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Silky shark post-release survival evaluation in tropical tuna purse seiners using hoppers with ramps

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ABSTRACT

Silky sharks are the principal elasmobranch bycatch species encountered in tropical tuna purse seine sets. In this work we present results from research cruises on purse seiners equipped with hoppers with ramps on their working deck. The hopper's tray improves the chances of spotting sharks occurring within the tuna catch, and the door can greatly prevent sharks from accidentally going down to the lower deck, from where release times are delayed. The ramp adds a safety element, as less shark handling is required by crew, and helps speed up release. Release times for sharks on these vessels were mostly less than two minutes. Our results show that shark survival can be significantly enhanced using hoppers with ramps, doubling and even tripling shark survival rates reported in previous purse seine studies. However, there can be post-release survival (PRS) variability, which can be attributed to different factors. Particularly, time in the sack seems to affect the state in which sharks arrive on deck, presumably due to an inability to respire for obligate ram ventilators whilst confined in the sack. Therefore, hoppers with ramps have the capacity to maximize the survival of sharks arriving onboard in good condition, but research should also focus on actions prior to and during the set, that ensure sharks are released before sacking or at least arrive on deck in the best condition possible.

INTRODUCTION

One of the principal impacts of fisheries on marine ecosystems is bycatch, especially when the species involved are endangered, threatened or protected (ETP). Tropical tuna purse seiners have relatively low levels of bycatch per ton caught (Murua et al. 2021a). Nevertheless, some species like sharks and rays can be accidentally caught and are particularly vulnerable to fishing related mortality due to their late maturity and low fecundity life histories (Dulvy et al., 2004; Stewart et al., 2018), resulting in global population declines (Juan-Jordá et al., 2022). Of the shark species caught in sets associated with fish aggregating device (FAD) are silky sharks (*Carcharhinus falciformis*) (Amande et al., 2010; Hall and Roman, 2013; Griffiths et al., 2018; Hutchinson et al., 2019). Like tunas, silky sharks show an aggregative behavior towards natural and artificial floating objects and therefore are more likely to be caught inside the purse seine net during sets on FADs (Clavareau et al., 2021). Finding solutions to reduce impacts on sharks in FAD fisheries has been a management priority in recent years.

Given the complexity of developing selective fishing strategies in tropical tuna purse seine fisheries that use FADs, due to the numerous target and non-target species mixed in a single aggregation (Taquet et al., 2007), the most practical approach currently, until further research is conducted to release elasmobranchs from the net, is to improve handling and release protocols once they arrive on deck (Murua et al., 2024).

Over the last decade, some research has focused on releasing sharks from the net, and ideally before the net is set, which offers the best chance for shark survival since it avoids the stress of the brailing operation (Restrepo et al., 2018). While some of these activities, such as using escape windows in the net, attracting sharks away from the FAD before setting the net, and fishing sharks within the net to release them immediately, have shown promise, they have proven challenging to implement during fishing operations. These efforts require further research, particularly into the sensory capabilities of sharks to be lured away from the FAD, as well as technological advancements and innovations. The limited number of trials conducted to date is partly due to the high costs and risks associated with conducting such research in real fishing conditions.

Nowadays, most sharks are still being released by extracting them from the brail and moving them by hand to return them to the water. Poor practices such as holding sharks by the gills or lifting them by the tail with ropes are prohibited but still observed in some cases (Maufroy et al., 2020). Handling large and very active sharks is dangerous so they are often left on deck until they become lethargic or unresponsive, but the extra time on deck will likely reduce their survival chances. Time spent out of the water is one of the principal factors affecting PRS in elasmobranchs in good condition (Mandelman et al., 2022). Therefore, a speedy release is key to improving PRS. As observed in several survival studies in purse seiners, sharks that are not released from the brail in the top deck and fall to the lower deck (i.e., where fish holds are located) have a very high mortality rate unless the vessel is fitted with a release opening or gutter (Onandia et al., 2021). Release of sharks in the lower deck is greatly delayed as each animal needs to be carried up a narrow set of stairs to the top deck for release in the water.

