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Short-term response of giant trevally (*Caranx ignobilis*) to capture and handling in a catch-and-release fly fishing recreational fishery, Republic of the Seychelles, Western Indian Ocean.

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ABSTRACT

Giant trevally (*Caranx ignobilis*, GT) are growing in popularity as a target for tourism-based recreational fisheries throughout their range in the Indo-Pacific. Although predominately catch-and-release (C&R), to date there is no species-specific scientific evidence to support capture and handling guidelines. As such, we examined how GT caught via fly fishing gear while in shallow water responded to capture and handling in the Alphonse Island Group, Republic of the Seychelles. Specifically, we evaluated the physical injury for GTs captured via fly fishing gear, as well as their reflex impairment and post-release activity (using tri-axial accelerometer biologgers) following three air exposure treatments (0 s, 15 s, 30 s). We also had a reference treatment where GTs were caught and landed quickly via a handline, and not exposed to air (0 s) prior to release. Hooking location for both gear types was predominately the jaw or corner of the mouth (fly fishing, n = 30; 83.3%; handline; n = 12, 85.7%), but one fish hooked in a critical location for each capture gear. Across all treatments, only one fish (2%) in the handline treatment was considered a potential short-term post-release mortality following being deeply hooked in the gills and subsequently losing equilibrium upon release. GT reflex impairment and overall post-release activity measured via overall dynamic body acceleration were not influenced by fight time and air exposure treatments used in our study. For GTs across all treatments, locomotor activity was lower in the initial minutes following release than during the second half of the ten minute monitoring period. Overall, our study suggests that GTs in the Alphonse Island Group are resilient to being caught via fly fishing, handled, and air exposed for up to 30 s. However, given the diversity of angling locations for GTs (e.g., shallow flats, deeper reefs) and gear types (e.g., conventional tackle, lures with several treble hooks), additional assessments are needed to help act as the foundation for more universal best practices that can inform management plans for GT recreational fisheries.

1. Introduction

Giant trevally (*Caranx ignobilis*, GT), with a life span upwards of 25 years (Andrews, 2020) and a member of the Carangidae family, occur in tropical and subtropical coastal waters of the Indo-Pacific (Glass et al., 2021). This large-gaped predator is mainly thought to be piscivorous (Farmer and Wilson, 2011; Sudekum, 1991; Whitfield and Blaber, 1979), but depending on location, prey availability, or life stage, they also rely on benthic invertebrates to some extent (Dale et al., 2011; Meyer et al., 2007). GT inhabit tidal lagoons and estuaries, coral and rocky reefs, and adjacent mesopelagic waters (Daly et al., 2021, 2019; Lédée et al., 2015; Meyer et al., 2007; Papastamatiou et al., 2015; Wetherbee et al., 2004), and likely play an important role as apex predators in reef and island marine ecosystems (Glass et al., 2020). GT are also important to subsistence, commercial, and recreational fisheries, holding considerable cultural and economic value for many local communities and regional commerce (Abdussamad et al., 2008; Gaffney, 2000; Verschuuren et al., 2015).

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Over the past few decades, the popularity of targeting GT with fishing rod and reel by the recreational sector has increased dramatically. The aggressiveness of the strike, intensity of the fight, and large potential size of GT (72.8 kg world record, The International Game Fish Association, 2021) is attractive to recreational anglers (McLeod, 2016). There is a segment of the angling community that is able to afford to travel to remote locations to target novel gamefish (Ditton et al., 2002; Golden et al., 2019), including for GT (Griffin et al., 2021). This demand to pursue GT and other species that inhabit shallow nearshore flats has considerable economic value through direct and indirect spending by recreational anglers, as well as the development of fishing lodges, employment as guides and for hospitality services, and other related activities (Cooke et al., 2016; Wood et al., 2013). For example, the estimated annual economic impact of flats fishing in The Bahamas and Belize were worth of \$169 and \$56 million USD, respectively (Fedler, 2019, 2014). Although no recent economic impact has been estimated for GT, in 2000 in Hawaii, the recreational/subsistence fishery that included GT was estimated to be \$31 million USD (Gaffney, 2000), which would be around \$44 million USD after being adjusted for inflation (Grabowski and Franklin, 2017). As such, ensuring that stocks of recreationally targeted species, like GTs, are effectively managed and remain robust can be the foundation for sustainable tourism-based economies (Barnett et al., 2016).

Recreational angling for GT in tourism-based fisheries is predominantly catch-and-release (C&R) (McLeod, 2016). C&R is often used as a tool to minimize the impacts of recreational angling on fish populations (Adams, 2017; Arlinghaus et al., 2007; Cooke and Philipp, 2004). However, this practice operates under the assumption that how individual fish are caught, handled, and released does not influence survival and fitness (Aas et al., 2002; Quinn, 1996; Wydoski, 1977). This premise has been a focus of the growing discipline of C&R science (Cooke and Schramm, 2007), that continues to demonstrate that the response to C&R can be specific to hook/gear type (Cooke et al., 2003b, 2003a; Meka, 2004), angling practices (Brownscombe et al., 2017), and/or specific to differences among species based on morphology, physiology, ecology, and behavior (Cooke and Suski, 2005). Ultimately, consequences from C&R can range from no detectable/minimal sub-lethal effects and high survivorship to reduced fitness and/or post-release mortality (Arlinghaus et al., 2007; Cooke et al., 2002a; Cooke and Philipp, 2004; Cooke and Schramm, 2007; Davis, 2002; Holder et al., 2020). As C&R is promoted as a conservation tool, it is imperative that species-specific and even situation-specific science be conducted to evaluate the potential impacts, and, in turn, use scientific evidence to inform best practices (Brownscombe et al., 2017). Thus, to meet conservation endpoints for C&R species, it is essential to assess and quantify physical injury, e.g., from hooking (Muoneke and Childress, 1994), reflex impairment and survival, e.g., from reflex action mortality predictors (RAMP; Brownscombe et al., 2015; Davis, 2010; McLean et al., 2020; Raby et al., 2012), and post-release behavior impairment, e.g., from locomotor activity estimates (Brownscombe et al., 2013; Holder et al., 2020; LaRochelle et al., 2021; Lennox et al., 2018), during and following angling events.

To date, there has been no study that has examined how GT respond to C&R. The purpose of this study was to assess physical injury, reflex impairment, and post-release locomotor activity of GT targeted in the fly fishing recreational fishery. To accomplish this, GT were angled via fly fishing tackle, as well as via handline as a reference. At time of capture, all fish were evaluated for hooking damage. GTs caught via fly fishing gear were subjected to one of three air exposure treatments to simulate a range of admiration periods by recreational anglers, while all handlined GTs remained submerged. Prior to release, reflex impairment (RAMP) were assessed and triaxial accelerometer biologgers were temporarily affixed to the caudal peduncle of all GT to quantify short-term post-release activity and survival. Collectively, this work can be used to inform management practices for GT recreational fisheries throughout their range.

