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Site-specific post-release predation of bonefish (*Albula glossodonta*) in a catch-and-release recreational fishery: informing voluntary actions and management strategies for a Blue Economy

Lucas P. Griffin [a,b,*], Gail Fordham [c,d], George Curd [c], Sascha Clark Danylchuk [e], Christopher Narty [c], Eleanor Brighton [f], Steven J. Cooke [g], Andy J. Danylchuk [b]

[a] Department of Integrative Biology, University of South Florida, Tampa, FL 33620, USA
[b] Department of Environmental Conservation, University of Massachusetts Amherst, 160 Holdsworth Way, Amherst, MA 01003, USA
[c] Island Conservation Society, P.O. Box 775, Pointe Larue, Mahé, Seychelles
[d] Blue Marine Foundation, 3rd Floor South Building, Somerset House, London WC2 R1LA, United Kingdom
[e] Keep Fish Wet, 11 Kingman Road, Amherst, MA 01002, USA
[f] Alphonse Fishing Company and Blue Safari Seychelles, PO box 378, Victoria, Mahe, Seychelles
[g] Fish Ecology and Conservation Physiology Laboratory, Department of Biology, Carleton University, 1125 Colonel By Dr., Ottawa, ON K1S 5B6, Canada

A R T I C L E I N F O

Handled by A.E. Punt

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A B S T R A C T

Bonefish (*Albula* spp.) support recreational catch-and-release (C&R) fisheries in tropical and subtropical regions, contributing to conservation efforts and advancing Blue Economy initiatives. However, post-release predation (PRP) poses challenges to the sustainability of these fisheries, particularly in predator-dense environments. This study assessed physical injury, reflex impairment, and PRP for bonefish (*Albula glossodonta*) in the Alphonse Group of islands, Republic of Seychelles, a well-established sport fishing destination. There was a significant effect of air exposure on reflex impairment, with fish exposed to air for 30 seconds being more impaired than those exposed to 0 or 10 seconds. However, air exposure, among other angling event characteristics, did not affect PRP (overall PRP = 13 %). Notably, PRP was highly site-specific, with 75 % of predation events occurring at a single location where bonefish were 15 times more likely to be predated compared to other sites. Cryptic predation was prevalent, as only 17 % of predation events were preceded by observing potential predators. Sicklefin lemon sharks (*Negaprion acutidens*) were responsible for most PRP, often tracking and preying on bonefish within an average of 9 minutes after release (30–1080 seconds; 545 ± 315 seconds). To reduce PRP risk, these findings highlight the need for regular PRP assessments, adaptive management, and site-specific strategies that include voluntary actions of anglers and guides to avoid locations where PRP is prevalent. Incorporating evidence-informed practices into conservation and management plans can promote sustainable recreational fisheries while supporting conservation and economic growth in a Blue Economy.

1. Introduction

Bonefish (*Albula* spp.) are a globally distributed group of 12 species that inhabit tropical and subtropical regions (Wallace and Tringali, 2016). Members of this genus exhibit a high degree of site fidelity in nearshore habitats (Brownscombe et al., 2019b; Griffin et al., 2023), including seagrass beds, sand flats, and coral reef flats, where they largely forage for benthic invertebrates (Colton and Alevizon, 1983; Crabtree et al., 1998; Griffin et al., 2019; Murchie et al., 2019). Throughout tidal cycles, bonefish move into the shallower areas of flats during flood tides to forage and retreat to deeper waters during ebb tides, contributing to nutrient transfer and energy flow within nearshore ecosystems (Brownscombe et al., 2017a, 2014; Murchie et al., 2013). In addition to their fidelity to coastal areas, bonefish will aggregate and migrate offshore to spawn in depths exceeding 100 m (Danylchuk et al., 2011; Lombardo et al., 2020). In some regions, such as the Indo-Pacific and the Caribbean, bonefish hold cultural significance and support subsistence and artisanal fisheries (Allen, 2014; Danylchuk et al., 2007a; Filous et al., 2019a; Ostrega et al., 2023). Globally, bonefish also support recreational C&R fisheries across their range, creating opportunities for

* Corresponding author at: Department of Integrative Biology, University of South Florida, Tampa, FL 33620, USA.
E-mail address: lpgriffin@usf.edu (L.P. Griffin).

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sustainable economic growth in local communities while promoting conservation initiatives (Filous et al., 2021; Perez et al., 2020; Wood et al., 2013). The combined annual economic impact of bonefish and other flats species in Belize, The Bahamas, and the Florida Keys exceeds USD 689 million (Smith et al., 2022). Such fisheries also support Blue Economy strategies in many coastal and island nations, which aim to balance economic reliance on marine resources with sustainability, conservation goals, and socio-economic benefits (Choudhary et al., 2021; Pauly, 2018).

Despite their ecological, cultural, and economic importance, bonefish populations face a number of threats that jeopardize the sustainability of the fisheries they support. Habitat loss, degradation, and overharvest are among the major drivers of population declines (Adams et al., 2014; Brownscombe et al., 2019a), which are further compounded by the cascading effects of climate change (Danylchuk et al., 2023). Their nearshore pre-spawning aggregations and predictable offshore spawning migrations make them particularly vulnerable to overharvest during spawning seasons (Adams et al., 2019; Filous et al., 2019b; Ostrega et al., 2023). The two most commonly targeted C&R bonefish species, *A. glossodonta* in the Indo-Pacific and *A. vulpes* in the Caribbean, are classified as Near Threatened and Vulnerable, respectively, by the International Union for Conservation of Nature (Adams et al., 2012a, 2012b). Although C&R has been widely promoted as a conservation tool (Arlinghaus et al., 2007), poor handling, prolonged fight times, and excessive air exposure during an angling event can have unintended consequences, compromising survival and recovery of released fish (Brownscombe et al., 2017b; Cooke and Suski, 2005).