To reduce some of these difficulties associated with locating and releasing sharks from the deck during the brailing operation, well designed hoppers or chutes can assist. Some vessels in the Pacific have been regularly using hoppers for several decades (e.g., USA fleet). Initially the hopper was used in the 1970s to discard unwanted fish and to control the flow of fish into the wells when there were no conveyor belts. Now hoppers have been repurposed as a bycatch release device (BRD) that aid with the release of non-target and or non-retained species (Murua et al., 2021b, 2023a). Efficient hoppers should have a large enough tray to lay out the brail contents for spotting sharks (even the smaller juvenile individuals) and a fast open-close regulated door to stop sharks and other bycatch from going into the lower deck when observed in the tray. These hoppers are usually located on the portside of the deck, but in some instances, they can also be situated in the starboard, in between the winch and the chokers.

To assist with the transport of the sharks spotted in the hopper to the water (i.e., usually fishers would have to carry sharks from the center of the deck to the starboard side for release), an inclined ramp has been fitted in some vessels connecting from the hopper to the water's edge. In this way fishers can simply move the shark from the tray to the ramp and the shark slides down directly to the water. Release ramps benefit both fisher safety as they reduce direct contact between crew and sharks and at the same time positively impact shark survival through lower handling stress and faster release times.

It is critical to conduct studies that characterize the applicability and success rate of best release practices and BRDs so that RFMO recommended best practices are supported by robust scientific research (Wosnik et al., 2023). To test the effectiveness of the hoppers with ramps on shark PRS rates captured in tuna purse seiners operating in the Pacific Ocean, we here present results from two trips where orelease times, shark vitality indices and satellite linked survival pop-up archival tags were deployed..

METHODS

This study was conducted in the P/V Charo and P/V Rosita C, two purse seiners of similar sizes (i.e., length 85 m and fish hold capacity 2000 cubic metres) outfitted with a hopper and ramp. Both vessels are owned by the same company (Bolton Foods – Trimarine), operate in the same areas of the Pacific Ocean and utilize similar fishing strategies. The first research trip was conducted between 23 May and 25 July 2022 and the second between 14 May and 9 July 2023. During each trip data on the set type (e.g., FAD or free school), set size, the number of sharks caught, biological parameters (e.g., length, sex), vitality index and release mode (e.g., with the hopper with ramp, from the lower deck), brail number and release time were recorded.

The vitality index was recorded following the condition at release proposed by Heuter and Manire (1994), and are as follows: state 0 corresponds to sharks in'very poor condition and or dead' (i.e., dying, with no vital signs, excessive bleeding, incapable of reviving when released at sea, not swimming, sinking), state 1 equates to 'poor (exhausted, low vital signs, some bleeding, prolonged reanimation time when released at sea, limited swimming), state 2 is 'fair (tired, some signs of vitality, moderate sign activity), state 3 equates to 'good condition' (active and energetic, moderate signs of vitality on deck and when released in the water), and state 4 being 'very good' (i.e., active and energetic, strong signs of vitality on deck and when returned back to sea).

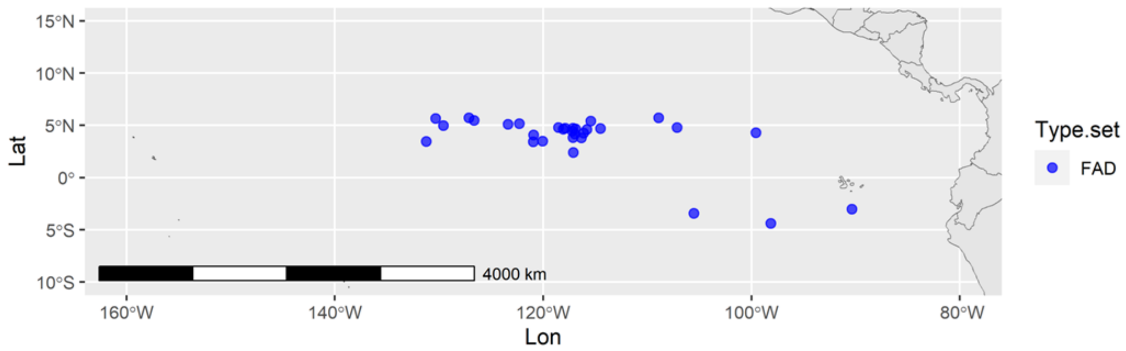
Satellite pop-up survivorship tags (SPATs) from Wildlife Computers were employed to check PRS in each trip. The tags were programmed to detach after a maximum of 60 days and were configured to transmit minimum and maximum temperature, depth data and light level changes daily and depth time series data every 10 minutes for the last four days of the tag's deployment. If the depth of the tag reached more than 1700 m or the tags would automatically detach and float to the surface, indicating the death of the animal. Tags that are shed early due to an attachment failure and remain at the same depth for more than 3 days (e.g. floating at the surface) begin transmitting the data to the overhead satellite array and were determined to be a 'premature detachment or floater' where the animal was still alive and swimming upon detachment. Tags were fixed close to the base of the dorsal fin with Domeier anchors soaked with iodine to prevent infections. Sharks with tags lasting over 10 days before release and displaying normal vertical and horizontal behaviour were considered to have survived after release.