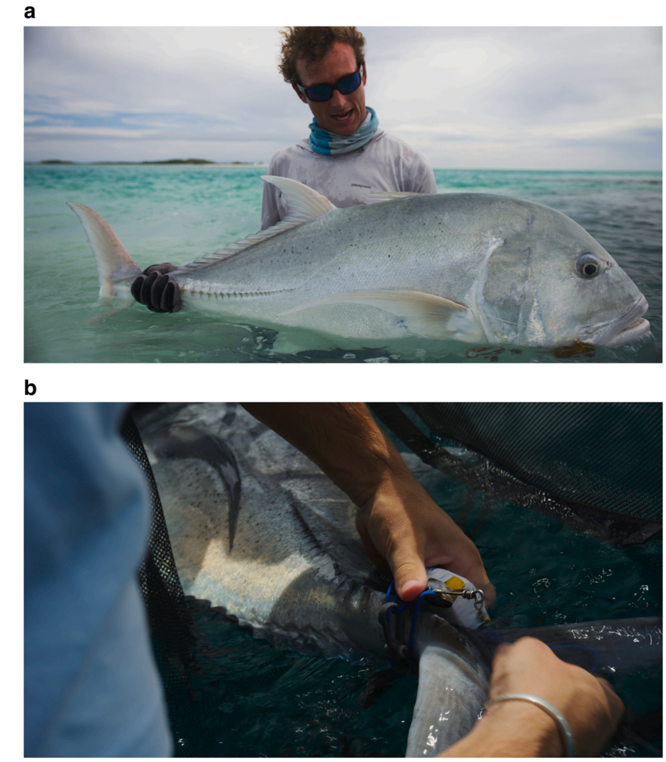

Fig. 1. (a) a caught giant trevally, and (b) attachment of accelerometer logger package to giant trevally. Photo credits: Sport Fishing Televison.

2. Materials and methods

2.1. Study site

This study took place on Alphonse Atoll (−7.005542, 52.727201) in the Western Indian Ocean, which is part of the Alphonse Island Group in the outer islands of the Republic of Seychelles. Alphonse Atoll includes the land mass of Alphonse Island which covers an area of 174 ha and is the location of a small airport and tourism operation, as well as a 540 ha lagoon and 402 ha of peripheral reef flats. The inner lagoon is relatively shallow (< 10 m), and is predominately sandy bottom, with occasional coral patches dispersed throughout, and one main dredged channel to access the deeper oceanic waters that surround the Alphonse Island Group. Lastly, predator density (e.g., sharks capable of GT capture) within the study site was assumed to be low with rare sightings of large sharks.

2.2. Capture and handling

All procedures used in this research were approved by UMass IACUC, protocol 2016–0049, and under a research permit from the Seychelles Bureau of Standards. Sampling occurred opportunistically between November 2019 and March 2021, with all GTs caught within the lagoon (approximately 26–31°C water temperature) of the Alphonse Atoll. GTs in the Alphonse Island Group fishery are almost exclusively caught by fly fishing (Fig. 1a) as part of the angling-based tourism operations of the Alphonse Fishing Company and Blue Safari Seychelles. Our study solely focused on GTs caught via fly fishing equipment (12 wt fly rod and reel, single hook barbless flies 6/0–10/0), except for a reference group that was captured using heavy handline (113 kg monofilament line, single hook barbed 20/0 circle hooks) baited with miscellaneous fish carcasses. GTs were targeted and caught by experienced fishing guides on a ~ 5 m vessel. When captured, fish were fought (when using fly fishing equipment), landed, and handled (pre-treatments) like as they would be in a typical chartered fishing trip.

For each fish, angling time, measured as the amount of time (in seconds) from hooking to landing, and release, was recorded. Once captured, each GT remained submerged in water, held in a mesh cradle, for processing. Hook placement (e.g., jaw or corner of the mouth, roof of the mouth, tongue, gills, esophagus), relative degree of hooking damage, e.g., minimal tissue injury to excessive tissue tearing and/or bleeding, and relative degree of difficulty removing the hook e.g., not difficult with minimal hook removal time (< 5 s), moderately difficult with additional hook removal time (≥ 5 and < 30 s), or very difficult with excessive hook removal time (≥ 30 s), were observed and, subsequently, informed a hooking impact score ranging from mild, moderate, to severe. GT were measured (fork length, FL, to the nearest cm). At this point, an accelerometer biologger data package (Gulf Coast Data Concepts X16-mini, Waveland, Mississippi, USA) was temporarily affixed using elastic bands to the caudal peduncle of the GT (see Holder et al., 2020), to measure post-release activity (see below). Attaching the accelerometer biologger package took less than 30 s

Fly angled GT were randomly assigned to one of three air exposure treatments (0, 10, and 30 s), while all handlined GT remained submerged (0 s of air exposure) during handling. RAMP (Davis, 2010) was assessed at the time of release for each GT. Five reflex indicators were used: 'head complex', the presence of steady operculum beats during handling; 'vestibular ocular response', the tracking and rolling of the eye as the orientation of the fish changes; 'body flex', the presence of flexion in the torso (within 3 s) when a fish is held along the dorsoventral axis; 'tail grab', the presence of burst swimming action when a fish is grabbed by the caudal peduncle (within 3 attempts); and, 'equilibrium', the ability of the fish to right itself within three seconds after being placed upside down in water. These indicators were chosen due to their simplicity of use and their previous validation in physiological and behavioral impairment studies in other species, e.g., bonefish (*Albula vulpes)* (Brownscombe et al., 2015, 2013) and permit (*Trachinotus falcatus*) (Holder et al., 2020). For individual indicators, binary RAMP scores of 0 (reflex absent) and 1 (reflex present) were used. Indicator scores were then converted to a proportional RAMP impairment score ranging from 0 to 1, where a cumulative score of 1 indicated no overall impairment and a score of 0 indicated total reflex impairment.

2.3. Post-release activity

The accelerometer logger package affixed to GT (Fig. 1b) was tethered to an offshore fishing rod and reel (54 kg braided line), that was put in the free-spool setting when the GT was released. In all cases, tracking occurred from a boat to ensure there was as little resistance as possible on the tether. After a 15 min tracking and observation period, the drag on the reel was engaged and used to apply enough tension to break the elastics and release the accelerometer logger package from the GT so that it could be retrieved and the data downloaded (Chhor, 2021; Holder et al., 2020; LaRochelle et al., 2021; Lennox et al., 2018). Due to coral heads within the lagoon, on four occasions, the tether line became tangled on coral heads, forcing the trial to end before the desired 15 min monitoring period.

