Environ Biol Fish (2026) 109:45
https://doi.org/10.1007/s10641-026-01811-1

Hooking injury, physiological stress, and post-release activity patterns of giant trevally (*Caranx ignobilis*) captured using spinning gear in a catch-and-release recreational fishery

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Received: 5 November 2025 / Accepted: 5 February 2026

Abstract Giant trevally (*Caranx ignobilis*; GT) is an apex predator in tropical waters of the Indo-Pacific and a target species of catch-and-release recreational fisheries, and little is known about the impacts that capture and handling have on GT. We evaluated the injury, physiological status, and post-release behavior of 73 GT caught using spinning gear with top-water lures that had different hook configurations in Kiritimati, Republic of Kiribati. GT caught using lures with a single J-hook or single treble hook were most often hooked in the mouth, while those caught on lures with two hooks (regardless of hook type) were more often hooked in the body. Unhooking difficulty and physical injury were greater for GT simultaneously hooked in both the mouth and body, particularly with lures having double treble hooks. Duration of air exposure increased when GT were captured on lures with one or two treble hooks and for larger fish. There was no mortality of GT at the time of release. Impairment of reflexes, particularly the ability to maintain equilibrium and bursting response, increased with fight time and duration of air exposure. Physiological measurement suggests that glucose and lactate levels increased with fight time, but only glucose increased with air exposure duration. GT tracked with pop-off biologgers showed consistent behavioral patterns including a short period (~5 min) of low activity. Collectively, these results provide the first quantitative evidence of how GT respond to catch-and-release when caught with conventional tackle and thus can be used to inform best practices and management strategies.

Keywords Recreational fisheries · Catch-and-release · Pacific Ocean · Hook type · Lures · Reflex impairment

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Introduction

Giant trevally (GT), *Caranx ignobilis* (Forsskål 1775), is one of the largest members of the Carangidae family that occupies tropical and subtropical coastal waters of

Published online: 16 February 2026

the Indo-Pacific (Talbot and Williams 1956; Williams 1958; Berry et al. 1981). This large-gaped piscivore is a highly mobile apex predator (Sudekum et al. 1991; Farmer and Wilson 2011) that inhabits tidal lagoons, coral reefs, and adjacent mesopelagic waters (Meyer et al. 2007; Lédée et al. 2015; Papastamatiou et al. 2015; Daly et al. 2019, 2021) and likely plays an important role in tropical island marine ecosystems (Glass et al. 2020). The spatial ecology of GT makes them accessible to encounters with humans, especially as targets of subsistence, commercial, and recreational fisheries, which makes them culturally and economically important for communities across their home range (Abdussamad et al. 2008; Gaffney 2000; Verschuuren et al. 2015).

The allure of targeting GT in recreational fisheries has increased dramatically over the past few decades (McLeod 2016). The aggressiveness of the strike, intensity of the fight, and potential size of GT can be attractive to recreational anglers (McLeod 2016). With global travel becoming safer and more reliable, remote and exotic locations where recreational angling for GT occurs are also becoming more accessible and economically feasible for anglers (McLeod 2016; Griffin et al. 2021). The increased demand for targeting GT and other recreationally targeted fishes has considerable economic value through direct and indirect spending of anglers, the development of hotels and fishing lodges, employment of fishing guides and for hospitality services, and other commerce (Wood et al. 2013). For instance, it was estimated that the flats fishery in The Bahamas was worth $169 million USD annually, with much of the income staying in local communities (Fedler 2014). As such, evidence-based management to help maintain stocks of flats species, like GT, can play an important role in supporting fishing-based tourism and its contribution to the Blue Economy (Barnett et al. 2016).

Most recreational angling for GT is catch-and-release (C&R) (McLeod 2016), which is a strategy adopted by fisheries managers and anglers to minimize the impacts of fishing on target species and their populations. C&R angling can be an effective management tool to conserve fisheries if individual fish being captured survive the angling event with negligible injuries, minimal physiological stress, and no impacts on their fitness (Bartholomew and Bohnsack 2005; Arlinghaus et al. 2007). The growing discipline of C&R science continues to demonstrate that the response of fish to C&R is species-specific (Cooke and Suski 2005) and ranges from high survivorship and no detectable sub-lethal effects (e.g., Bower et al. 2019), to considerable post-release mortality (e.g., post-release predation, Danylchuk et al. 2007), behavioral alterations (LaRochelle et al. 2025b), and extensive sub-lethal impacts, including impaired feeding (Meka and Margraf 2007) and reduced reproductive output (Ostrand et al. 2004; Richard et al. 2013). The effects of C&R can also depend greatly on angler experience (Brownscombe et al. 2017), gear/hook type used (Arlinghaus et al. 2007; Skomal 2007; LaRochelle et al. 2025a), physical injury (Danylchuk et al. 2014; Bower et al. 2016), water temperature (Thorstad et al. 2003), and air exposure (see Cook et al. 2015). Further, the social norms of participants within the recreational angling community can have significant influence on the angling and handling practices (see Danylchuk et al. 2018). As such, if C&R is to be used as a conservation tool, it is imperative that species-specific and even situation-specific science be conducted to evaluate the potential impacts so that knowledge gained from the research can be used to inform best practices in the recreational fishery (Cooke and Suski 2005).

To date, only one study has examined how GT respond to C&R, and it focused on fly fishing (Griffin et al. 2022). Yet, there remains a portion of GT anglers that use spinning gear with artificial lures that are configured with multiple single or treble hooks. Although GT were resilient to being captured and released while fly-fishing, all flies were single barbless hooks warranting further exploration on the impacts of multiple hooks. The purpose of this study was to quantify the hooking injury, physiological status, and post-release activity of GT targeted using conventional spinning gear with artificial lures in the recreational C&R fishery of Kiritimati (Christmas Island), Republic of Kiribati. We used this opportunity to also test a custom pop-off electronic biologging package equipped with an internal data storage tag that could allow for greater insights into fish behavior and activity patterns following C&R. Collectively, the data presented here can be used to inform anglers and fisheries managers on C&R best practices for GT caught with spinning gear and artificial lures.

Methods

Study site and sampling periods

This study took place on Kiritimati Atoll (Fig. 1) (Christmas Island), Republic of Kiribati, which is a part of the Line Island chain in the Indo-Pacific Ocean. The atoll has a large inner lagoon (217 km^2) composed of shallow sand flats and deeper channels (3–5 m), while the outer seaward coast is rimmed by coral reefs that descend rapidly to > 200 m. Fishing for GT occurred predominantly along the western side of the atoll, including just outside of the mouth of the lagoon, and over the coral shelf that extends from the shoreline to the edge of the deep water drop-off. Water depths of sampling areas ranged from 3 to 30 m.

Sampling coincided with trips when recreational anglers were going to Kiritimati to target GT. Their participation in the research was instrumental for providing access to GT caught via authentic angling events, and a way to increase ownership over the outcome of the study and how results get communicated throughout the angling community (Danylchuk et al. 2011). Specifically, sampling occurred over three discrete periods, 07–10 February 2014, 05–10 June 2014, and 29 January–07 February 2015. The sampling period in June 2014 only focused on collecting data on angling metrics, hook placement, and hooking damage (i.e., injury), while sampling during the other periods included assessing physiological stress. Sampling in 2015 was also used to quantify short-term post-release activity patterns and movements of GT using a custom pop-up electronic biologging package (see below).

