6
1171	SB + DB-S	0	3	7	10	70.0

Table 3. Reported recapture rates (RR) of blue sharks (*Prionace glauca*) by conventional tag type. N tagged: total number of sharks tagged; N recap.: total number of sharks recaptured; Max.Dist.: largest distance recorded from tagging and recapture locations; Max. TaL: Maximum reported time at liberty of all recaptures. M(capsule): stainlees-steel dart tag with capsule; M(streamer): stainlees-steel dart tag with plastic streamer; SB: single-barb plastic dart tag; DB-S: small double-barb plastic dart tag; DB-L: Large double-barb plastic dart tag. Results from this study are hilighted in grey for each tag type.

Reference	Location	N tagged	N recap.	RR	Max. Dist. (km)	Max. TaL (years)	Tag type
Queiroz et al. (2005)	Portugal	168	34	20.2	3187	3.5	M(capsule)
Mas et al. (this study)	Southwestern Atlantic	352	25	7.1	5724	4.8	M(capsule)
Kohler and Turner (2019)	Atlantic Ocean	117962	8213	7.0	7402	15.9	M(capsule)
Fitzmaurice et al. (2003)	Portugal	387	26	6.7			Rototag
Matsunaga (2009)	Atlantic Ocean	462	27	5.8	3200	1.7	M(streamer)
Wögerbauer et al. (2016)	Ireland	18278	895	4.9	6840	17	Rototag
Tricas (1977)*	Northeast Pacific	120	3	2.5	119	0.9	M(streamer)
Campana et al. (2015)	Canada	2374	54	2.3			M(streamer)
Sippel et al. (2011)	Northeast Pacific	9512	205	2.2			M(capsule)
Stevens (1990)	Northeast Atlantic	2585	51	2.0	7176	10.7	Rototag
Holdsworth et al. (2016)	New Zealand	4684	87	1.9	8536	3.3	M(streamer)
Burnett et al. (1987)	Northwest Atlantic	65	1	1.5	237	0.1	SB
NSW-GFTP (2021)	Australia	5228	79	1.5	5350	4.9	M(streamer)
Sippel et al. (2011)	Northwest Pacific	18180	207	1.1			M(streamer)
Mas et al. (this study)	Southwestern Atlantic	4458	45	1.0	4657	3.1	SB
Matsunaga (2012)	Southern Hemisphere	2765	26	0.9	6960	4.8	M(streamer)
Burnett et al. (1987)	Northwest Atlantic	1583	14	0.9	1072	9.5	M(streamer)
Mas et al. (this study)	Southwestern Atlantic	1321	11	0.8	3267	1.5	DB-S
Ugoretz*	Northeast Pacific	6958	49	0.7	6147	3.8	M(streamer)
Burnett et al. (1987)	Northwest Atlantic	382	2	0.5	807	0.2	M(capsule)
Mas et al. (this study)	Southwestern Atlantic	344	1	0.3	10	0.0	DB_L
da Silva et al. (2010)	South Africa	441	1	0.2	5991	1.4	SB

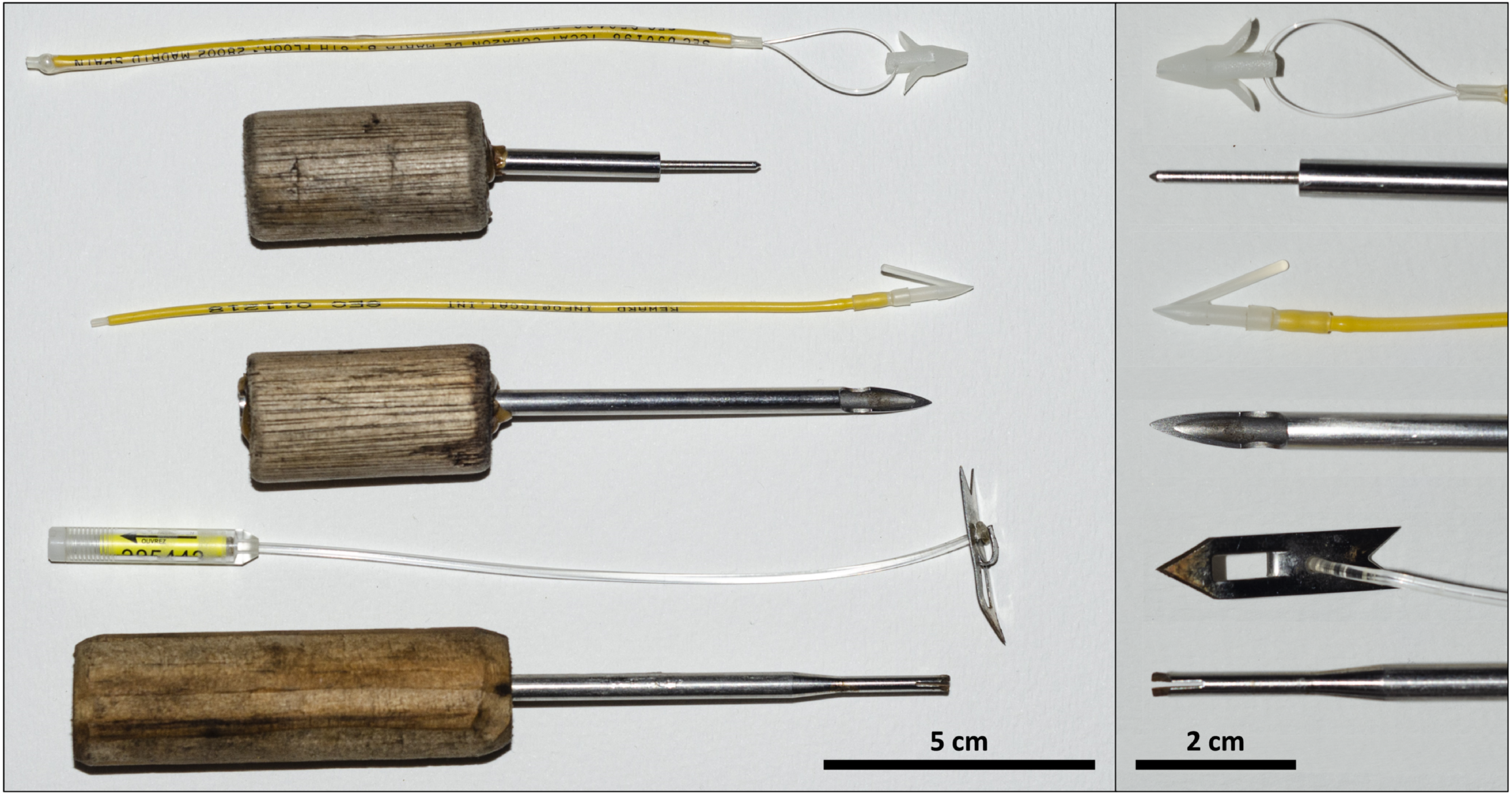
* in Kohler & Turner (2001)