RESULTS

In the first research trip 31 sets were made, all on floating objects (30 FAD sets and 1 natural log set) and shark interactions were observed in 30 sets (Table 1; Figure 1). In total 317 sharks were captured, 96 % being silky sharks (303 individuals), where 49 % were males, 45 % females and 6 % were unidentified, and total length ranged between 58 cm and 205 cm. The average number of sharks per set was 10 individuals. During the second trip a total 26 sets were done, with shark interactions being present in 22 of them (21 FAD sets and 1 free school set), with a total of 312 silky sharks recorded and an average of 14 sharks per set, with 49% being male and 50% female, and 1% unidentified and total length varied between 64 cm and 230 cm.

Table 1- Types of set, number of sharks and size range in experimental trips

Trip	Number of floating object sets	Number of free school sets	Number of sharks	Size range (cm)
1	31	0	303	58-205
2	25	1	312	64-230



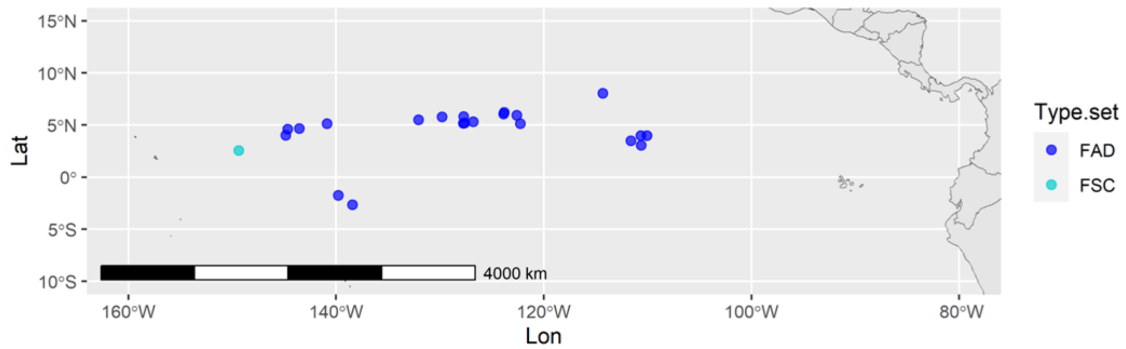


Figure 1 – Set positions for first research trip (top) and second trip (bottom) in the Eastern Pacific Ocean. Dark blue – FAD set, Light blue – Free School Set.

During the first trip 86% sharks were released from the upper deck with the hopper and ramp, while 14% accidentally went down to the lower deck and were transported by hand or with a stretcher to the upper deck for release (Table 2). In the second trip 96 % of sharks were released from the hopper in the top deck and only 4 % of sharks accidentally reached the lower deck. Most release times in both trips were within 2 minutes or less from the shark arriving on the vessel (Figure 2).

Table 2- Silky shark release location in purse seiner vessels equipped with a hopper with ramp