Capture, blood sampling, and reflex impairment

Recreational anglers used heavy spinning gear (213–244 cm heavy action rods, high-capacity

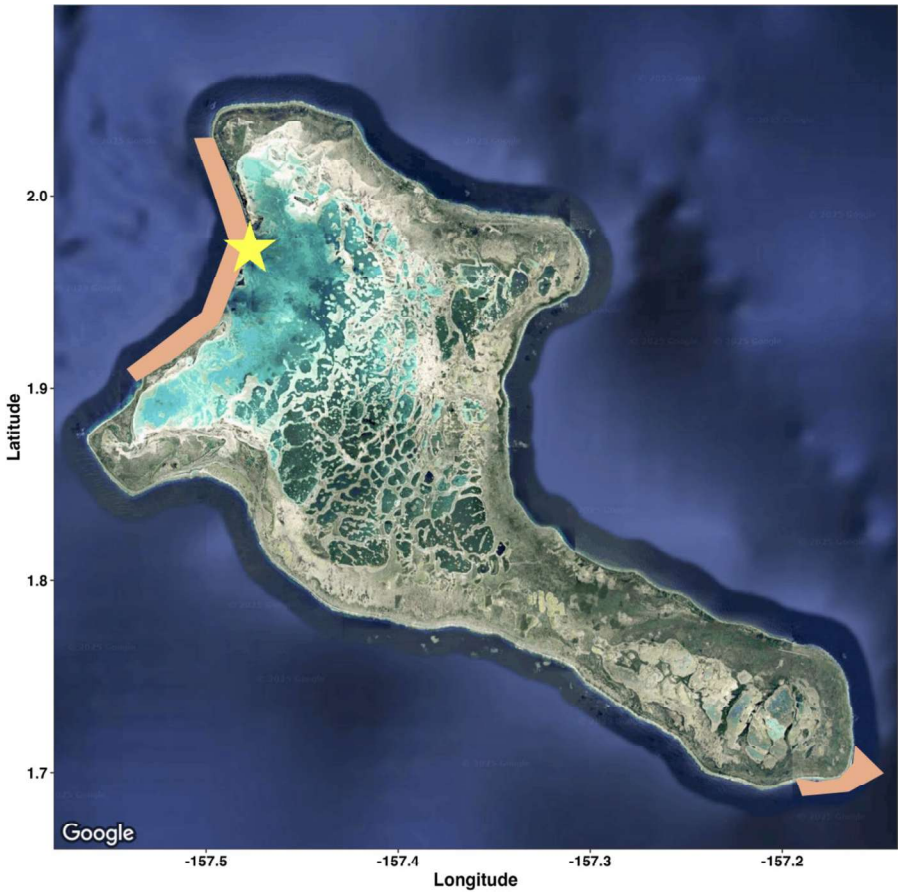


Fig. 1 Image of Kiritimati atoll (Christmas Island) where the study occurred. The peach polygons indicate the general area where giant trevally (*Caranx ignobilis*) were captured and released. The yellow star indicates where the giant trevally were released with custom pop-up biologgers

reels, 34–50 kg braided line) and topwater poppers and stickbaits (100–250 g) to capture GT. Fishing baits were outfitted with either barbed treble hooks (6/0–7/0), barbed single J-hooks (7/0), or a conjunction of both styles (single hook in the middle of the lure and treble at the back of the lure). The array of hook configurations (e.g., style and number of hooks) was always noted. Number of hooks was split into two categories: lures with 3 or less hook points and lureds with 4 or more hook points. The use of barbed hooks is common when using conventional tackle for GTs (McLeod 2016). All fishing was conducted by boat in the coastal waters of the atoll in depths ranging from 4 to 35 m, or just inside the mouth of the lagoon. Anglers casted the large topwater baits while the boat was adrift and used erratic retrievals to entice GT to strike.

For each fish, fight time (the amount of time (seconds) from hooking to landing) was recorded. All GT were brought into the boat for dehooking. To land fish, anglers or fishing guides reached over the side of the boat and used a gloved hand to grab the GT by the caudal peduncle. The other hand was often placed under the ventral portion of the fish's body to support the weight of the GT as it was brought on board the boat. This handling method minimized the GT coming into contact with the side of the boat, as well as kept the fish handler safe from the sharp protrusions on the caudal peduncle and sharp hooks generally located in the mouth and posterior sections of the fish's body. Dehooking occurred once the GT was on board the boat. Pliers were used to remove hooks unless the hooks fell out of the fish on their own when the tension of the fishing line was reduced as the fish was brought on board. Using pliers is common in the GT recreational fishery because of the leverage needed to remove the large hooks, while the use of pliers also reduced the risk of accidental hooking to the angler or guide.

All GT were measured (fork length in mm; FL) and the duration of air exposure during handling was recorded (in seconds). Hook placement, unhooking difficulty, hooking damage (i.e., injury), and bleeding at the site of hooking (yes or no) were recorded as the lure was removed. Hook placement was scored as either mouth, body, or both (Fig. 2). Hook placement scored as mouth had hooks within the mouth or on the exterior of the mouth, while hooks that were on any other part of the body or head were deemed to be body hooked (Fig. 2). Unhooking difficulty was scored between 0 and 5 (categorical), where hooks that were easily removed were scored a 0 and hooks that were more difficult or challenging to remove were scored a 5. Hooking damage was scored as a yes or no, and GT were deemed to have hooking damage if there was any signs of tears or bleeding from the hooks.

Non-lethal blood samples were obtained from a subset of GT after they were brought on board the boat by recreational anglers. Blood sampling occurred < 30 s after landing and immediately after dehooking so as not to potentially cause additional hooking damage to the fish or risk a hook becoming dislodged and impacting the researcher. The GT were air exposed during the blood sampling period, and this was included in the overall air exposure period. Less than 2 mL of blood was drawn from the caudal vasculature with a 22 G needle (BD Vacutainer Multisample Needles and 4.0 mL lithium heparin collection tubes, 75 USP, Becton, Dickson and Company (BD), NJ, USA). Blood was analyzed immediately for lactate (mmol/L, Lactate Plus, Nova Biomedical, Waltham, MA, USA), glucose (mmol/L, Accu-Chek Compact Plus, Roche Diagnostics, Basel, Switzerland), and pH (HI-99161, Hanna Instruments, Woonsocket, RI, USA) using point-of-care devices. These devices have been previously validated for use on fish (Stoot et al. 2014). Fish that had blood drawn were released immediately after sampling and not included in behavioral trials.

Impairment of reflexes (Davis 2010) was assessed at the time of release for the remaining GT. Three reflex indicators were used: "tail grab," the presence of burst swimming action when a fish is grabbed by the tail; "body flex," the presence of flexion in the torso when a fish is held along the dorsoventral axis; and, "equilibrium," the ability of the fish to right itself within 3 s after being placed upside down in water. These indicators were chosen due to their simplicity of use given the configuration of the boats and their previous validation in physiological and behavioral impairment studies in other species, e.g., *Albula vulpes* (Linnaeus, 1758) (Brownscombe et al. 2013; Brownscombe et al. 2015; also see Lennox et al. 2024). For individual indicators, binary reflex impairment scores of 0 (reflex present) and 1 (reflex absent) were used. Indicator scores were then converted to a proportional impairment score ranging from 0 to 1,