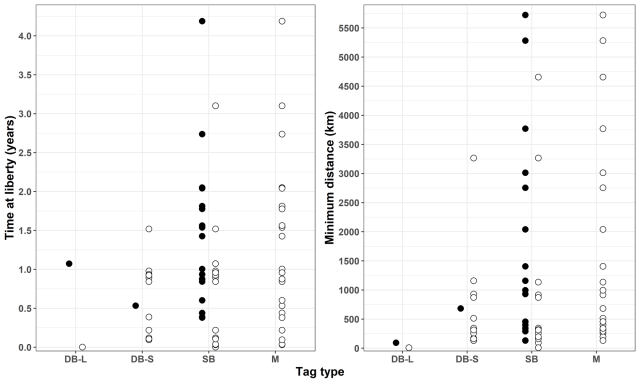
Figure captions

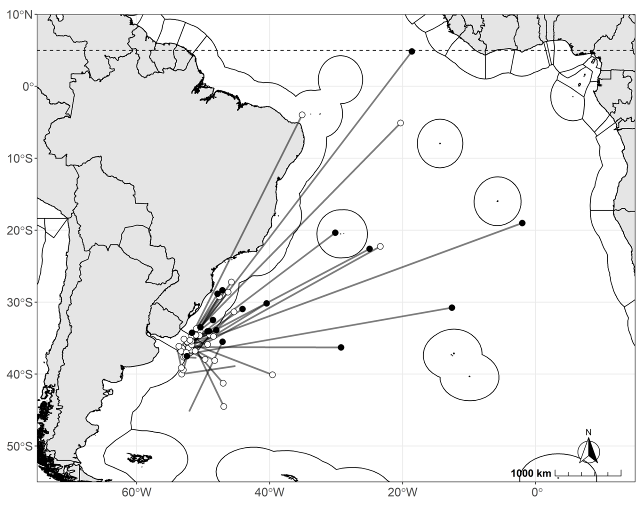
Fig. 1. Conventional tags and applicators used for single- and double-tagging of blue sharks (*Prionace glauca*) in the southwestern Atlantic Ocean. A detailed view of each tag type anchor and tag applicator tip is provided on the right panel. From top to bottom: double-barb dart tag (DB-S), single-barb (SB-S) dart tag, and stainless-steel dart tag (M). Each tag type anchor is shown in the inset. The large double-barb dart tag (DB-L) also used in this study is not shown here, but is identical to the DB-S tag except for the dimensions of the anchor (see Section 2).

Fig. 2. Summary of recaptured double-tagged blue sharks (*Prionace glauca,* n = 35) from the southwestern Atlantic Ocean, showing whether tags were lost (solid circles) or retained (open circles) when recaptured. Tag fate (lost or retained) is shown for each of the four conventional tag types used in relation to time and minimum distance covered between release and recapture events. DB-L: large double-barb plastic dart tag; DB-S: small double-barb plastic dart tag; SB: single-barb plastic dart tag; M: stainless-steel dart tag (see Section 2 for further details on tag types).

Fig. 3. Recaptured location (circles) and minimum distances covered (straight lines) of blue sharks (*Prionace glauca*) tagged in the southwestern Atlantic Ocean. All blue sharks were tagged with single-barb plastic dart tags (SB), and some also tagged with other dart-type tags (Section 2). White- and black-filled circles indicate sharks that retained or lost the SB tag by the time of recapture. Black polygons depict Exclusive Economic Zones.


5 cm
2 cm


Time at liberty (years)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
Minimum distance (km)
5500
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
DB-L
DB-S
SB
M
Tag type



10°N
0°
10°S
20°S
30°S
40°S
50°S
60°W
40°W
20°W
0°
N
1000 km