Trip	Release location (%)	
	Top deck	Lower deck
1	86	14
2	96	4

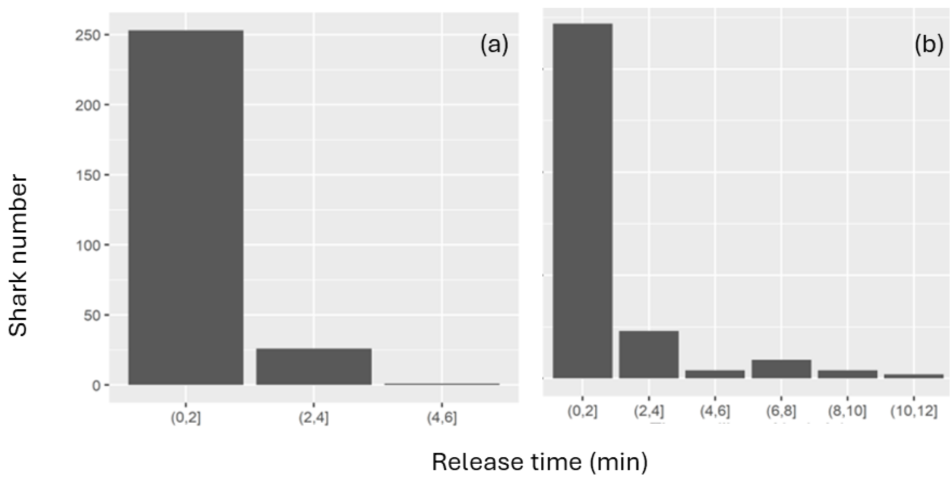


Figure 2- Shark release time after arriving on deck in (a) first trip and (b) second trip of vessels with hopper with ramp.

In relation to the order of brail in which sharks arrived on deck after sacking, for both trips about over half the sharks arrived in the first two brails, and the rest in the third brail or later. The only difference between trips was that in the first trip about 5% of sharks came up entangled in the net during hauling, before sacking and brailing took place. The time of formation of the sack until brailing commences was also recorded, with the average sacking taking 18 minutes in trip one and 26 minutes in trip two.

Table 3- Phase of shark release by brail number. *Sharks arriving on deck entangled in the purse seine net while hauling before brailing.

	Brail Number (%)			
Trip	**Net***	**1**	**2**	**≥ 3**
1	5	27	25	43
2	0	24	32	44

When examining the vitality index in the first trip the most frequent state was 2 (i.e., correct) with 52 % of sharks and only 11 % being in a very poor state. Meanwhile, in the second trip many sharks displayed a very low condition, with 56 % showing a vitality state of 0 (i.e., dead or moribund), followed by 27 % of sharks with a vitality state of 2 (Table 4).

Table 4 – Vitality index of sharks released during research trips.

Trip	**Vitality Index (%)**				
	0	**1**	**2**	**3**	**4**
1	11	27	52	9	1
2	56	2	27	14	1

In the first trip 16 sharks tagged with s-PATs which were set to 60 days and provided high resolution information for the last 4 days before release. Of these 3 tags malfunctioned and did not provide information (Table 5). Of the 13 sharks with functional tags, 11 of them had tags attached over the estimated survival time stipulated (e.g., 10 days after release). In this trip sharks with the most frequent vitality states of 2 and 3 were satellite tagged but no animal in states 1 and 4. To correct this, survival of sharks with vitality index 1 and 4 from a previous trip following the same tagging protocols (see Onandia et al., 2021) were included in the estimation.

Table 5 – Satellite tagged shark information including length, sex, departure and release date, vitality state, brail number, reason of shark release and days at sea.

Trip	Length (cm)	Sex	depDate	relDate	Vitality	Brail	Tag release	Days
1	170	Female	17/06/2022	16/08/2022	3	1	Programmed	60
1	160	Female	17/06/2022	28/06/2022	3	1	Premature	11
1	173	Female	17/06/2022	04/07/2022	3	2	Premature	17
1	142	Male	19/06/2022	26/06/2022	2	2	Premature	7
1	174	Male	19/06/2022	18/08/2022	2	3	Programmed	60
1	156	Male	22/06/2022		2	1	Error	
1	154	Male	26/06/2022	14/08/2022	3	1	Premature	49
1	174	Female	27/06/2022	20/07/2022	3	1	Premature	23
1	167	Male	28/06/2022	20/07/2022	3	2	Premature	22
1	196	Male	28/06/2022		3	3	Error	
1	162	Female	29/06/2022	28/08/2022	2	1	Programmed	60
1	152	Female	29/06/2022		2	3	Error	
1	174	Female	01/07/2022	30/08/2022	2	4	Programmed	60
1	172	Female	02/07/2022	17/07/2022	2	1	Premature	15
1	192	Male	04/07/2022	24/07/2022	2	3	Premature	20
1	155	Female	11/07/2022	30/07/2022	2	5	Premature	19
2	150	Female	27/05/2023	14/06/2023	2	1	Premature	18
2	174	Male	31/05/2023	16/07/2023	2	2	Premature	46
2	101	Male	04/06/2023	05/06/2023	0	1	Too Deep	1
2	185	Female	17/06/2023	01/07/2023	3	1	Premature	14
2	163	Female	17/06/2023	04/07/2023	2	1	Premature	17