2.4. Data processing and analyses

All processing and analyses were conducted using RStudio (v. 1.4.953, R Core Team, Boston, MA) and the level of significance was set at $p \leq 0.05$. Unless indicated otherwise, values are presented as mean $\pm$ 1 standard deviation (SD). Statistical assumptions were evaluated (Zuur et al., 2010) and if violated, non-parametric methods were implemented. For any analyses involving inferential models, Akaike information criterion aided in all covariate selection and assumptions were evaluated for all models. R packages for data comparisons, wrangling, and visualizations/tables included rstatix (Kassambara, 2019), dplyr (Wickham et al., 2015), lubridate (Spinu, 2016), data.table (Dowle et al., 2019), ggplot2 (Wickham, 2011), and sjplot (Lüdecke, 2018).

2.4.1. Angling metrics

Differences in body size (via FL) of GT were tested across gear types and fly angled air exposure treatments using a Welch two sample t-test and a one-way ANOVA, respectively. Differences in fight times across gear types and across 0 s air exposed groups (handline vs. fly angled) were assessed via Wilcoxon-rank-sum tests, and also among the three fly angled treatment groups using a Kruskal Wallace Test. Pearson's r correlations between fight time and fish length were calculated separately for GTs captured via handline and fly fishing. To examine the frequency of hooking location and impact among each gear type, we converted each category into percentages.

2.4.2. Reflex indices

Differences in GT proportional RAMP scores were tested across gear types, 0 s air exposed groups (handline vs. fly angled), and fly angled air exposure (0, 10, 30 s) treatments using a Wilcoxon-rank-sum tests and a Kruskal Wallace Test, respectively. Each RAMP indictor was also examined individually amongst treatments, and RAMP scores were compared relative to post-release behaviors of observed impaired fish.

We then grouped handlined GTs and fly angled fish with 0 s air exposure to isolate and examine the effect of fight time on reflex indices. The effect of fight time on RAMP scores were evaluated using a generalized linear model with a binomial distribution, via the glmmTMB function in the glmmTMB package (Magnusson et al., 2017). Subsequently, to best represent realistic angling conditions specific to C&R fisheries, we generated additional models only using data from GT captured via fly fishing. Here, using the covariates, fight time and air exposure, we implemented generalized linear models to examine their effect(s) on RAMP. Generalized linear models were implemented using air exposure defined at the treatment levels (0, 10, 30 s) and as a binary categorical factor; i.e., exposed or not exposed. Further, models were implemented with the covariates listed as interaction terms, additive terms, and as singular terms alone.

2.4.3. Post-release activity

For post-release accelerometer data, the raw acceleration values were converted to units of g (equal to 9.81 m s^{-2}) by dividing each axes (x, y, and z) by 2048 (standard conversion factor for the loggers). For each axis, static acceleration was calculated using a 2 s box smoother (Brownscombe et al., 2018) using the *rollmean* function in the R package zoo (Zeileis et al., 2014). Subsequently, the dynamic acceleration (g) value for each axis was derived by subtracting static acceleration values from the raw detection values. Then, overall dynamic body acceleration (ODBA; g), a reliable measure of overall animal activity levels (Brownscombe et al., 2018; Gleiss et al., 2011), was then calculated by summing the absolute values of dynamic acceleration in each axis (Gleiss et al., 2011) and the mean was calculated at each minute post-release. Subsequently, the correlation between overall ODBA values and RAMP scores were also assessed for both gear types.

Differences in ODBA were tested across gear types, 0 s air exposed groups (handline vs. fly angled), and fly angled air exposure (0, 10, 30 s) treatments with a Welch two sample t-test and a one-way ANOVA, respectively. Then, using linear models, via the lm function in the RStudio base platform (v. 1.4.953, R Core Team, Boston, MA), we tested the effect of fight time on post-release activity by, again, grouping handlined GTs and fly angled fish with 0 s air exposure. The effect of the interaction, minutes post-release and fight time, on averaged ODBA values per three-minute intervals (ordinal factor) was also tested using a linear mixed effects model with trial ID as the random effect, via the lmer function in the lme4 package (Bates et al., 2015).

Subsequently, like in Section 2.4.2, using only data from GT captured via fly fishing, we used linear models to examine the effects of fight time and air exposure on ODBA. Again, models were implemented using air exposure defined at the treatment levels (0, 10, 30 s) and as a binary categorical factor; i.e., exposed or not exposed and models were implemented with the covariates listed as interaction terms, additive

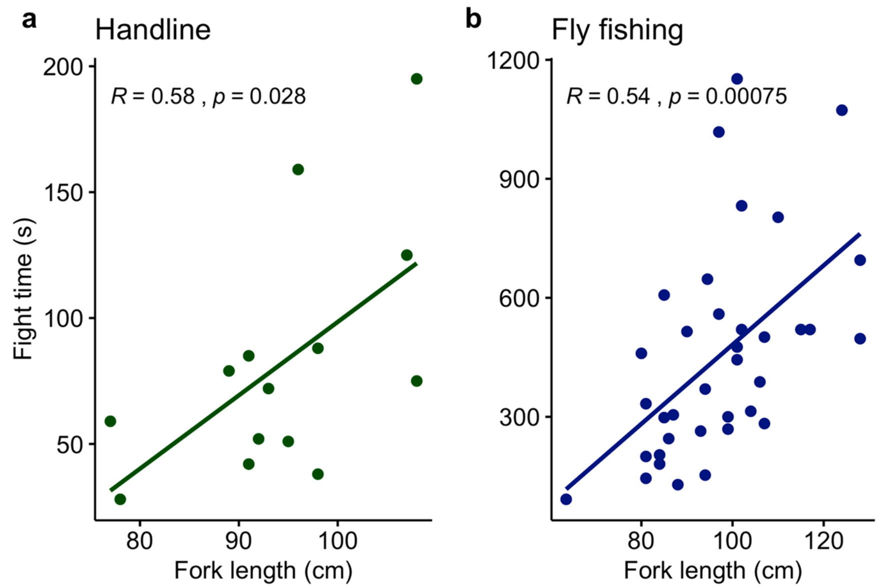

Fig. 2. Relationship between fight time and fork length for giant trevally captured via a) handline and b) fly fishing. Pearson's r correlation coefficients (R) and corresponding p-values are shown in the upper left panels and a linear regression line was plotted for each panel, respectively.

terms, and as singular terms alone.