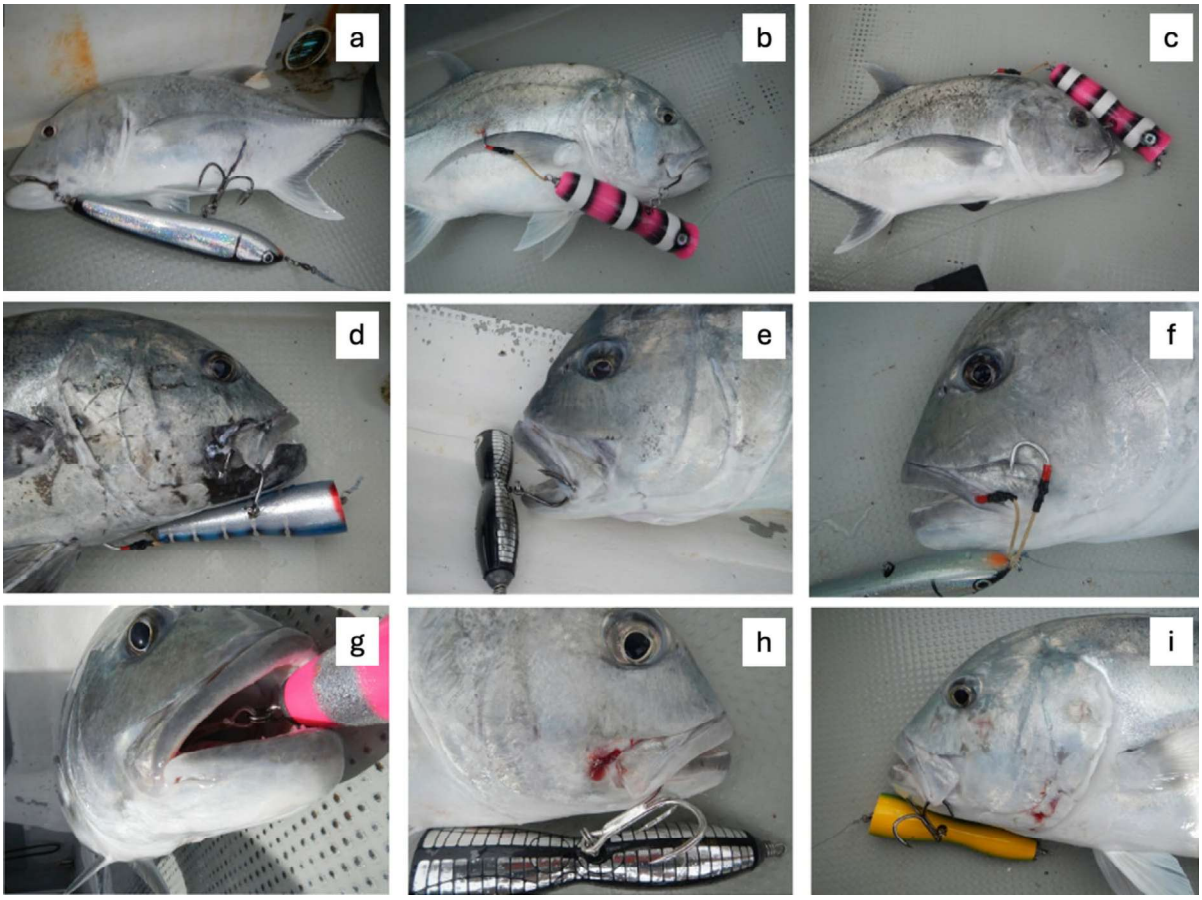


Fig. 2 Range of hook placements for giant trevally (*Caranx ignobilis*) captured with topwater lures. **a–d** Fish that are hooked in the mouth and body and **e–i** pictures of fish that are strictly hooked in the mouth

where a cumulative score of 0 indicated no overall impairment and a score of 1 indicated total impairment. Reflex impairment levels were scored in four different categories (i.e., 0, 0.33, 0.66, 1).

Post-release behavior

Post-release locomotor activity, movement patterns, and depth profiles were measured for a subset of GT using a custom pop-up electronic tag (Fig. 3). This custom pop-off tag was attached to the GT while air exposed (included in the air exposure period) on board. The tag housing was a molded plastic cylinder (80 mm long × 35 mm OD diameter, 28 mm ID, 23 g in air) with a screw-on cap and single O-ring to waterproof the inner compartment. Weights (steel washers, 20–30 g) were secured to the inside of the cylinder as ballast so that the tag floated vertically in the water when released from the GT. Several of the tag components were affixed to the outside of the cylinder using epoxy (J-B Weld, Marietta, GA, USA). A small plastic tube (30 mm long × 10 mm ID) was used as a secure attachment point for harness material that held the device tightly to the caudal peduncle of GT. Also on the outside of the cylinder was an acoustic transmitter with pressure sensor (VEMCO, Bedford, NS Canada; V13P 1H, 46 mm, 13 g in water, 6.9 g in air, continuous transmission rate of 2000 ms, 24-day battery life) to manually track the depth and location of GT following release. Also attached to the outside of the cylinder was a radio transmitter (Advanced Telemetry Systems, Isanti, MN; 3X xtal 3 stage board, bottled-shaped transmitter, 25 g, 120 ppm Pulser W, 25 ms Pulser R, 70-day battery life, 30

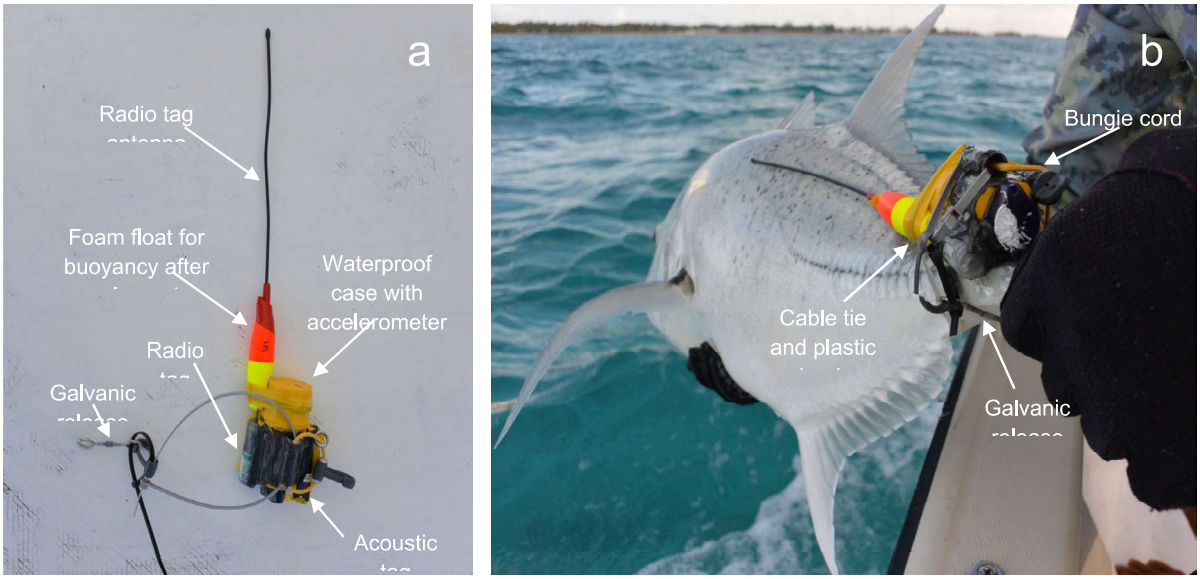


Fig. 3 Custom pop-up biologger used to measure post-release activity of giant trevally (*Caranx ignobilis*). **a** The position of the radio tag and acoustic tag affixed to the side of the waterproof cylindrical case that contains the accelerometer logger. **b** The pop-up biologger affixed to the caudal peduncle of a giant trevally, secured with a harness constructed of bungee cord, cable tie with plastic hook, and a galvanic release

cm coated antenna) that was used to locate the device once it floated to the surface of the water following release from the GT.