Sublethal stress and injuries sustained during angling events can lead to impairment and decreased locomotor performance, thus increasing bonefish vulnerability to post-release predation (PRP) (Brownscombe et al., 2013; Cooke and Philipp, 2004; Dallas et al., 2010; Danylchuk et al., 2007b, 2007c; Lennox et al., 2017; Moxham et al., 2019). For example, in the Bahamas, Danylchuk et al. (2007c) reported bonefish that lost equilibrium following capture were six times more likely to be predated within the first 20 minutes post-release. However, in predator-dense areas, such as those with great barracuda (*Sphyraena barracuda*) and sharks (*Negaprion* spp., *Carcharhinus* spp.), PRP may still be high regardless of handling practices as predators are known to congregate near angling hotspots (Casselberry et al., 2024; Raby et al., 2014). For example, in Anna Atoll, French Polynesia, where blackfin reef shark (*Carcharhinus melanopterus*) abundances are high, bonefish released without air exposure experienced PRP of 33 %, while those exposed to air had PRP > 60 % (Lennox et al., 2017). High PRP could undermine the effectiveness of C&R practices, threatening the long-term viability of bonefish populations and related recreational fisheries that can contribute to the Blue Economy. As such, identifying the prevalence of impairment and PRP and its key drivers, including location-specific factors, predator presence, and angling practices, could be important for informing science-based best practices that contribute to sustainable recreational fisheries (Adams, 2017; Brownscombe et al., 2017b).

The objective of our study was to assess how the capture, handling, and fishing location influenced PRP for bonefish (*Albula glossodonta*) in a catch-and-release recreational fishery in the Alphonse Group of islands, Republic of Seychelles (Griffin et al., 2021). Blue Safari Seychelles Fly Fishing (BSSFF) (https://www.alphonsefishingco.com) operates within the Alphonse Group, providing high-end angling experiences for visiting tourists. Here, fly anglers primarily target six main species, including giant trevally (*Caranx ignobilis*), milkfish (*Chanos chanos*), Indo-Pacific permit (*Trachinotus blochii*), moustache triggerfish (*Balistoides viridescens*), yellowmargin triggerfish (*Pseudobalistes flavimarginatus*), and bonefish (Danylchuk et al., 2024; Griffin et al., 2021). With individual anglers frequently catching more than 20 bonefish per day, the Alphonse Group is considered one of the top bonefish fishing destinations in the world (Brown, 2008). While BSSFF enforces strict C&R protocols to promote sustainability (Griffin et al., 2022), the effect of angling and PRP on bonefish populations in this fishery remains unknown. An acoustic telemetry study involving bonefish in The Seychelles (i.e., Moxham et al., 2019) documented rather high PRP (at least 43 %) but those fish were surgically implanted with transmitters (average hooking to release time of approximately 11 minutes) which confounds findings when applied to a C&R context. To meet our objective, we quantified elements of the angling event, such as fight time, air exposure, hook location, and angling location on reflex impairment and PRP occurrences. By identifying the key drivers of reflex impairment and PRP, we hoped to provide evidence-informed best practices for the C&R fisheries. These efforts support not only sustainable fisheries management but also the broader objectives of Blue Economy strategies being adopted in the Seychelles, which seek to harmonize conservation with economic resilience (Benzaken et al., 2022).

2. Methods

2.1. Study site

This research was conducted at the Alphonse Group (7.10°S, 52.75°E) in the Outer Islands of the Republic of Seychelles (Griffin et al., 2021). Alphonse Group consists of two low lying coralline atolls, Alphonse and St. François. Alphonse Atoll includes the land mass of Alphonse Island (174 ha), a lagoon (540 ha), and peripheral reef flats (402 ha) (Spencer et al., 2009). St. François Atoll includes two islands, Bijoutier (2 ha) and St. François (17 ha), and is encircled by a reef before reaching > 2000 m depth. It consists of extensive shallow reef flats (3732 ha) and a large inner lagoon (1650 ha, < 10 m depth). Flats are comprised of sand, seagrass, and coral rubble with a tidal range of approximately 2 m. The majority of the inner lagoon consists of a sandy substrate interspersed with coral heads and is divided by shallow 'finger flats,' which form a network of inner basins connected by natural channels. The most commonly sighted potential bonefish predators in the Alphonse Group included giant trevally, sicklefin lemon sharks (*Negaprion acutidens*), and great barracuda.

2.2. Capture and handling

Fishing occurred from January 8–18, 2019, and January 24 to March 12, 2022, throughout Alphonse Group, with the majority occurring in St. François Atoll, the main area where clients of BSSFF target bonefish. Bonefish were targeted by wading across shallow flats and caught using 7–10 wt fly rods and reels, 10–20 lb. leaders, and small (size 6–8) barbless flies. Although water depths remained consistent at 0.2–0.6 m, capture locations were classified as near (< 200 m) or far (> 200 m) from deeper water, either within the inner lagoon or along the outer edge of the atoll. For each captured bonefish, recorded data included capture location, air exposure duration (0, 10, or 30 seconds), fork length (FL, cm), fight time (s), handling time (s), anatomical hook location, hook removal difficulty (categorically scored from 0 as easy to 5 as difficult), incidence of bleeding at the hook site (yes vs. no), and observed predator in the area prior to capture or release (yes vs. no).

Immediately at landing, fish were assessed for reflex impairment (Davis, 2010), which is widely used to assess the condition of recreationally caught fish due to being highly predictive for behavioral impairment and post-release mortality (Brownscombe et al., 2013; Lennox et al., 2024; Raby et al., 2012). Reflex impairments assessed included righting reflex (loss of equilibrium), tail grab, eye roll (vestibular-ocular response, VOR), body flex, and head complex. Reflexes were scored as present (passed) and absent (failed). Righting reflex was tested by rotating the fish ventral side towards the water's surface. Fish that were able to right themselves (ventral side down) within 3 seconds were recorded as having no equilibrium loss, and righting time was assigned as 3 seconds. Those that took longer than 3 seconds were deemed as failing the righting reflex test, and the total duration to right themselves was recorded (s). Tail grab was assessed by grabbing the fish by the tail, with an escape attempt indicating a present reflex. The VOR was evaluated by rolling the fish on its side with tracking eye movement, indicating a present reflex. Body flex was assessed by lifting the fish from the center of its body, with flexing indicating a present reflex. Head complex was determined by observing opercular movement, with regular ventilation recorded as a present reflex. Reflex scores were then converted to successes (1 s) vs. failures (0 s) proportion, with each reflex weighted equally (0.2 per reflex). All reflexes were also reassessed just prior to release to evaluate the effects of handling. A full reflex score of 1 would indicate all reflexes passed and a score 0 would indicate all reflexes failed.