2	164	Male	17/06/2023	22/06/2023	3	2	Premature	5
2	178	Male	24/06/2023	29/06/2023	3	1	Premature	5
2	144	Female	29/06/2023	29/06/2023	2	3	Too Deep	0

Applying the survival percentages defined by vitality state (i.e., 100% survival for sharks in excellent condition (state 4), 77.8% for sharks in good condition (state 3), 81.8% for sharks in a correct condition (state 2), 33.3% for individuals in poor condition (state 1) and 0% for sharks in very poor condition (state 0)), the average PRS for the first trip was estimated at 59.2% (Table 6), with survival being higher in the first brails and individuals with higher vitality states. Therefore, total mortality for sharks encountered during the whole trip would be 40.8%. In the second trip 8 sharks were tagged with s-PATs and 50% of them survived. Surviving sharks were released in the first and second brail with vitality indexes of 2 and 3. Other 2 sharks tagged (25%) died shortly after being released. The other 2 remaining ones (25%) had premature releases, we believe that due to tag malfunction, but for analysis purposes they were considered that sharks died after release. In the second trip, overall survival rate was estimated at 34.6% (Table 7).

Table 6 – Shark post release survival estimation for first research trip on vessel with hopper and ramp considering tag survival data with brail number and vitality index.

Brail	vit0	vit1	vit2	vit3	vit4	PRS (n)	PRS (%)
0	1	0	6	6	1	10,6	75,5
1	5	21	43	14	0	53,1	63,9
2	3	20	51	3	0	50,7	65,9
3	26	40	58	4	1	64,9	50,3
PRS (n)	0	27	129	21,0	2,0	179,2	59,2

Table 7 – Shark post release survival estimation for second research trip on vessel with hopper and ramp considering tag survival data with brail number and vitality index.

Brail	vit0	vit1	vit2	vit3	vit4	PRS (n)	PRS (%)
0	0	0	0	0	0	0	0
1	29	5	22	19	1	35,4	46,6

2	56	2	25	17	0	34,3	34,3
3	90	0	37	8	1	37,5	27,6
PRS (n)	0,0	2,3	68,7	34,2	2,0	107,3	34,4

DISCUSSION

This research shows how large-scale tuna purse seiners equipped with hoppers with ramps can help reduce post-release mortality of sharks brailed onboard. The results using satellite tags indicate release survival rates of silky sharks of between 34 and 59 percent, which is substantially higher than previous studies measuring shark survival in purse seiners using manual best practices only without BRDs. Hoppers with enough tray capacity to sort out target from non-target species and a stoppage door to reduce number of sharks accidentally going down to the lower deck can assist fishing companies in their objectives of achieving better release practices and lower impacts on marine ecosystems.

When bycatch is released from the brail directly, without a hopper, many sharks end up in the lower deck accidentally because it is difficult to observe them in between such a large mass of tuna (e.g., brail capacity can range from 5 to 10 tons). Because most purse seiners do not have release gutters in the lower deck to assist with fast evacuation (but see Onandia et al., 2021), releases from this area are normally delayed resulting in higher mortality. Our results showed that with the hopper in one trip less than 15 % of sharks went to the lower deck and in the other less than 5 %.

Furthermore, the use of hoppers fitted with ramps increases crew safety during shark handling. Expanding the brail contents on the hopper's tray helps spot most sharks and is somewhat safer for fishers as they have easier access to manipulate sharks and quickly deposit them on the release ramp. The addition of a release ramp connecting directly from the hopper to the water's edge reduces contact time between fishers and sharks (i.e., do not need to be transported by hand across the working deck). The efficiency of this release operation is supported by the short release times recorded, where the majority of sharks were released in time periods under two minutes. This is considered a critical point, as time out of the water is one of the most determinant factors influencing mortality of elasmobranchs after time in the sack in this fishery. Importantly the skippers and crew of the vessels in this study have participated in multiple best practices workshops (e.g., Code of Good Practices and ISSF Skippers Workshops; Grande et al., 2019; Murua et al., 2023b) and are aware of the importance that their best practices can have on the survival of shark species. Having BRDs onboard alone does not ensure good release results. It is the commitment of fishers to apply the best protocols to release animals which increases the efficiency of these tools.