To test if a relationship existed between ODBA and time after release in relation to air exposure and fight time, we fit two separate additive linear mixed effects models (one for air exposure at the treatment levels and another for air exposure as a binary categorical factor) that included the interaction of minutes post-release (aggregated by three-minute intervals) and trial ID as the random effect. Finally, for each gear type, the relationship of ODBA across the monitoring period was evaluated with the covariate minutes post-release (ordinal factor at three-minute intervals) alone.

ANOVAs were subsequently used for linear models and linear mixed effects model to identify any significant predictors and, if detected, a Tukey post-hoc test via the glht function in the multcomp package (Hothorn et al., 2016), was used to compare differences.

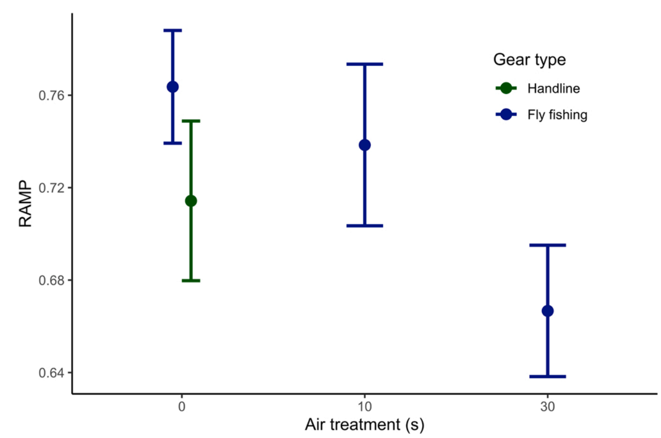

Fig. 3. Reflex action mortality predictors scores for giant trevally by air exposure treatment (0 s, 10 s, and 30 s) and capture method (green = handline, blue = fly fishing). Mean and 95% confidence are shown.

3. Results

3.1. Angling metrics

A total of 50 GT were caught for the study in the Alphonse Island lagoon; 36 were by fly fishing, and 14 were hooked by heavy handline and quickly landed (i.e., reference). GTs caught by fly angling ranged in size from 63.5 to 128 cm FL (97.1 ± 14.3 cm), and GT caught by handline ranged from 77 to 108 cm FL (94.4 ± 9.6 cm), and there was no significant difference in body size between capture methods ($t(35.52) = -0.79$, $p = 0.44$). There was no significant difference in body size of GT among the 0 s, 10 s, and 30 s air exposure treatments ($F(2, 47) = 0.11$, $p = 0.9$). Fight times for handlined GTs (82 ± 48 s) were significantly shorter than fly angled fish (453 ± 267 s; $W = 10$, $p < 0.001$), including fly angled GTs in the 0 s air exposure treatment (463 ± 272 s) ($W = 3$, $p < 0.001$). Fight times among the three fly angled treatments (0 s of air, 463 ± 272 s fight time; 10 s, 433 ± 258 s; 30 s, 466 ± 292 s) were not significantly different ($H(2) = 0.13$, $p = 0.94$). Fight time was positively correlated with body size for GTs captured via handlined ($r(12) = 0.58$, $p = 0.03$) and those captured via fly fishing ($r(34) = 0.54$, $p < 0.001$) (Fig. 2).

Fly angled GT ($n = 36$) were hooked in the jaw or corner of the mouth ($n = 30$, 83.3%), the roof of the mouth ($n = 2$, 5.6%), the tongue ($n = 1$, 2.8%), or deeply hooked in the back of the mouth ($n = 3$, 8.3%). Handlined GT ($n = 14$) were hooked in the jaw or corner of the mouth ($n = 12$, 85.7%), the tongue ($n = 1$, 7.1%), or deeply hooked in the back

Table 1
Summary of reflex action mortality predictors (RAMP) scores and associated angling characteristics for giant trevally across the treatments separately and combined. Averaged predictor metrics include head complex (HC), vestibular ocular response (OV), body flex (BF), tail grab (TG), and equilibrium (EQ).

Gear	Air	n	RAMP mean	RAMP sd	Hook impact mean	Hook impact sd	Fight time mean	Fight time sd	HC	OV	BF	TG	EQ
combined	NA	50	0.72	0.11	1.24	0.52	349.20	282.32	1	1	0.52	0.08	0.98
handline	0	14	0.71	0.13	1.21	0.58	82.00	47.71	1	1	0.57	0.07	0.93
fly	0	11	0.76	0.08	1.18	0.40	463.00	272.31	1	1	0.73	0.09	1.00
fly	10	13	0.74	0.13	1.08	0.28	433.23	258.40	1	1	0.54	0.15	1.00
fly	30	12	0.67	0.10	1.50	0.67	465.58	291.85	1	1	0.25	0.00	1.00

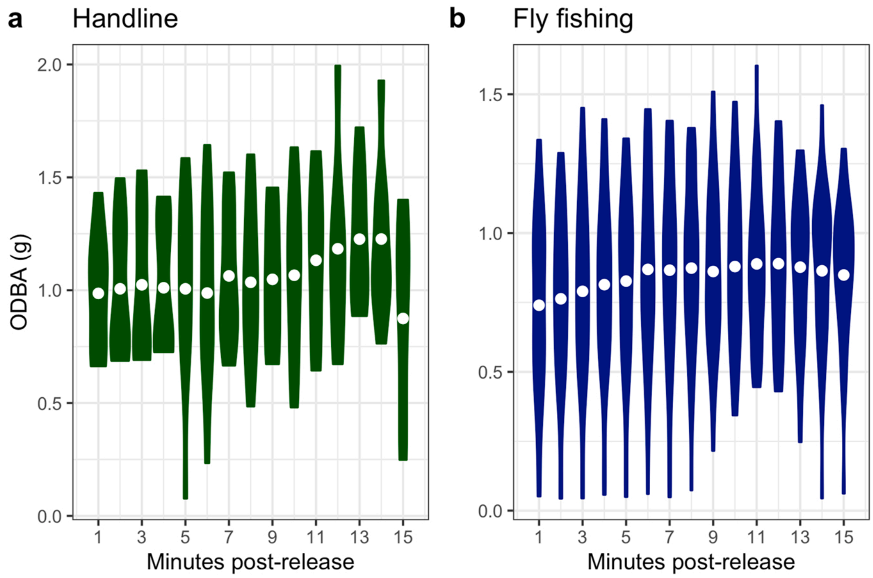

Fig. 4. Violin plots highlighting the distribution of averaged overall dynamic body acceleration (ODBA) aggregated across each minute post-release for giant trevally captured via (a) handline and (b) fly fishing. Means are shown for each minute (white dots).

of the mouth (n = 1, 7.1%). The majority of hooking impact were ranked as mild (fly, n = 28, 77.8%; handline, n = 12, 85.7%) or moderate (fly, n = 7, 19.4%; handline, n = 1, 7.1%). For all GTs captured, only two ranked as severe and both of these GT were deeply hooked (fly, n = 1, 5.6%; handline, n = 2, 14.3%).