To assess post-release survival, we followed an established method for monitoring PRP in bonefish (Cooke and Philipp, 2004; Danylchuk et al., 2007c; Lennox et al., 2017). Each fish was visually tracked by attaching a small, brightly colored fishing float via a small hook carefully inserted into the dorsal musculature just behind the dorsal fin. The float was connected to the line above the fish (~ 10 m) on 5.4 kg test fluorocarbon, which was tethered to a spinning rod with the bail left open to ensure minimal resistance on the fish during tracking. While wading on the flats, we tracked each fish for up to 20 minutes following release, which is the time period predation is most likely to occur for bonefish (Danylchuk et al., 2007c). The predator species, behavior, and time (seconds) to predation were recorded in attempted or successful predation events. All procedures were approved by the University of Massachusetts Amherst Institutional Animal Care and Use Committee (IACUC) protocol 3545.

2.3. Data analyses

Generalized linear models (GLMs) with a binomial distribution and logit link were used to assess the effect of fight time (numeric) and size (numeric) on righting ability (yes vs. no) at capture, as well as the effects of fight time, size, air exposure duration (categorical: 0, 10, or 30 seconds), and handling time (numeric) on righting ability at release. In addition, GLMs with a binomial distribution and logit link were also used to assess the effect of fight time and size on reflex scores at capture, as well as the effects of fight time, size, air exposure duration, and handling time on reflex scores at release. Separate models were developed for reflex scores at capture and release, with each reflex in the assessment converted into a binary outcome of 'success' (unimpaired) versus 'failure' (impaired) (Griffin et al., 2022, 2024). Pairwise comparisons of air exposure levels were estimated using marginal means with Tukey-adjusted p-values (Tukey, 1977). For analyses and figures focused on reflex scores, only data from 2022 was used to ensure consistency, as different recorders across the two years conducted reflex impairment assessments.

To assess PRP, a generalized linear mixed model (GLMM) with a binomial distribution and logit link was used to examine the effects of air exposure duration, distance to deep water (numeric), and predator observed (yes vs. no) on PRP (mortality vs. survival), with fishing location (categorical) included as a random effect. A GLM evaluated PRP at the highest PRP location, known as Brown Spot, with air exposure duration and predator observed. Kaplan-Meier survival curves and log-rank tests were used to compare survival probabilities between Brown Spot and other fishing locations (Kleinbaum and Klein, 2012). A Cox proportional hazards model estimated the relative risk of PRP, with Schoenfeld residuals used to assess proportional hazards assumptions. All analyses were conducted in R (version 4.4.2) and RStudio (version 2024.09.1) (R Core Team, 2024) using the glmmTMB (Brooks et al., 2017), emmeans (Lenth, 2024), and survival (Therneau, 2024) packages. Model assumptions, diagnostic checks, and visualizations were performed with the performance (Lüdecke et al., 2024), sjPlot (Lüdecke, 2024), DHARMa (Hartig, 2024), and survminer (Kassambara et al., 2024) packages. Mean and standard deviation (mean ± standard deviation) and confidence intervals (95 % CI) were reported. Statistical significance was set at $\alpha = 0.05$.

3. Results

A total of 94 bonefish (29–60 cm FL, 43 ± 6.1 cm FL) were captured at 15 locations (one in Alphonse Atoll and 14 in St. François Atoll) and across two sampling years (2019: n = 36, 42 ± 7 cm FL; 2022: n = 58, 43 ± 6 cm FL). Hook removal difficulty was scored as 0 in 47 % of cases (n = 27), 1 in 54 % (n = 31), 2 in 29 % (n = 19), 3 in 10 % (n = 6), and 4 in 15 % (n = 9). Hook locations included the corner of the mouth at 49 % (n = 42), upper jaw at 25 % (n = 21), tongue at 13 % (n = 11), lower jaw at 6 % (n = 5), outside the mouth at 6 % (n = 5), and deep in the throat at 1 % (n = 1), with 5 % (n = 4) not recorded. Blood was observed in 5 % of cases (n = 5), with 95 % (n = 88) showing no visible blood.

Reflex scores ranged from 0.4 to 1.0 (0.8 ± 0.2) at capture and release (Fig. 1). At capture, there were no significant effects of fight time ($p = 0.31$) or size ($p = 0.81$) on righting ability (Table 1). Similarly, at release, fight time ($p = 0.17$), size ($p = 0.51$), or handling time ($p = 0.49$) were not significant predictors of righting ability, although air exposure at 30 s was nearly significant ($p = 0.05$). For all reflexes combined, neither fight time ($p = 0.54$) or size ($p = 0.52$) had significant effects at capture (Table 2). At release, however, air exposure significantly influenced reflex scores (Table 2). Pairwise comparisons of estimated marginal means showed that fish exposed to 30 seconds of air had lower reflex scores compared to those with 0 seconds of exposure (odds ratio = 2.9, $p = 0.009$) and 10 seconds (odds ratio = 2.1, $p = 0.002$; Fig. 2). There was no significant difference between fish exposed to 0 and 10 seconds of air ($p = 0.83$). Fight time ($p = 0.12$), size ($p = 0.08$), and handling time ($p = 0.57$) did not significantly affect reflex scores at release.

There were 12 confirmed instances of PRP (13 %; 2019: n = 1; 2022: n = 11) recorded at four of the 15 fishing locations (Fig. 3). Seven PRP events were attributed to lemon sharks, while the predator species for the remaining five events could not be confirmed. In the PRP events attributed to lemon sharks, sharks were often observed patrolling the area following the release of a bonefish, exhibiting meandering movements before eventually tracking and preying on the fish as it swam away. Two depredation attempts were also observed, one involving a great barracuda and the other a lemon shark, with the latter resulting in a PRP event. Four of the 12 PRP events (33 %) occurred after predators were observed in the vicinity, with lemon sharks accounting for most of these events, except for one by a great barracuda. The location Brown Spot accounted for nine of the 12 PRP events (75 %), with 17 bonefish in total captured here (53 % PRP) across two days in 2022 (February 26 and March 12). This location was characterized by an extensive sandy flat that was far (> 200 m) from deepwater access. Only one PRP event (8 %) occurred near deeper water (< 200 m) along the lagoon's peripheral edge, at the perimeter of the location known as One Palm.