Prior to deployment, a triaxial accelerometer logger (Gulf Coast Data Concepts, Waveland, MS; X16-mini, with 500 mAh battery, 14 g in air, 25 Hz sampling rate) was activated and inserted into the cylinder. The acoustic tag and radio tag were also then activated, and the tagging package was affixed to the caudal peduncle of the GT. A small bungee cord (0.3 cm wide, 10–30 cm max stretch) and small plastic cable tie (10 cm long, 0.3 cm wide) were inserted through the plastic attachment tube on the cylinder and then stretched in opposite directions around the caudal peduncle to provide a custom fit depending on the size of the fish. On the bungee cord and cable tie were small plastic hooks (1.5 cm in length) that were used to secure a customized galvanic release (Neptune Marine Products, Port Townsend, WA, USA) with a minimum of a 4-h dissolution time. This pop-off package weighed up to 89 g and was only slightly positively buoyant, allowing it to be retrieved once ejected from the GT.

Once the tracking device was attached, the GT was put back in the water and released. As soon as the tag was immersed, a timer was started to provide an estimated time for the complete dissolution of the galvanic release. When sea states allowed, GT were manually tracked using a manual acoustic receiver with a directional hydrophone (VR100; VEMCO, Bedford, NS Canada). We also monitored for the signal of the radio tag using a portable radio receiver (Lotek Wireless, Ontario, Canada; Biotracker with flexible Yagi antenna (50 ohms)), and once detected, we homed in on the signal and retrieved the tag. There are no previous studies that have assessed to see if these tags impact the swimming performance of GT.

Tri-axial acceleration data were used to calculate the overall dynamic body acceleration (ODBA) of GT that was used to quantify locomotor activity (Halsey et al. 2009; Gleiss et al. 2011). The ODBA is calculated by summing the absolute acceleration of all three axes (surge, sway, and heave) and removing the static (gravity) acceleration (Shepard et al. 2008). Static acceleration is removed from the absolute acceleration using a 2-s box smoother (Shepard et al. 2008; Brownscombe et al. 2018). Fish were deemed moribund if the acceleration of the fish was near zero, the depth constant, and no apparent locomotor activity was observed.

Data analysis

All data analyses and visualization were conducted using RStudio version 2024.04.2+764 (RStudio Team 2024) via R version 4.4.0 (R Core Team 2024). When applicable mean and ± 1 standard deviation are reported, a Fisher's exact test for count data was used to assess if there were non-random relationships between number of hook points, hooking location, and injury. To further assess the difference between number of hook points with hooking location and injury, an adjusted Bonferroni pairwise comparison test was used. Unhooking difficulty was analyzed using an ordinal logistic regression using the *clm* function from the *ordinal* package (Christensen 2023) and fit with the number of hook points, hooking location, and the fork length as the predictor variables. This was then followed up using a pairwise comparison post-hoc test using the *emmeans* function from the *emmeans* package (Lenth 2024). Finally, a binomial generalized linear model was fit with injury as the response variable, unhooking difficulty, hooking location, and fork length as predictor variables. Multicollinearity was evaluated using the variance inflation function where values < 5 suggest no collinearity. A Fisher's exact test for pairwise comparisons was then used to determine the differences in injury for each hooking location.

Using all GT angling data, the relationship between fight time and fork length was examined with Pearson's *r* correlation. A linear model was fit with air exposure as the response variable, GT fork length, and number of hook points as the predictor variables. A Tukey's HSD post-hoc test was then fit using the *glht* function from the *multcomp* package (Hothorn et al. 2008) to further assess the differences in air exposure durations across number of hook points. Assumptions of linearity, normality, and homoscedasticity were visually analyzed using residual plots.

To assess the impacts on the overall immediate reflex impairment of GT, an ordinal logistic regression model with duration of air exposure, fight time, and bleeding as the predictor variables were used. Both tail grab response and the equilibrium test were modeled using binomial generalize linear models fit with fight time, air exposure duration, and presence of bleeding as the response variables. Body flex was not modeled given the small sample size of this reflex test (i.e., only 2 fish did not pass this test). Further, we fit two classification tree models with tail grab and equilibrium as response variables with air exposure, fight time, and injury as the predictor variables. Again, body flex was not modeled given the small sample size. We used these classification trees to find thresholds of air exposure duration and fight times as an indicator of when reflex impairments are likely going to occur. The classification tree also ranks the level of importance for each variable in the model. The variable importance provides information on how influential the respective predictor variables are on the response variable (i.e., predictive power). Classification trees were built using the *rpart* function from the *rpart* package (Therneau and Atkinson 2023). Finally, three linear models were fit with blood glucose, lactate, and pH as the response variables with fight time and air exposure duration as the predictor variables. Assumptions for the linear models were verified using diagnostic plots.

Results

Angling metrics

A total of 72 GT (mean fork length = 823 ± 146 mm, range 585–1290 mm) were captured using topwater poppers ($n = 42$) and stickbaits ($n = 29$). One other GT was caught for the study, but the lure type was not recorded. Hooking location was only recorded for 68 of the 72 GT captured in the study, and of those 68 GT, one was removed from the hooking analysis given that it was the only individual that was hooked exclusively in the body. That individual that was removed from the hooking analysis was captured on a popper with two treble hooks.

The number of hook points on the lures had a significant influence on the hooking location of GT (Table 1, Fig. 2; $p = 0.045$, 95% CI = 0.041–1.098). Lures with 3 or fewer hook points tended to hook fish more often in the mouth ($n = 12$, 80%) compared to being hooked in the mouth and body ($n = 3$, 20%). When lures were configured with 4 or more hooks, GT were just as likely to be hooked in the mouth ($n = 26$, 50%) as they were to be hooked both in the mouth and in the body ($n = 26$, 50%). Overall, physical injury did not differ significantly with the amount of hook points ($p = 0.355$, 95% CI = 0.496–10.344).

Table 1 Hook configuration, hooking location on the body, and the number of hook points across all fish in the study

Hook configuration	*n*	Hook points	Mouth	Body and mouth	Body
Single	9	1	9	0	0
Treble	3	3	3	0	0
Single, single	3	2	0	3	0
Single, treble	11	4	9	2	0
Treble, treble	42	6	17	24	1

Unhooking difficulty was influenced by the hooking location ($\chi^2 = 9.097$, $p = 0.003$), but not by the number of hook points ($\chi^2 = 0.105$, $p = 0.746$) or body size ($\chi^2 = 0.035$, $p = 0.851$). Unhooking difficulty increased when fish were hooked both in the mouth and on the body, compared to fish that were only hooked in the mouth ($t_{54} = 2.326$, $p = 0.024$). Hooking injury increased with unhooking difficulty ($\chi^2 = 5.162$, $p = 0.023$), and hooking location had a significant influence on the presence of injury ($\chi^2 = 24.783$, $p < 0.001$). Those GT hooked in both the mouth and body had a greater incidence of hooking injury compared to those just hooked in the mouth ($p < 0.001$). The fork length of GT had no influence on the hooking injury ($\chi^2 = 3.822$, $p = 0.051$).

Unsurprisingly, fight time (184 ± 155 s, range 33–1181 s) tended to be longer for larger GT (linear correlation; $r = 0.70$, df = 67, $p < 0.001$; Fig. 4).