3.1.1. *Reflex indices*

Proportional RAMP scores (0: fully impaired, 1: fully un-impaired) ranged from 0.4 to 1.00 (0.72 ± 0.11) across all treatments and gear types (Table 1, Tables A1). There was no difference in the GT RAMP scores between handlined (0.71 ± 0.13) and fly angled (0.72 ± 0.11) fish (W = 225, p = 0.95) or between handlined GT and fly angled fish that were not exposed to air (W = 62.5, p = 0.33). Though it was near significant and behavioral impairment for fly angled GTs appeared to increase with air exposure (Fig. 3), there were only weak evidence that air exposure had an effect on RAMP (H(36) = 5.2, p = 0.07, eta-squared = 0.1).

Tail grab (0.08 ± 0.27) and body flex (0.54 ± 0.5) were impaired most commonly, while head complex and vestibular ocular response were never impaired. Equilibrium only failed in one trial involving a handlined GT (108 cm FL) that was hooked deeply near the gills with a hooking impact score noted as "severe". Upon release, this fish lost equilibrium and briefly floated until weakly swimming as it descended. This individual was the only observed potential immediate mortality of the total 50 trials, and had the lowest RAMP score (0.4). The only other deeply hooked GT occurred via fly fishing (86 cm FL), had a RAMP score of 0.6, and was the only fish in our study observed pursued by a shark post-release, however no predation event was observed.

For GT with 0 s air exposure (both handline and 0 s air exposure fly angled GTs) there was no effect of fight time on RAMP (z = 0.57, p = 0.57). For fly angled GTs only, there was also no effect of fight time and/or air exposure (at treatment levels or as a binary factor) across all model variations on RAMP (Tables A1).

3.1.2. *Post-release activity*

Across trials, ODBA values (averaged across minutes post-release)

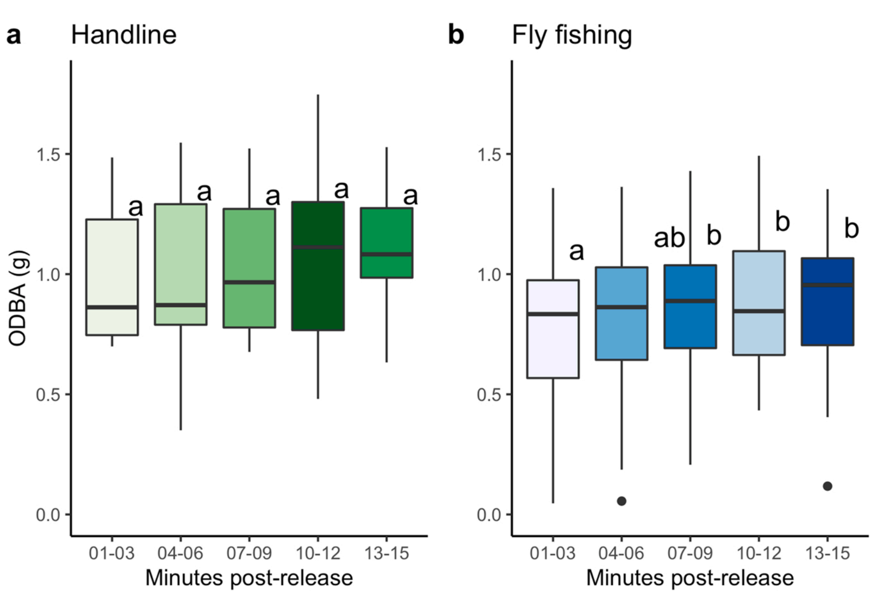

Fig. 5. Overall dynamic body acceleration (ODBA) for giant trevally across three-minute intervals post-release and for giant trevally captured via a) handline and b) fly fishing. Boxes indicate 25th and 75th percentiles with horizontal lines and color darkness indicating the median and whiskers show upper and lower extremes with outliers as dots. Letters represent the results of a Tukey post-hoc test, with the differing letters indicating significant dissimilarities in ODBA at the respective intervals.

ranged from 0.18 to 1.49 g (0.89 ± 0.3 g) with individuals demonstrating variable responses in ODBA after release (Fig. A1). There was no correlation between ODBA and RAMP scores for handlined ($r(9) = 0.35$, $p = 0.35$) or fly angled ($r(27) = -0.4$, $p = 0.85$) fish. There was also no difference in the ODBA between handlined (1.03 ± 0.32 g, Fig. 4a) and fly angled (0.85 ± 0.29 g, Fig. 4b) fish ($t(12.51) = 1.5$, $p = 0.16$) or between handlined GT and fly angled fish that were not exposed to air (0.82 ± 0.29 g) ($t(15) = 1.41$, $p = 0.18$). There was also no differences in average ODBA values across fly angled air exposure groups ($F(2, 24) = 1.09$, $p = 0.35$).

For GT with 0 s air exposure (both handline and 0 s air exposure fly angled GTs) there was no effect of fight time on ODBA ($F(1,15) = 0.34$, $p = 0.57$); and there was also no effect of the interaction, fight time and minutes post-release, on ODBA ($F(4, 132.18) = 0.48$, $p = 0.75$). For fly angled GTs only, there was also no effect of fight time and/or air exposure (at treatment levels or as a binary factor) across all model variations on ODBA (Tables A2). Further, there was no interactive effect on ODBA across time when using the interaction of minutes post-release with air exposure at the treatment level ($F(8, 124.04) = 0.63$, $p = 0.75$) and fight time ($F(4, 124.16) = 0.8$, $p = 0.52$). Using the same model but with air exposure as a binary factor (exposed vs. not exposed), there was, again, no effect of air exposure ($F(4, 128.01) = 0.81$, $p = 0.52$) or fight time ($F(4, 128.15) = 0.82$, $p = 0.52$).

Using minutes post-release (aggregated by three minute intervals) as a covariate alone, the difference in ODBA across the post-release monitoring period was not a significant for GTs captured via handline ($F(4, 30.03) = 0.47$, $p = 0.75$, Fig. 5a) but was significant for those captured via fly gear ($F(4, 102.03) = 5.91$, $p < 0.001$, Fig. 5b). Specifically, for those captured by fly gear, ODBA values across the first several minutes of monitoring (1–3 min) were significantly lower than the last three time intervals of monitoring (7–9 min: $z = -3.35$, $p = 0.01$; 10–12 min: $z = -4.37$, $p = < 0.001$; 13–15 min: $z = -3.77$, $p = 0.01$) (Fig. 5b).