Predictors of PRP, including distance from deeper water, air exposure, and observed presence of predators (Fig. 4), were assessed with a GLMM (Table 3; marginal $R^2 = 0.3$, conditional $R^2 = 0.4$). No fixed effect was significant, but predator presence had a near-significant effect ($p = 0.06$). The spatial variability of location accounted for 19 % (intraclass correlation coefficient) of the total variance in PRP. After selecting only fish captured and released at the Brown Spot (n = 17; Fig. 5), an additional GLM with the variables air exposure and observed predators ($R^2 = 0.1$; Table 4) had no significant effects ($p > 0.3$).

After excluding one PRP event with no recorded time, predation times ranged from 30 to 1080 seconds (545 ± 315 seconds). Survival probability differed significantly between fish released at Brown Spot and other fishing locations ($p < 0.001$). At Brown Spot, survival was 75 % by 720 seconds (12 minutes) and then declined to 47 % (95 % CI 28–81 %) by 1080 seconds (18 minutes). Survival at other locations was 96 % (95 % CI 92–100 %) at 300 seconds (5 minutes), with no additional mortality events afterward. Bonefish released at Brown Spot were 15 times (95 % CI 4–57; z = 4.0, $p < 0.001$; proportional hazards test: $\chi 2 = 3.5$, $p = 0.06$) more likely to experience PRP than those released at other locations (Fig. 6).

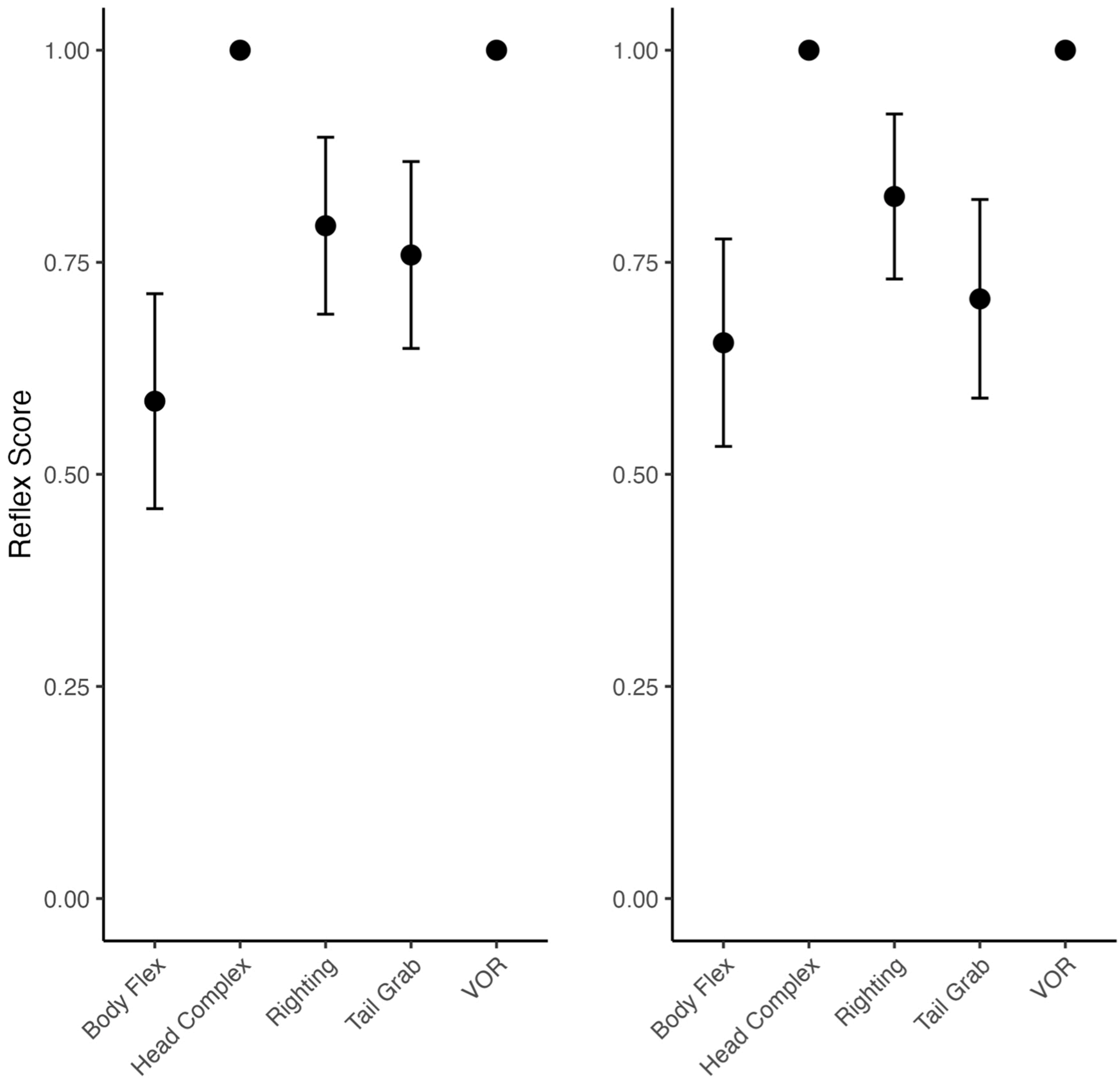

Fig. 1. Reflex scores for bonefish caught and released in the Alphonse Group, Seychelles. Reflex was assessed using five reflex indices at two time points: capture (left panel) and release (right panel). Reflex score is shown as the mean proportion impaired for body flex, head complex, righting, tail grab, and vestibular-ocular response (VOR). Error bars represent 95 % confidence intervals. A reflex score of one would indicate no impairment.

Table 1
Summary of the generalized linear models assessing the effect of fight time (seconds), size (fork length cm), handling time (seconds), and air exposure duration (0, 10, or 30 seconds) on righting ability for bonefish at capture and release in the Alphonse Group, Seychelles.