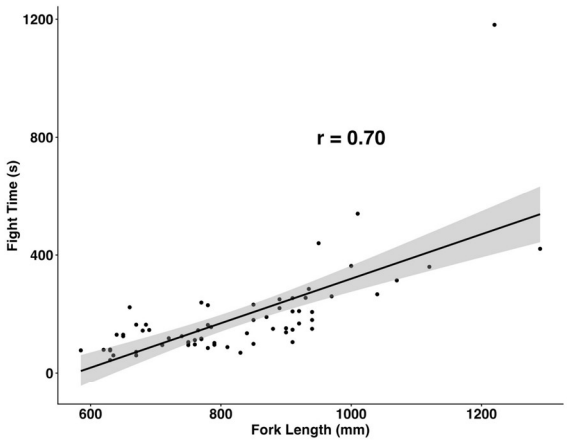


Fig. 4 Correlation between the fork length of giant trevally (*Caranx ignobilis*) and fight time in seconds. Shaded area represents the 95% confidence interval

Duration of air exposure ranged from 38 to 504 s (mean 298 ± 122 s), which occurred during hook removal and admiration. Larger fish tended to be air exposed for longer, but the effect was minimal, with an increase of 1.5 s per 10 mm in length (estimate = 0.149, $F_{62,1} = 9.552$, $p = 0.003$). Duration of air exposure was also significantly influenced by the hook configuration used ($F_{62,4} = 19.243$, $p < 0.001$). Specifically, duration of air exposure for GT hooked with double treble hooks (Fig. 5) was longer than fish hooked with a singular J-hook ($t = 6.024$, $p < 0.001$), double J-hooks ($t = 4.030$, $p = 0.001$), or lures with a J-hook and a treble hook ($t = 6.527$, $p < 0.001$).

Reflex impairment and physiology

There was a total of 63 GT that were assessed for their reflex impairment levels. Longer fight times led to more reflex impairment ($x^2 = 4.133$, $p = 0.042$); fight times longer than 175 s always resulted in at least one reflex being impaired (Fig. 6). Aggregate reflex impairment score for GT was not influenced by the duration of air exposure ($x^2 = 0.768$, $p = 0.381$) or by the incidence of hooking injury

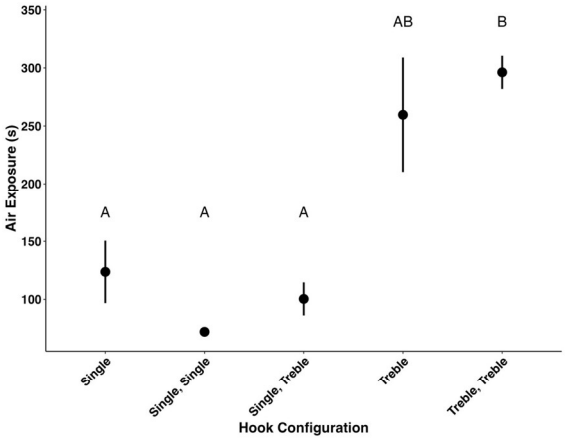


Fig. 5 Mean (± standard error) air exposure period of giant trevally (*Caranx ignobilis*) post-capture across the different hook configurations used. Dissimilar letters represent significantly different air exposure periods across the respective hook configuration types. Majority of the fish were captured on lures with two-treble hooks ($n = 45$; treble, treble), followed by lures that were configured with a single J-hook and treble hook ($n = 11$; single, treble). Lures with a singular single hook captured nine fish (single). Lures with a singular treble (treble), and lures configured with two single J-hooks captured three fish each (single, single). All hooks used were barbed

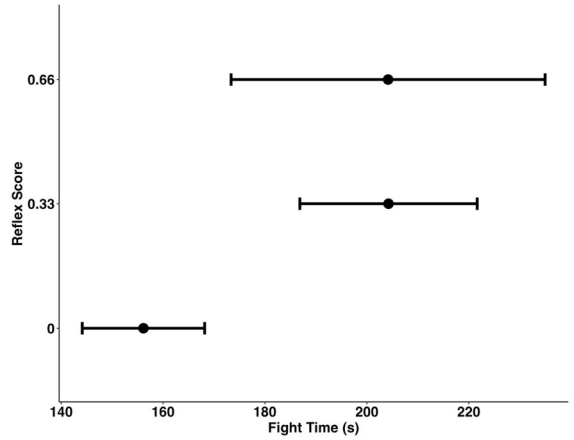


Fig. 6 Mean (±standard error) fight time for each reflex impairment level of giant trevally (*Caranx ignobilis*)

($x^2 = 1.166$, $p = 0.280$). Equilibrium had a higher probability of being impaired with longer durations of air exposure ($x^2 = 9.866$, $p = 0.002$), but was not affected by fight time ($x^2 = 3.229$, $p = 0.072$) or the presence of hooking injury ($x^2 = 0.475$, $p = 0.491$). Longer fight times resulted in an increase in the frequency of the loss of the tail grab reflex ($x^2 = 4.748$, $p = 0.029$); however, tail grab was not influenced by the duration of air exposure ($x^2 = 0.359$, $p = 0.549$) or the presence of hooking injury ($x^2 = 0.494$, $p = 0.482$). Body flex was not significantly influenced by the duration of air exposure ($x^2 = 0.448$, $p = 0.503$), fight time ($x^2 = 1.998$, $p = 0.158$), or the presence of hooking injury ($x^2 = 1.634$, $p = 0.201$). Of the GT assessed for reflex impairments, 41 (65%) could not regain equilibrium, 10 (16%) did not respond to the tail grab reflex test, and 6 (10%) had no body flex during testing.