4. Discussion

Overall, we found that GT caught via fly fishing displayed no significant differences in reflex impairment and post-release activity relative to being captured via handline and across a range of air exposures. For fish not air exposed at all, there was also no detectable differences in outcome between GT caught via fly fishing and a reference group rapidly landed using a heavy handline. Across all treatments and the reference group, immediate post-release mortality was low (2%) and linked to hooking in critical locations. Combined, our results suggest that under the conditions tested, GTs are relatively resilient to the negative effects often imposed by capture and handling.

Severe hooking injuries have been shown to impede fish survival. This is especially true when deep hooking occurs and results in internal esophageal and/or organ tissue damage (e.g., gills, stomach) (Arlinghaus et al., 2007; Bartholomew and Bohnsack, 2005; Cooke et al., 2012; Muoneke and Childress, 1994; Schaefer, 1989). While we were unable to assess any long-lasting sublethal impacts (e.g., feeding impairment) from hooking injury, of the 50 trials in this study, only one GT (2%) was documented as a potential mortality after losing its equilibrium at and after release, and this fish was deeply hooked near the gills. The only other fish that was deeply hooked was pursued by a lemon shark post-release (the only incidence of predatory activity for all 50 fish caught and released in our study). Our low incidence of deep hooking and high rate of survivorship is likely in part due to our use of circle hooks when the handline was used, and active fishing practices since both have been shown to reduce injury and mortality rates (Cooke and Suski, 2004; Lennox et al., 2015; Meyer and High, 2010; Schill, 1996; Sullivan et al., 2013). In a closely related Carangidae species, pompano (*Trachynotus ovatus*), Alós et al. (2008) found that when circle hooks were combined with active angling practices, there were no instances of mortality or deep hooking. However, under passive angling conditions and regardless of hook type, Alós (2009) documented a 24.1% post-release mortality rate for pompano and was largely attributed to deep hooking injury. Overall, deep hooking is likely negligible when fly fishing for GT due to a combination of active hook setting by anglers and because of how GTs aggressively strike flies.

Air exposure and fight time can also have a compounding effect on the stress response of captured and released fish (Barton et al., 1986). Driven by anaerobic metabolism, fish are landed when they are no longer able to resist (Kieffer, 2000). Subsequently, when captured individuals are exposed to air exposure, cardiac disturbances along with physiological homeostasis disruptions occur (Cooke et al., 2002b; Cooke and Suski, 2005). Collectively, depending on the duration and species, these factors can lead to an array of lethal and sub-lethal effects (Cook et al., 2015; Cooke and Suski, 2005). For example, Schreer et al. (2005) reported that following 120 s of air exposure, multiple brook trout (*Salvelinus fontinalis*) exhibited ~75% reduction in swimming performance across three months of monitoring. In another example, although also related to temperature, Richard et al. (2013) demonstrated that when Atlantic salmon (*Salmo salar*) were exposed to up to 10 s of air, offspring production was significantly reduced, with further reductions as air exposure increased. In our study, while there was only weak evidence that air exposure influences reflex impairment, we found no significant differences (at the statistical alpha level set at 0.05) between air exposure and/or fight time on GT impairment in terms of reflexes or overall post-release activity. Ultimately, these data suggest short-term effects of air exposure and extended fight times are minimal. These results were similar with Holder et al. (2020), who assessed the C&R suitability of another related Carangidae species, the Atlantic permit (*Trachinotus falcatus*), and found physiological stress responses (blood lactate, glucose, pH), behavioral impairment (RAMP), and post-release activity (accelerometer loggers) did not differ between durations of air exposure (zero- vs. two-minutes) and/or fight time. Collectively, our results and those from Holder et al. (2020) may demonstrate that physiological and behavior impairment from angling may be minimal for Carangidae species that are captured by active angling techniques with species-appropriate fishing gear.

Beyond hooking injury and post-release behavior impairment, predation events during (i.e., depredation) or after the angling event may be detrimental to the sustainability of a C&R fishery. For example, while Holder et al. (2020) reported minimal physiological and behavior impairment of Atlantic permit following release, depredation rates in spawning areas that coincided with high predator densities were concerning with sometimes 50% of all permit hooked being depredated. Although predator density was low in the selected study site and depredation for GT was not observed, if predator burdens become high, GT may be susceptible to predation events regardless of their resiliency to the effects of C&R angling. Further, considering activity levels for fly angled GT were suppressed for several minutes after release, they could also be vulnerable to post-release mortality if greater physical injury and sub-lethal impacts occur (Bartholomew and Bohnsack, 2005). For example, Danylchuk et al. (2007) documented that for bonefish (*Albula vulpes*) that lost equilibrium, often corresponding to air exposure duration, were six times more likely to be predated than those that did not lose equilibrium. While depredation and post-release predation (within 15 min) in our study site was not an issue, there have been occasional but rare recorded depredations in nearby areas within the Alphonse Group. Further, considering GT are known to form large spawning aggregations (Daly et al., 2018) that have increased predator densities (Daly et al., 2014), future assessments are warranted elsewhere.

Globally, the GT recreational fishery is diverse spanning several gear types (e.g., fly, conventional/spin, handline), lure (e.g., jigs, poppers) and bait types, and across a wide range of habitats (e.g., shallow flats, along reefs, pelagic environments). For GT fisheries that exclusively or sometimes use bait (e.g., Amarasinghe et al., 2011; Friedlander and Dalzell, 2004), anglers that rely on passive fishing approaches, may result in higher frequencies of deep hooking and instances of mortality.