	Righting Ability at Capture			**Righting Ability at Release**		
Predictors	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*
(Intercept)	2.20	0.10 – 48.63	0.618	19.08	0.51 – 709.66	0.110
Fight Time	1.00	0.99 – 1.00	0.311	0.99	0.99 – 1.00	0.166
Size	1.01	0.93 – 1.10	0.808	0.97	0.89 – 1.06	0.510
Handling Time				1.00	1.00 – 1.01	0.494
Air Exposure [10]				1.01	0.30 – 3.37	0.986
Air Exposure [30]				0.33	0.11 – 1.02	0.053
Observations	92			91		

Table 2
Summary of the generalized linear models assessing the effect of fight time (seconds), size (fork length cm), handling time (seconds), and air exposure duration (0, 10, or 30 seconds) on reflex scores for bonefish at capture and release in the Alphonse Group, Seychelles. Significant values are in bold.

	Reflex Scores at Capture			**Reflex Scores at Release**		
Predictors	*Odds Ratios*	*CI*	*p*	*Odds Ratios*	*CI*	*p*
(Intercept)	2.69	0.24 – 29.98	0.420	1.28	0.06 – 27.22	0.873
Fight Time	1.00	0.99 – 1.00	0.544	0.99	0.99 – 1.00	0.123
FL	1.02	0.96 – 1.09	0.517	1.07	0.99 – 1.16	0.081
Handling Time				1.00	0.99 – 1.00	0.573
Air Exposure [10]				1.36	0.48 – 3.87	0.565
Air Exposure [30]				0.28	0.12 – 0.66	0.003
Observations	57			57		

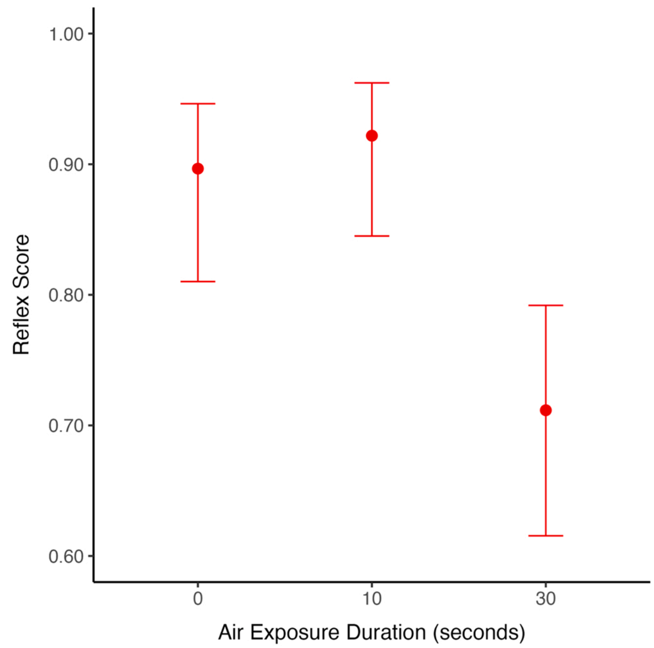

Fig. 2. Predicted reflex scores for bonefish in the Alphonse Group, Seychelles, across three air exposure durations (0, 10, and 30 seconds). Error bars represent 95 % confidence intervals. A reflex score of one would indicate no impairment.

4. Discussion

Catch-and-release fisheries aim to balance the economic and ecological benefits of recreational angling by minimizing post-release mortality (Cooke and Suski, 2005). However, environmental and behavioral factors can undermine the effectiveness of C&R as a conservation tool by increasing the risk of physiological impairment and PRP (Raby et al., 2014). For example, air exposure is widely recognized as a primary stressor for angled fish, and minimizing it is a fundamental best practice for anglers (Brownscombe et al., 2017b; Cook et al., 2015; Pelletier et al., 2007). In line with prior research, we found a significant relationship between air exposure and reflex impairment, with bonefish exposed to 30 seconds of air having greater impairment than those exposed to 0 or 10 seconds. Similar patterns were observed by Brownscombe et al. (2015) in Puerto Rico, where bonefish reflex impairment increased after 2 minutes of air exposure. However, unlike prior studies, our results did not show a direct relationship between air exposure, equilibrium loss, and PRP. For example, in The Bahamas, bonefish that lost equilibrium were six times more likely to be predated (Danylchuk et al., 2007c). In French Polynesia, PRP increased from 33 % with no air exposure to over 60 % with air exposure (Lennox et al., 2017). These collective differences highlight the complexity of PRP dynamics, the need to consider each fishery independently, and additional site-specific and ecological factors that can influence PRP.

In our study, PRP occurences were highly site-specific, with 75 % of PRP events occurring at one location, where the PRP occurrence was 53 %. Bonefish at this location were 15 times more likely to experience predation than other sites, highlighting the importance of predator abundance in determining PRP. For example, Cooke and Philipp (2004) reported 0 % PRP in low-predator areas of the Bahamas compared to 39 % in high-predator areas. Similarly, Lennox et al. (2017) identified predator density as the primary driver of PRP in Anna Atoll in French Polynesia, while Moxham et al. (2019) reported PRP occurrences as potentially high as 90 % in predator-dense (Filmalter et al., 2013) areas like St. Joseph Atoll in the Seychelles (although bonefish in this study were surgically implanted with transmitters prior to release which presumably confounds PRP occurrences). Although predator observations before release was a near-significant predictor of PRP in our study,