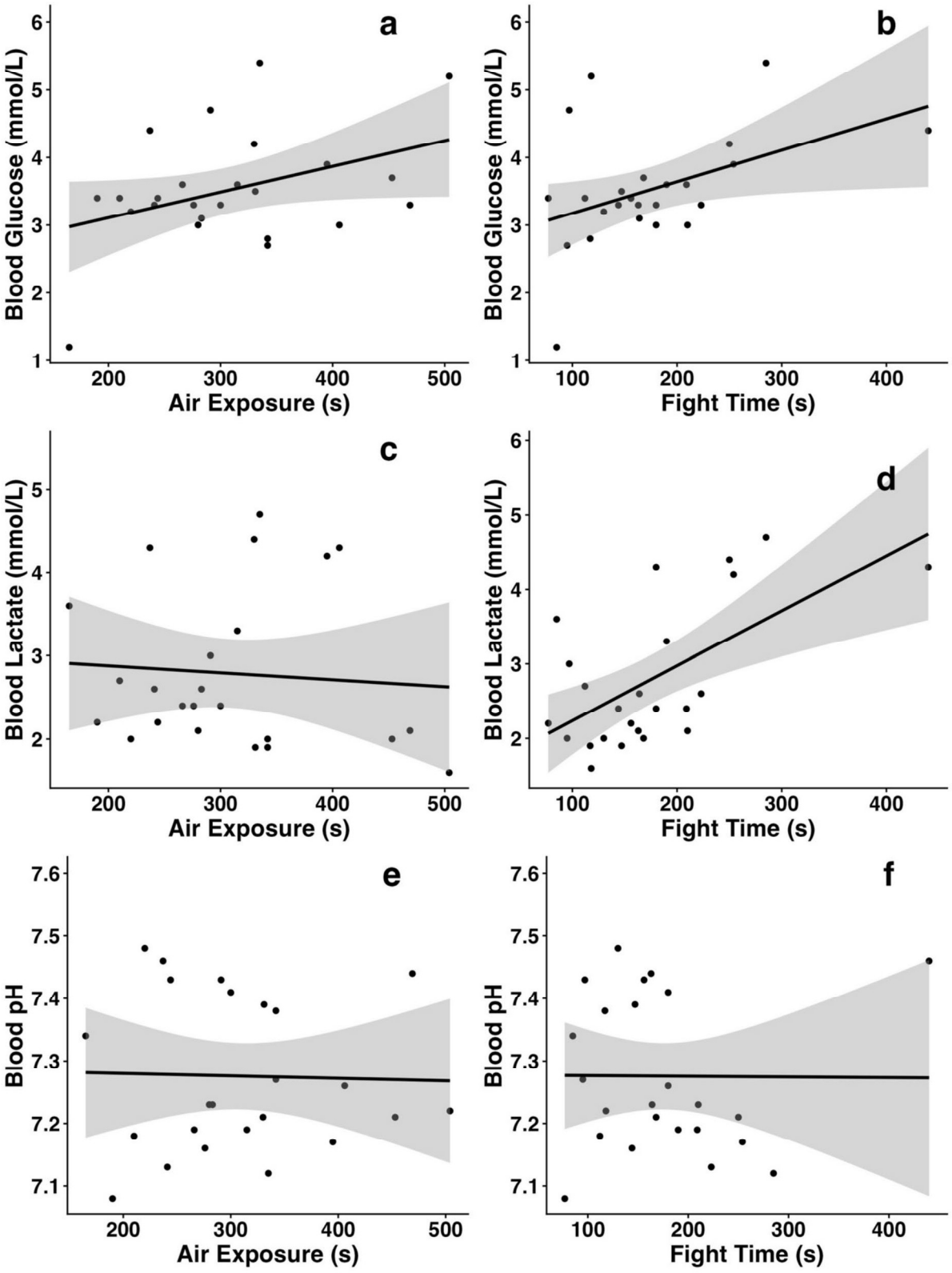
The classification tree identified fight time as the best predictor of impairment of the tail grab reflex (variable importance [VI] = 73) followed by air exposure (VI = 13), and then bleeding (VI = 13). Using fight time alone, the model was able to predict 57% of tail grab impairment with a cut-off of 166 s, where fish that were fought for longer had greater reflex loss. The classification tree for the equilibrium identified air exposure as the best predictor (VI = 55), followed by fight time (VI = 37), and then bleeding (VI = 7). Air exposure alone with a threshold of 218 s was able to predict 65% of equilibrium loss in GT.

Blood glucose ($n = 26$, 3.5 mmol/L ± 0.8, range = 1.2–5.4) had a positive relationship with both air exposure duration (Fig. 7a, $F22,1 = 4.536$, $p = 0.045$) and total fight time (Fig. 7b, $F22,1 = 4.556$, $p = 0.044$). There was also a positive relationship between blood lactate ($n = 26$, 2.7 mmol/L ± 1.0, range = 1.3–4.7) and fight time (Fig. 7c, $F22,1 = 7.589$, $p = 0.012$), but not between the air exposure period and blood lactate (Fig. 7 d, $F22,1 = 0.868$, $p = 0.362$). Finally, pH ($n = 26$, 7.3 mmol ± 0.1, range = 7.1–7.5) of GT was not influenced by the fight time (Fig. 7e, $F22,1 = 0.084$, $p = 0.775$) or the duration of air exposure (Fig. 7f, $F22,1 = 0.087$, $p = 0.771$).

Post-release behavior

GT affixed with tagging packages ($n = 11$; Table 2) were tracked manually for up to 3 h 10 min post-release (mean 103 min, SD 59.2). These fish often traversed nearshore regions above the coral reef shelf for a short period and then made more rapid movements offshore over deeper water. A majority of the tracked GT moved offshore in a northwest direction toward an offshore seamount (Fig. 8). Examining post-release activity levels, GT typically exhibited a period of lower activity (2–5 min), followed by a spike in activity that remained consistent for the remainder of the tracking periods (Fig. 9).

During the tracking period, GT occupied varied water depths (mean = 4.6 ± 4.0 m, range 0–31 m) and exhibited variable depth use patterns among individuals. The two largest GT descended rapidly immediately following release to water depths exceeding 25 m. Yo-yo diving was observed for most GT as they moved offshore, with fish descending to depths > 10 m, but for short periods (< 5 min) prior to ascending to near surface. Patterns in locomotor activity (i.e., ODBA; Fig. 9) indicated that after the initial release period, GT spent much of their time actively swimming while either traversing waters along the coral reef shelf or moving offshore over pelagic waters (Fig. 8). All captured GT were alive at the time of release, and there was no evidence of short-term mortality during the monitoring period of GT tagged with pop-off packages.


a
Blood Glucose (mmol/L)
Air Exposure (s)
b
Blood Glucose (mmol/L)
Fight Time (s)
c
Blood Lactate (mmol/L)
Air Exposure (s)
d
Blood Lactate (mmol/L)
Fight Time (s)
e
Blood pH
Air Exposure (s)
f
Blood pH
Fight Time (s)

◂**Fig. 7** Blood physiology parameters of giant trevally (*Caranx ignobilis*) caught with topwater lures. Rows refer to different blood variables assessed, while the columns are for both air exposure and fight time. Shaded area represents the 95% confidence interval

Discussion

We found no evidence for short-term (< 3 h) post-release mortality from angling or from post-release predation in GT. Locomotor activity was lower during the initial 5 min post-release but began to slowly increase with time, similar to results from Griffin et al. (2022) for GT caught and released after angled via fly fishing in the Seychelles. Although no short-term post-release mortality occurred, GT did exhibit physiological effects and reflex impairment typical of fish caught and handled as part of a recreational fishery. Although survival may be relatively high for GT captured by both conventional and fly-fishing gear, these fish are still affected by the capture event to some degree. Our results suggest that fight time, air exposure, and hook configuration (which directly relates to handling time) are important aspects that need to be considered in GT catch-and-release fisheries due to their impacts on blood physiology and reflex impairment. Fish with more severe physiological impairment can suffer from sub-lethal impacts such as feeding impairments (Meka and Margraff 2007) and reduced reproduction output (Ostrand et al. 2004; Richard et al. 2013). These fish are also more likely to be vulnerable to predators after release (though none was observed here) and may be susceptible to delayed post-release mortality. Yet, delayed mortality could still occur; however, this mortality is likely to be low given the observed survival of GT fitted with pop-off tag packages.

Exterior tags can have an influence on the behavior and swimming performance of different fishes (e.g., McCleave and Stred 1975; Peake et al. 1997; Janak et al. 2012). The external biologging package used in this study could have had an influence on the swimming behavior of GT. It is entirely possible that the behaviors observed post-release are not necessarily from the capture event, but rather the addition of the external pop-off biologging package. Without a full understanding of how these external packages influence GT, it is hard to disentangle the influence that the capture event has on the post-release behavior rather than just the addition of the package itself.