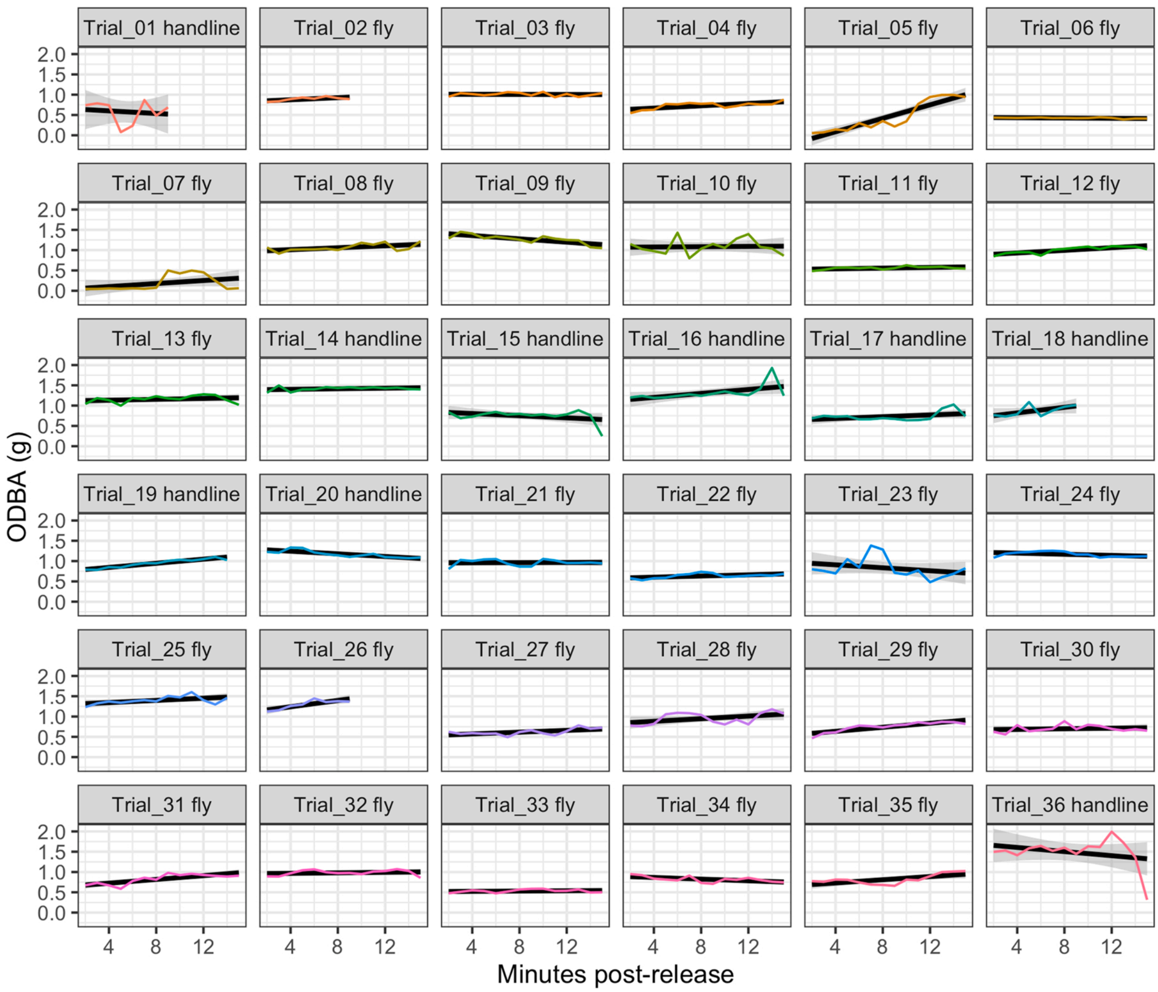

Fig. A1. Overall dynamic body acceleration (ODBA) for giant trevally across minutes post-release for each trial. Color lines connect averaged OBDA per minute values and linear trends are shown via black lines with 95% confidence intervals shaded. The capture gear type is shown at the top of each panel for all trials.

In GT spin fishing-oriented fisheries, anglers often use large (10–30 cm) double (front and back) treble hooked poppers. While not evaluated in this study, the use of treble hooked lures and their effects on GT should be examined since these hooks are likely to become embedded in sensitive locations that may be detrimental to fish survival, e.g., foul hooked, gills, and/or eyes (Trahan et al., 2021). Beyond injury related to gear choice, GT may also be susceptible to other angling and handling stressors and require additional research, especially in GT fisheries where fish are routinely landed out of water, e.g., onto the shore or boats. Within this fishery, handling is routinely done by experienced fishing guides and in the water with care to not damage sensitive locations, thus, this study likely represents a best-case scenario in terms of initial handling. However, since this fishery requires catch-and-release of GT, individuals may be repeatedly caught which has unknown consequences on the animal's physiology and, in turn, their fitness (Cooke et al., 2013). Further, angler presence may affect fish behaviors and space use, either through increased angler presence and encounter rates (see Lennox et al., 2017) or by other stimuli, e.g., boat noise (Jacobsen et al., 2014).

Ultimately, regardless of the GT fishery in question, anglers should adopt or continue to use best handling practices, e.g., minimizing air exposure and handling time (Brownscombe et al., 2017; Casselman, 2005). This may be especially critical for C&R fisheries since excessive fishing pressure can induce "timidity" (see Arlinghaus et al., 2017) and lead to learned hook avoidance with declines in catch (Askey et al., 2006; Fernö and Huse, 1983; Klefoth et al., 2012). Considering GT wariness has been reported within the Alphonse Island Group (Griffin et al., 2021) and best handling practices have already been strictly enforced (e.g., barbless hooks, minimizing fight times, air exposure, and handling time) and that this study suggests high survival rates are expected, learned hook avoidance by GT may be occurring. Supporting this hypothesis, as fishing operations continue to expand to less-pressured islands in the Seychelles, initial catch rates were found to be relatively high compared to that of the established GT fishery surrounding the Alphonse Island Group. Thus, rotating, displacing, or reducing angling pressure (e.g., number of anglers, boats, temporary closures, etc.) may be required to ensure sustainability into the future. Although unknown in the case of GT, ultimately, fish vulnerability to capture by hooks can either decline or remain the same over time (see Lennox et al., 2017). While mark-and-recapture could shed light on GT vulnerability, best handling practices to improve recovery time and to minimize unquantifiable stress or memory of angling events could benefit C&R GT fisheries.

Although statistical power is relatively low with small sample sizes, RAMP, ODBA values, and anecdotal observations collectively suggested GT are resilient to the angling effects tested. While this study's results are positive for the outlook of C&R GT fisheries, it should be noted that this study evaluated short term (15 min) post-release activity and survivorship, and there may be unknown delayed sub-lethal effects that could lead to post-release mortality days to weeks after release. For example, Kneebone et al. (2021), using survivorship pop-up satellite archival tags on yellowfin tuna (*Thunnus albacares*), reported that 75%

Table A1
Model summary outputs for models that included giant trevally reflex action mortality predictors (RAMP) scores as the dependent variable and a) fight time (s) and/or air exposure (0, 10, 30 s), or b) fight times (s) and/or air exposure (exposed vs. not exposed) as the independent variable(s).

a)