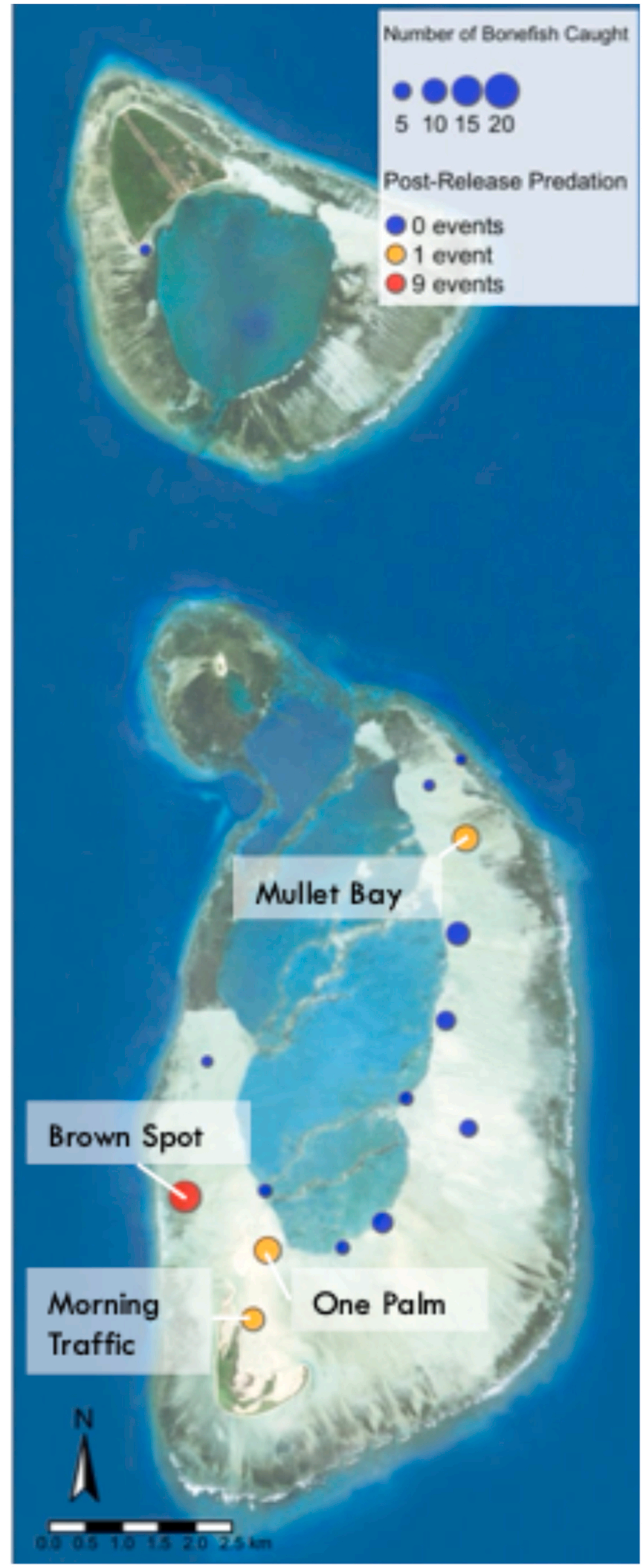

Fig. 3. Spatial distribution of bonefish captures and post-release predation (PRP) events in the Alphonse Group, Seychelles. Circle sizes represent the number of bonefish captured at each location, with larger circles indicating higher capture counts. Colors indicate the number of PRP events at each site: blue (0 predation events), orange (1 predation event), and red (9 predation events). The sites where PRP occurred are labeled.

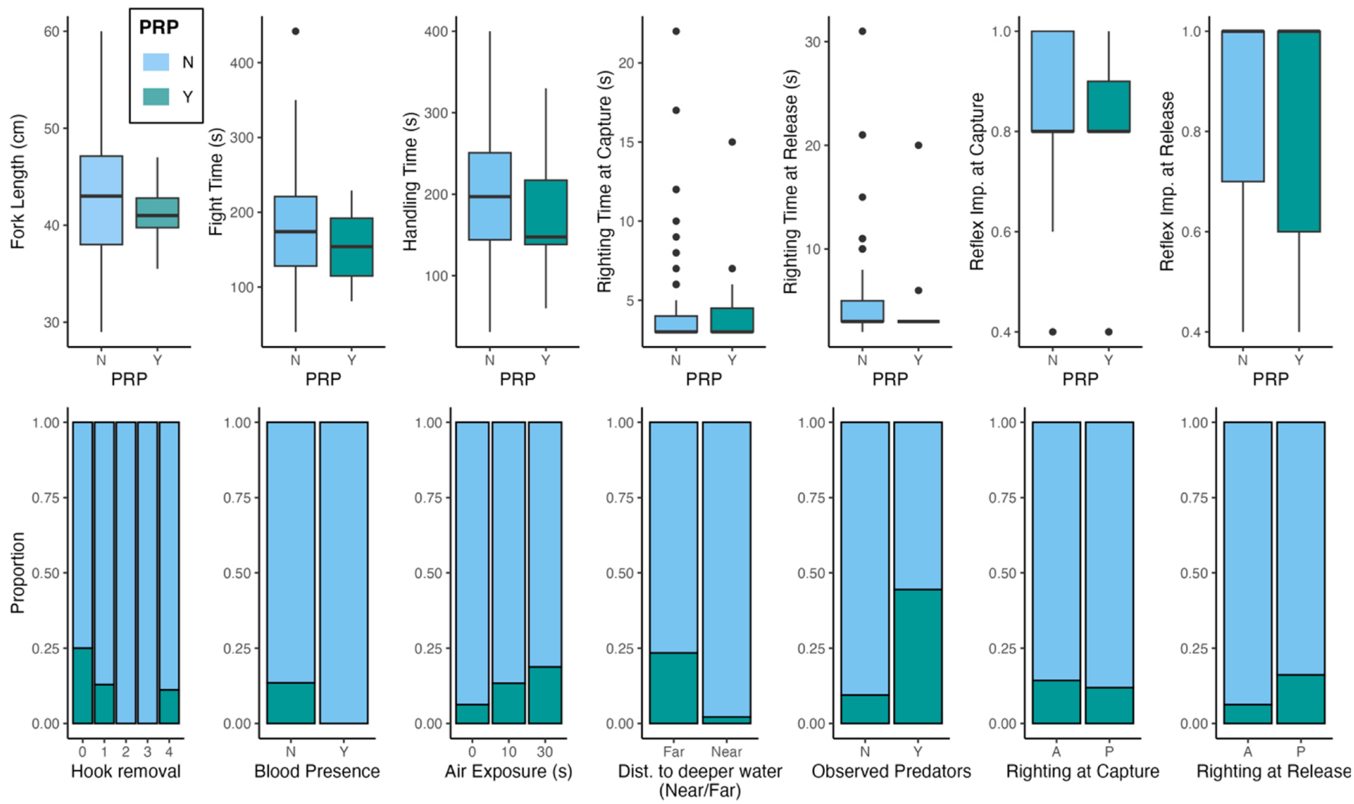

Fig. 4. Boxplots and bar plots illustrating the relationships between variables and post-release predation (PRP) outcomes for bonefish in Alphonse Group, Seychelles. The top row shows continuous predictors (fork length, fight time, handling time, righting time at capture, righting time at release, and reflex scores at capture and release) with PRP outcomes ('N' = no predation, 'Y' = predation) as grouped boxplots. The bottom row presents categorical predictors (hook removal difficulty, blood presence, air exposure, distance to deeper water, observed predators, and equilibrium loss at capture and release) as proportional bar plots stratified by PRP outcomes. Shaded colors indicate predation ('Y' = green) and non-predation ('N' = blue). Outliers are represented as points in the boxplots, and proportional differences are highlighted in the stacked bars.