Hook configuration had a cascading effect on many different aspects of a C&R angling event. The hook configurations of the lures in our study had an important impact on hooking location and unhooking difficulty that had an influence on the presence of physical injury and duration of air exposure. It is no surprise that lures configured with two treble hooks and six hook points were more often snagged on the body of the fish given the number of extra hooks points that are exposed during the strike and while being fought. The heightened unhooking difficulty associated with

Table 2 Metrics of each giant trevally (*Caranx ignobilis*) captured and fitted with a custom pop-off tag. Not injured or reflex test failed is indicated with a "N," and the presence of a reflex or if the fish was injured is represented by a "Y"

Fork length (mm)	Fight time (s)	Air exposure (s)	Lure	Hook configuration	Hooking location	Injury	Unhooking difficulty	Equilibrium
970	260	200	Stickbait	Treble, treble	Mouth	N	NA	Y
840	135	346	Stickbait	Treble, treble	Mouth, body	Y	2	Y
1070	314	295	Stickbait	Treble, treble	Mouth, body	Y	1	N
770	115	209	Popper	Treble, treble	Mouth	N	NA	Y
940	206	199	Stickbait	Treble, treble	NA	NA	NA	Y
690	146	125	Popper	Treble, treble	Mouth	Y	NA	N
1290	421	328	Stickbait	Treble, treble	Mouth, body	N	1	N
1220	1181	303	Stickbait	Treble, treble	Mouth, body	N	2	N
1040	267	197	Stickbait	Treble, treble	Mouth	N	1	Y
1000	363	304	Stickbait	Treble, treble	Mouth	N	3	N
700	NA	NA	Stickbait	Treble, treble	Mouth, body	Y	NA	N

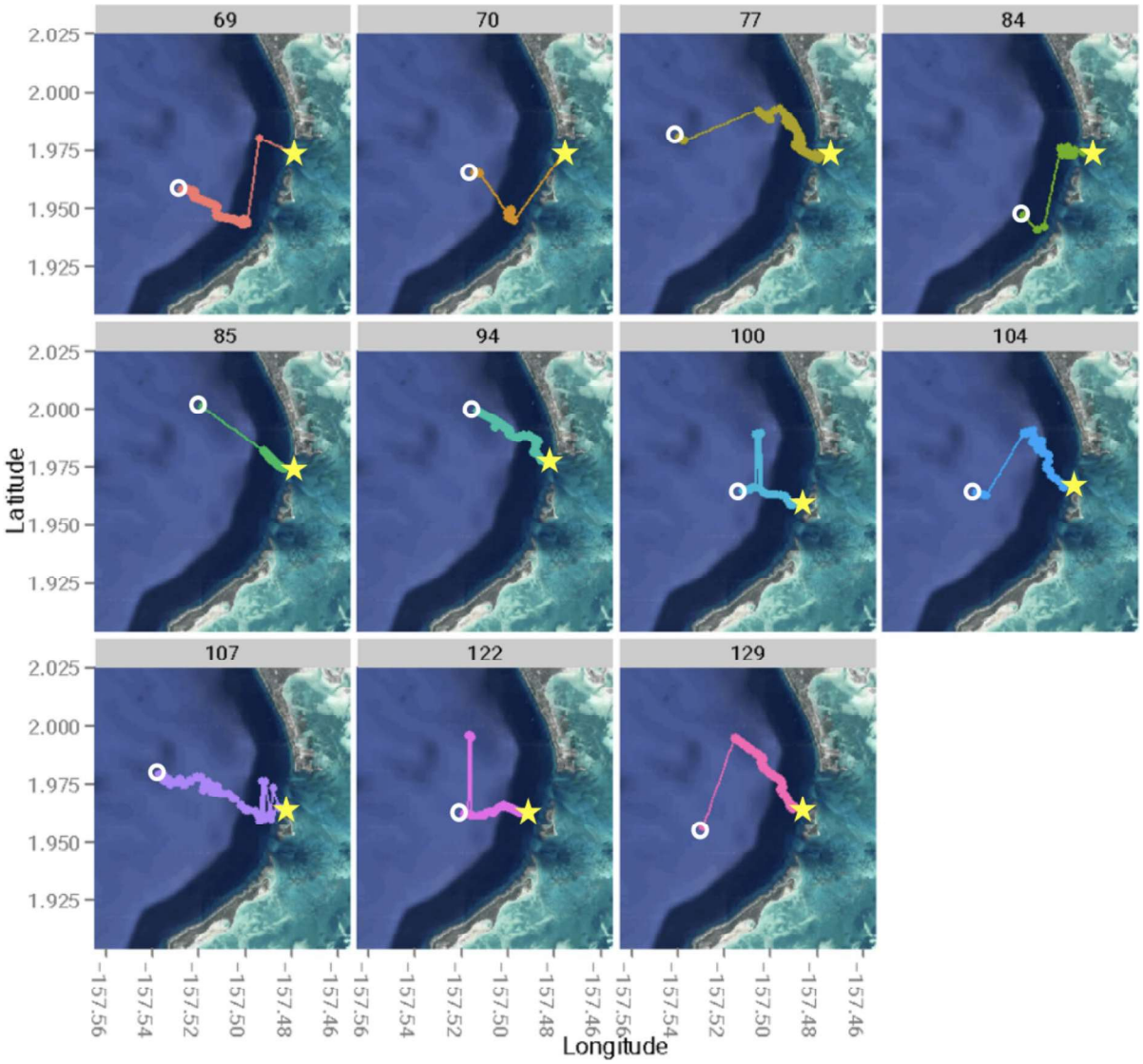


Fig. 8 Map of post-release manual tracking positions for an individual giant trevally (Caranx ignobilis) that exhibited a typical post release movement pattern in coastal Kiritimati. Fish were tracked for up to 3 h and 10 min post-release. Numbers at the top of each panel represent fork length of each fish tracked. The beginning of the monitoring periods (i.e., release point) is indicated with a yellow star, and the end points of tracks are marked by a white circle

lures that had two treble hooks, or with one treble and one J-hook, is likely due to the number of actual points that needed to be removed from the fish which simply takes more time and is complicated by the increased safety risk for the individual unhooking the fish. The hook configuration associated with poppers and stickbaits may potentially have 4–6 hook points embedded in the fish in different anatomical locations on the body (e.g., mouth, operculum, belly), which means that the anglers must strategically remove each individual hook point one at a time while cautiously avoiding re-hooking the fish with other previously removed hooks. With many hook points exposed, GT could unintentionally get hooked in locations such as the eyes, stomach, or operculum as seen in other species (Pelzman 1978; Lyle et al. 2007), amplifying physical damage while also making hooks more difficult harder to remove.