The study also supports findings from previous shark survival studies (e.g., Poisson et al., 2014; Hutchinson et al., 2012, 2015) that the vitality and survival of sharks decreases after the first and second brails. Presumably the longer amount of time the sharks spend confined in the sack under stressful conditions, will negatively affect survival chances. Generally, from one brail to the next between 2-3 minutes will pass (Murua et al., 2021b). These extra minutes might be critical for the wellbeing of these sharks which are obligate ram ventilators, meaning they need to swim in order to adequately breathe. In this sense, while the survival rate in both trips was relatively high compared to non-BRD studies, in the first trip there was a significantly higher survival rate (i.e., 25% more) despite both trips having comparable number of sharks and size ranges, fast release times below 2 minutes, and similar percentages of sharks released in each brail category. However, one significant difference between the first and the second trip was the dominant vitality index encountered in the first trip, with many sharks in a correct state, compared to the second trip, with a high proportion of sharks arriving on deck in a poorer condition. While many factors can influence the condition of sharks arriving on deck (e.g., water temperature, size of the shark, size of the catch, etc.), in the same way time in the sack during brailing can affect the vitality of sharks, we believe that the time sharks spend in the sack before brailing (i.e., during the formation of the sack) also impacts their stress levels and breathing ability. For example, in the second trip sack formation time was 30 % longer compared to the first trip. Since this observation, we have been looking at sacking up time in other vessels and their relationship to shark vitality indexes, and it seems to be higher in cases where the sack is quickly formed (unpublished data). Several aspects come into play when determining the speed of sack formation in a vessel, including skipper skills, winch power, set size, but perhaps the most important is the overall configuration of the purse seine net itself (i.e., number and shape of net panels). Often purse seine sacks have extra net sections, just in case very large sets are conducted (e.g., 500-ton set). However, these huge sets are extremely rare, and the vessel ends up instead having to haul this extra sack netting in every single set, which takes a longer time to retrieve. Refining net designs to accelerate the sacking operation would not only benefit shark survival but also improve the quality of the tuna being loaded onboard.

While hoppers with ramps can help maximise survival chances of the sharks arriving on deck in a correct to excellent state thanks to the faster release times, however for sharks coming onboard in a very poor state, it will be more difficult to ensure PRS. This effect will be compounded in vessels lacking hoppers and with long sacking up times. Therefore, to increase shark bycatch mortality mitigation we propose the use of holistic approaches which employ hierarchical steps (sensu Booth et al., 2020), including strategies prior to setting (e.g., shark capture avoidance developing acoustic and visual technologies to detect their presence at FADs, attraction of sharks away from FADs with attractors/deterrents), during the set (e.g., fish and release in the net, release windows in the net, more streamlined purse seine net designs to reduce sack formation time) and after the set (i.e., hoppers with ramps and other release devices). One thing to consider is that if more sharks arrive on deck with very high vitality, it might be more difficult and dangerous to handle them, potentially increasing crew injury risks. Methods and technologies to ensure maximum fisher safety will be even more important in these situations.

Fisheries technologist and scientists in different regions have been working in the development of novel technologies and methods for these pre-set and during-set solutions (Restrepo et al., 2018), but more research is still needed to develop practices that are fully implementable during regular commercial fishing operations. Currently, the phase in which selective technology in tuna purse seiners has advanced the most is in the development of tools to aid with release practices once bycatch species arrive on deck (e.g., hoppers with ramps, mobulid sorting grids, etc.) (Murua et al., 2024). Ensuring that sensitive bycatch species arriving on deck are released as quickly and as safely as possible will always be a priority and hoppers with ramps are proving to be the most effective device for now to reach this objective. If some purse seine vessels have deck size restrictions to fit these large BRDs at least other smaller tools such as ramps or sorting grids are recommended to assist with release practices.

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