Table 3
Summary of the generalized linear mixed model assessing the effect of distance to deeper water (far vs. near), air exposure duration (0, 10, 30 seconds), observed predator (yes vs. no), and righting at release (yes vs. no), on post-release predation (PRP) of bonefish in Alphonse Group, Seychelles. The random effect of fishing location was included and significant values are in bold.

	PRP		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	0.01	0.00 – 0.12	< 0.001
Distance to deeper water [Far]	7.64	0.67 – 86.78	0.101
Air Exposure [10]	1.00	0.11 – 9.00	0.999
Air Exposure [30]	2.28	0.34 – 15.52	0.399
Observed Predator [Y]	7.85	0.93 – 66.06	0.058
Random Effects			
σ^2	3.29		
$\tau_{00\ \text{Location}}$	0.78		
ICC	0.19		
N_{Location}	15		
Observations	94		
Marginal R^2 / Conditional R^2	0.291 / 0.426		

only 4 of the 12 recorded PRP events involved predators being observed beforehand. This suggests that predator observations alone do not predict PRP and that additional factors, such as predator behavior, prey stress levels, and site-specific environmental characteristics, also play a role. While predator densities on shallow water flats in the Seychelles have not been directly quantified to our knowledge, the Alphonse Group is generally considered to have lower predator densities compared to Anna Atoll, where sharks were observed at an encounter rate of 1.14 ± 1.26 per hour, frequently approaching within 1 m of anglers. This suggests that PRP at our study site may occur more cryptically. However, ongoing baited remote underwater video research off the flats at the Alphonse Group has recorded high numbers of lemon sharks. The mean incidence of PRP in our study was 9 minutes compared to 5 minutes after release in the predator-dense Anna Atoll (Lennox et al., 2017), and predators were often not observed before PRP events in our study. For example, for one bonefish the PRP event occurred just 30 seconds after release and there was no prior observation of any predators. Assessing PRP in environments where predation may occur cryptically, far from an angler, or without apparent predator presence, highlights the complexity of evaluating PRP without actively tracking bonefish following release.

Elevated stress metabolites, which persist in fish tissue for hours post-release (Suski et al., 2007), are likely exploited by sharks to locate bonefish (Dallas et al., 2010). These stress-related chemical cues, combined with the cognitive learning behaviors of sharks (Guttridge et al., 2009), can increase PRP risks in C&R fisheries (Raby et al., 2014). While recovery techniques, such as recovery bags, have been shown to improve post-release swimming abilities (Brownscombe et al., 2013), their effectiveness can be diminished in predator-dense environments where scent trails and stress metabolites attract predators (Lennox et al., 2017). Adaptive management strategies and voluntary actions like rotating fishing areas or temporary closures should be considered in locations with potentially unsustainably high PRP (Holder et al., 2020), particularly when areas with low-PRP rates are available. Periodic assessments, including tracking released fish as done in this study, are essential when evaluating PRP risks and to inform voluntary actions and more formal adaptive management strategies. Future research should prioritize additional sampling across time and space, quantifying predator