	RAMP			RAMP			RAMP			RAMP		
Predictors	*Estimate (± SE)*	*z*	*p*	*Estimate (± SE)*	*z*	*p*	*Estimate (± SE)*	*z*	*p*	*Estimate (± SE)*	*z*	*p*
Intercept	2.25 (0.75)	2.43	0.015	3.23 (1.03)	3.69	< 0.001	2.76 (1.20)	2.34	0.019	2.55 (1.65)	1.45	0.148
Fight time	1.00 (0.00)	0.50	0.618				1.00 (0.00)	0.52	0.600	1.00 (0.00)	0.41	0.679
Air (10 s)				0.87 (0.37)	-0.32	0.751	0.88 (0.38)	-0.29	0.769	0.87 (0.75)	-0.16	0.869
Air (30 s)				0.62 (0.26)	-1.14	0.253	0.62 (0.26)	-1.15	0.252	0.76 (0.64)	-0.33	0.742
Air (10 s):Fight time										1.00 (0.00)	0.03	0.975
Air (30 s):Fight time										1.00 (0.00)	-0.28	0.782
R^2 conditional / R^2 marginal	NA / 0.002			NA / 0.012			NA / 0.015			NA / 0.017		
AIC	82.990			83.786			85.500			89.367		

b)

	RAMP			RAMP			RAMP			RAMP		
Predictors	*Estimate (± SE)*	*z*	*p*	*Estimate (± SE)*	*z*	*p*	*Estimate (± SE)*	*z*	*p*	*Estimate (± SE)*	*z*	*p*
Intercept	3.23 (1.03)	3.69	< 0.001	2.25 (0.75)	2.43	0.015	2.80 (1.21)	2.37	0.018	2.55 (1.65)	1.45	0.148
Air (exposed)	0.74 (0.27)	-0.82	0.412				0.74 (0.28)	-0.81	0.418	0.84 (0.63)	-0.23	0.817
Fight time				1.00 (0.00)	0.50	0.618	1.00 (0.00)	0.48	0.632	1.00 (0.00)	0.41	0.679
Air (exposed):Fight time										1.00 (0.00)	-0.19	0.847
R^2 conditional / R^2 marginal	NA / 0.006			NA / 0.002			NA / 0.008			NA / 0.009		
AIC	82.558			82.990			84.319			86.282		

of the mortality events likely occurred via predation between 7 and 30 days post-release. Additional research is warranted surrounding GT post-release behavior impairment, survival, and predation with extended monitoring periods beyond 15 min, especially in other GT fisheries that have different gear types, handling standards, and predator densities. Further, within the context of evaluating angling impacts, the methodology of measuring and interpreting differences in locomotor activity estimates are relatively new (Brownscombe et al., 2013; Holder et al., 2020; LaRochelle et al., 2021; Lennox et al., 2018). Although the use of ODBA to test for post-release impairment is promising, it would be prudent to continue to evaluate the use of ODBA in other C&R oriented fisheries, especially for those that are known to be sensitive to angling events.

4.1. *Conclusions*

With only one potential immediate mortality, we found GT were relatively resilient to angling events and suggest post-release survivability is high. Overall, these findings are encouraging for GT C&R fisheries, as well as for other recreational/subsistence GT fisheries where many fish are released due to fish size restrictions related to harvest (e.g., in Hawaii, Grabowski and Franklin, 2017). In the Alphonse Island Group, we recommend the adoption or continued implementation of best handling practices (Brownscombe et al., 2017) to potentially help recovery time and to mitigate hook learning or timidness (Arlinghaus et al., 2017). Additional management strategies may be warranted to ensure the catchability of GT, and thus, the sustainability of the fishery

Table A2
Model summary outputs for models that included giant trevally overall dynamic body acceleration (ODBA) values as the dependent variable and a) fight time (s) and/or air exposure (0, 10, 30 s), or b) fight times (s) and/or air exposure (exposed vs. not exposed) as the independent variable(s).

a)

	ODBA			ODBA			ODBA			ODBA		
Predictors	*Estimate (± SE)*	*z*	*p*	*Estimate (± SE)*	*z*	*p*	*Estimate (± SE)*	*z*	*p*	*Estimate (± SE)*	*z*	*p*
Intercept	0.66 (0.11)	6.11	< 0.001	0.67 (0.13)	5.34	< 0.001	0.62 (0.22)	2.84	0.010	0.82 (0.10)	8.14	< 0.001
Fight time	0.00 (0.00)	2.02	0.055	0.00 (0.00)	1.84	0.079	0.00 (0.00)	1.01	0.323			
Air (10 s)				-0.08 (0.13)	-0.63	0.536	-0.20 (0.28)	-0.70	0.492	-0.05 (0.14)	-0.38	0.705
Air (30 s)				0.08 (0.14)	0.62	0.542	0.33 (0.29)	1.15	0.263	0.14 (0.14)	0.99	0.331
Air (10 s):Fight time							0.00 (0.00)	0.37	0.717			
Air (30 s):Fight time							-0.00 (0.00)	-0.84	0.408			
R^2 / R^2 adjusted	0.140 / 0.106			0.200 / 0.096			0.290 / 0.121			0.083 / 0.007		
AIC	10.076			12.106			12.885			13.796		

b)

	ODBA			ODBA			ODBA			ODBA		
Predictors	*Estimate (± SE)*	*z*	*p*	*Estimate (± SE)*	*z*	*p*	*Estimate (± SE)*	*z*	*p*	*Estimate (± SE)*	*z*	*p*
Intercept	0.66 (0.11)	6.11	< 0.001	0.66 (0.13)	5.19	< 0.001	0.82 (0.10)	7.97	< 0.001	0.62 (0.23)	2.70	0.013
Fight time	0.00 (0.00)	2.02	0.055	0.00 (0.00)	1.95	0.063				0.00 (0.00)	0.96	0.346
Air (exposed)				-0.01 (0.12)	-0.05	0.958	0.04 (0.12)	0.31	0.761	0.04 (0.27)	0.16	0.872
Air (exposed):Fight time										-0.00 (0.00)	-0.21	0.836
R^2 / R^2 adjusted	0.140 / 0.106			0.140 / 0.068			0.004 / − 0.036			0.142 / 0.030		
AIC	10.076			12.073			14.044			14.021		

(Adams, 2017). Considering fishing for GT will continue to increase globally, minimizing stress and adaptive management practices will be imperative to ensure GT remain as a suitable C&R species.

CRediT authorship contribution statement

Lucas P. Griffin, Andy J. Danylchuk, and Steven J. Cooke designed the study. Lucas P. Griffin, Gail Fordham, George Curd, Christopher Narty, and Andy J. Danylchuk conducted the field work. Lucas P. Griffin and Jacob W. Brownsombe analyzed the data. All authors interpreted the findings, wrote the manuscript, and approved the final version.

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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Appendix

(See here: Appendix Fig. A1 and Tables A1, A2).

Short-term response of giant trevally (*Caranx ignobilis*) to capture and handling in a catch-and-release fly fishing recreational fishery, Republic of the Seychelles, Western Indian Ocean.

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