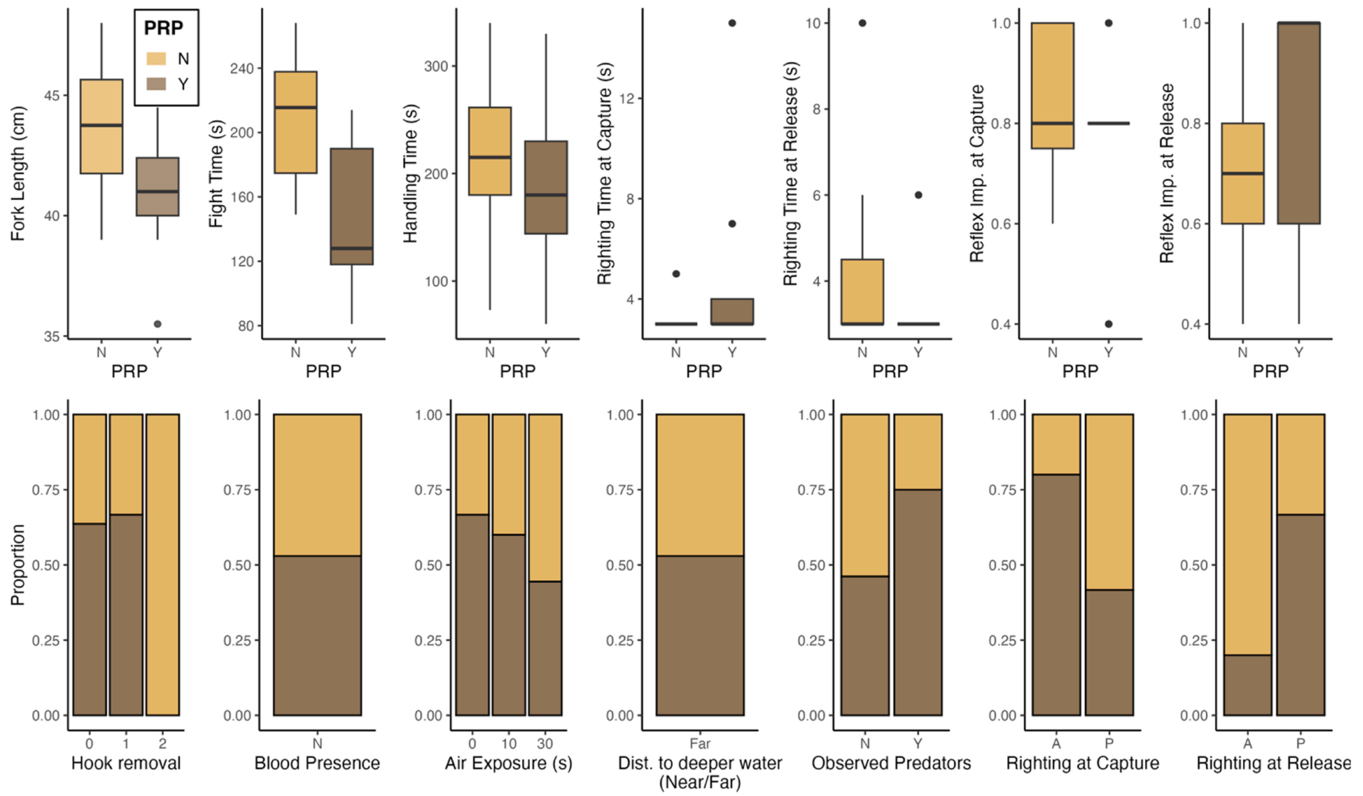

Fig. 5. Boxplots and bar plots illustrating the relationships between variables and post-release predation (PRP) outcomes for bonefish at the fishing location Brown Spot in Alphonse Group, Seychelles. The top row shows continuous predictors (fork length, fight time, handling time, righting time at capture, righting time at release, and reflex scores ('A' = absent, 'P' = present) at capture and release) with PRP outcomes ('N' = no predation, 'Y' = predation) as grouped boxplots. The bottom row presents categorical predictors (hook removal difficulty, blood presence, air exposure, distance to deeper water, observed predators, and righting at capture and release) as proportional bar plots stratified by PRP outcomes. Shaded colors indicate predation ('Y' = dark brown) and non-predation 'N' = light brown). Outliers are represented as points in the boxplots, and proportional differences are highlighted in the stacked bars.

Table 4
Summary of the generalized linear model assessing the effect of air exposure duration (0, 10, 30 seconds) and observed predator (yes vs. no) on post-release predation (PRP) of bonefish caught at the fishing location Brown Spot in Alphonse Group, Seychelles.

	PRP		
Predictors	*Odds Ratios*	*CI*	*p*
(Intercept)	2.00	0.18 – 22.06	0.571
Air Exposure [10]	0.31	0.01 – 10.10	0.509
Air Exposure [30]	0.34	0.02 – 5.40	0.444
Observed Predator [Y]	4.75	0.23 – 96.58	0.311
Observations	17		
R^2	0.1		

densities and their learned behaviors (i.e., habituation), as well as understanding the long-term population-level impacts of PRP for each fishery. Further, while integrating telemetry to monitor post-release movement and survival could provide better insights into the behavioral and ecological factors driving PRP (Moxham et al., 2019), potential tagging effects on fish behavior and predation risk must be considered (Klinard and Matley, 2020; Lennox et al., 2023; Matley et al., 2024). Lastly, the use of innovative mitigation strategies, such as predator deterrents (Mitchell et al., 2023), is promising. Yet, ultimately, simple and easy to implement measures like voluntarily changing fishing locations or more formal area-based fisheries management are likely most effective to resolve issues of PRP.

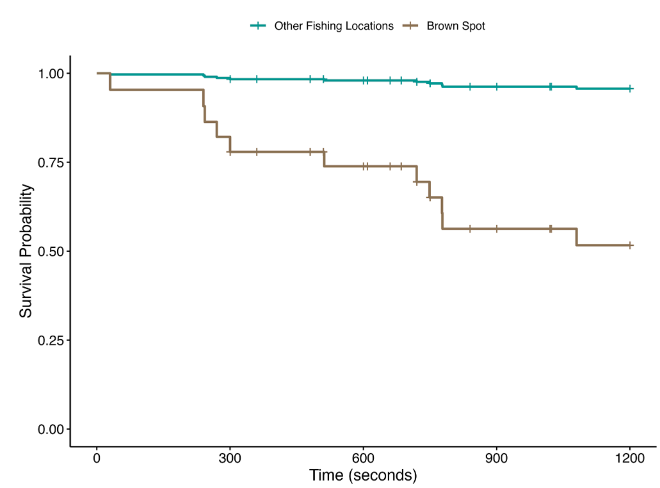

Fig. 6. Kaplan-Meier survival curves with post-release survival probabilities of bonefish in the Alphonse Group, Seychelles. The brown line represents survival probabilities for fish released at Brown Spot, while the green line represents survival probabilities for fish released at other fishing locations. Survival probability is plotted over time (seconds), with vertical ticks indicating censoring events.

5. Conclusion

Our findings demonstrate that PRP varies across locations within a fishery, even when best handling practices are implemented. Stakeholders and fisheries managers should focus on first identifying high-risk

PRP areas with semi-regular PRP assessments, as was done in this study. It is also important to understand the level of C&R mortality that can be sustained in different fisheries to determine the extent to which there may be issues related to the fish population (Corsi et al., 2025). If a site is identified as high risk, anglers, fishing guides, and managers should be prepared to implement voluntary adaptive actions such as rotating fishing sites or more formal spatial management plans that balance fishing pressure with incidence of PRP in C&R recreational fisheries. These insights also highlight an opportunity to strengthen goals linked to Blue Economy initiatives where sport fishing is increasingly recognized as a valuable contributor to conservation and economic resilience (Christ et al., 2020). By adopting evidence-informed conservation practices and promoting sustainable fisheries management, the Seychelles and other similar island nations focusing on a Blue Economy (Benzaken et al., 2022; Pauly, 2018) can continue to protect marine ecosystems while increasing economic resilience.

CRediT authorship contribution statement

Danylchuk Andy J.: Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Cooke Steven J.:** Writing – review & editing, Conceptualization. **Fordham Gail:** Writing – review & editing, Methodology. **Griffin Lucas:** Writing – review & editing, Writing – original draft, Methodology, Conceptualization. **Brighton Eleanor:** Writing – review & editing, Methodology. **Narty Christopher:** Writing – review & editing, Methodology. **Danylchuk Sascha Clark:** Writing – review & editing, Methodology, Conceptualization. **Curd George:** Writing – review & editing, Methodology.

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Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work, OpenAI was used to assist in minor grammatical proofreading. No major use occurred, and the authors take full responsibility for the content of the published article.

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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Data availability

Data will be made available on request.

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