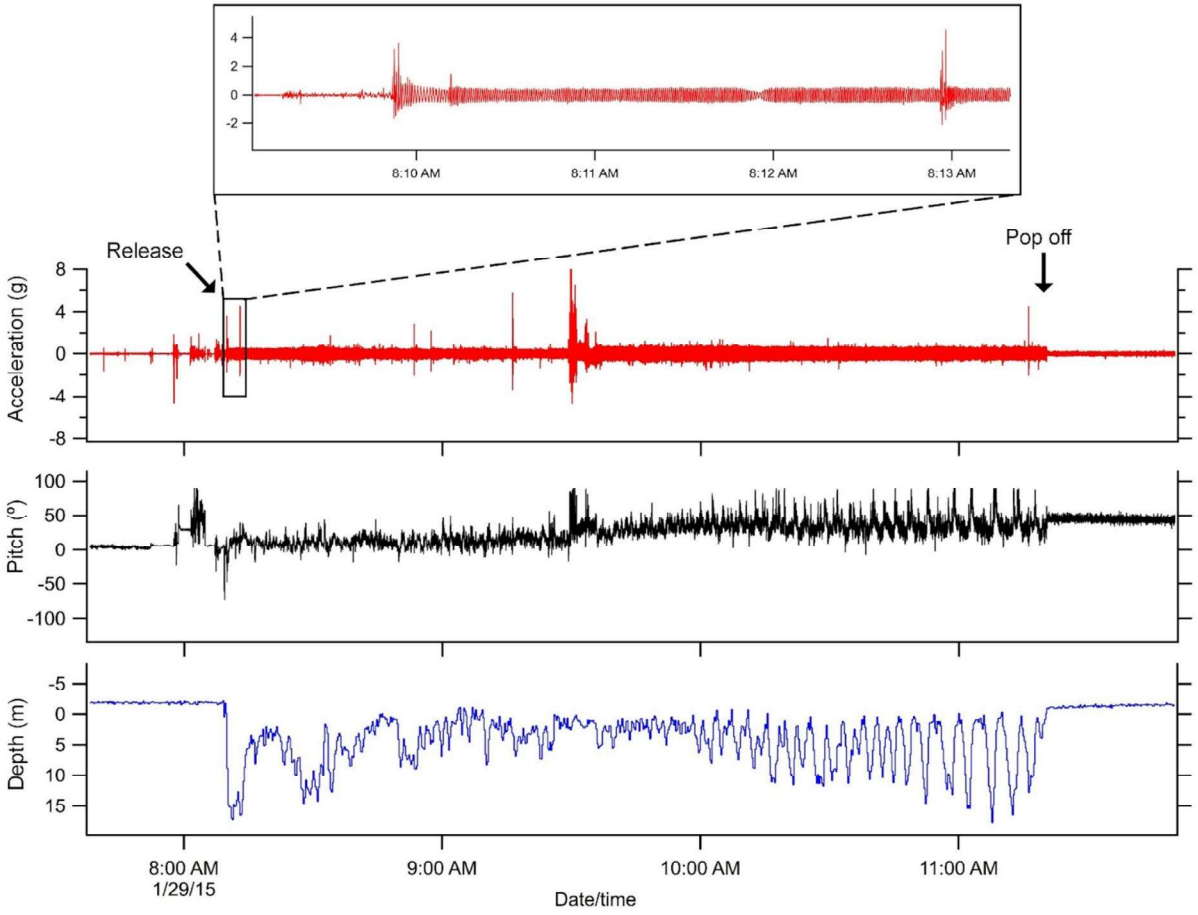


Fig. 9 Acceleration, body pitch, and water depth for an individual giant trevally (Caranx ignobilis) post release. Acceleration panel shows the release of the fish with the biologging package and the pop-off period. Inset plot shows a zoomed-in section of what the acceleration data looks like at the point of release. The acceleration panel shows different swimming behavior where sustained swimming is occurring the majority of the time with a few instances of burst swimming (e.g., spike in acceleration between 9:00 am and 10:00 am). The body pitch shows the angle of the fish along the *x* axis which corresponds with the yo-yo diving pattern in the depth panel. The depth panel shows the change in depth used during the monitoring period for a singular fish

We found that injury from hooks was greater when at least one hook was embedded in the body, rather than just being hooked in the mouth, and injury increased when hooks were more difficult to remove. This makes sense given that hooks could be embedded in places that are cartilaginous (e.g., some parts of the operculum), which would make it much more difficult to remove, creating a large tear when applying excess force to remove the hook(s). Although hook removal time was not recorded in this study, previous studies have suggested that hook removal time increases with unhooking difficulty (Hussey et al. 2025). We believe that the hook configuration and related hook placement on various anatomical parts of the body can lead to a prolonged air exposure associated with the hook removal. A previous study suggested that hook removal times can be reduced when replacing treble hooks with J-hooks (Trahan et al. 2021). In our study, GT hooked with lures that were equipped with a singular hook, either J-hook or treble hook, had significantly shorter air exposure periods. Reducing the number of hook points lures used to capture GT can help reduce the total air exposure time that is presumably attributed to the unhooking process.

In our study, it was clear that air exposure > 218 s increased the incidence of equilibrium loss and caused

elevated levels of blood glucose for GT. These results are similar to previous studies that identified increased duration of air exposure resulted in greater equilibrium loss (Danylchuk et al. 2007; Gingerich et al. 2007) and increased glucose levels (Thompson et al. 2008; White et al. 2008). However, it seems that fight time is more influential on the total reflex impairment levels of GT, where fight times > 175 s led to one, or more, reflex being impaired. Longer fight times resulted in loss of the tail grab response, higher blood glucose, and higher blood lactate concentrations, similar to Australian snapper *Chrysophrys auratus* (Forester, 1801) (Wells et al. 1986), milkfish *Chanos chanos* (Fabricius, 1775) (Danylchuk et al. (2024), and blacktip shark *Carcharhinus limbatus* (Valenciennes, 1839) (Whitney et al. 2017). The increase in glucose because of longer air exposure and fight times is likely occurring as a stress response to help fuel aerobic tissues (e.g., gills, heart) due to the heightened oxygen demand (Wood 1991; Wang et al. 1994; Barton 2002a). Glucose is mobilized to help enhance the oxygen uptake by the gills and to increase oxygen delivery to tissues (Wood 1991; Wang et al. 1994; Barton 2002b). Further, it is evident from our results that increased fight times resulted in elevated lactate levels which is similar to previous studies that suggest forced exercise results in the accumulation of blood lactate (Wendelaar Bonga 1997; Kieffer 2000; Wells and Baldwin 2006). During the fight, fish engage in burst type swimming (i.e., exhaustive exercise, Milligan 1996; Kieffer 2000). This burst swimming activity is fueled by anaerobic respiration and uses energy reserves stored in the white muscle tissue (Wood 1991; Wang et al. 1994). The by-product of this exhaustive exercise results in the accumulation of metabolic by-products, such as blood lactate (reviewed in Cooke et al. 2013 and Holder et al. 2022).

Overall, our study suggests that GT are relatively robust in their response to being caught with conventional artificial lures and brought on board a boat for hook removal prior to release. However, to reduce physical injury and to avoid a prolonged duration of air exposure while being unhooked, we recommend that anglers use lures configured with hooks that have 3 hook points or less (e.g., two single J-hooks or one treble hook). Furthermore, we recommend that anglers minimize fight times to < 175 s and keep air exposure durations < 218 s to reduce physiological stress and reflex impairment, especially in locations with a high predator burden that could increase post-release mortality in other contexts beyond which we studied here. Collectively, our results can be used to inform science-based best practices and codes of conduct to ensure that more GT are released in C&R recreational fisheries in the best condition possible.

Acknowledgements We are grateful for the support of Mr. Jacob Teem, and all the guides and staff of the Ikari House, anglers Tim and Sonya Pask, Dayne Hanna, Ed Sozinho, and Brian Thielke.

Author contribution Conceptualization: AJD, SJC, JWB, GDR; funding acquisition: AJD; data collection: AJD, JWB, GDR; data analysis: LL, JWB, GDR; writing: AJD, LL, JWB; and editing: AJD, SJC, LL, JWB, GDR, BB.

Funding Direct support was provided by Patagonia Inc. and Costa Sunglasses Inc. Danylchuk was supported by the National Institute of Food & Agriculture, U.S. Department of Agriculture, and the Massachusetts Agricultural Experiment Station and Department of Environmental Conservation. Cooke was supported by the Canada Research Chairs Program and the Natural Sciences and Engineering Research Council of Canada (NSERC). Brownscombe was also supported by NSERC. Danylchuk and Cooke are Research Fellows for Bonefish & Tarpon Trust.

Data availability The data that support the findings of this study are available from the corresponding author upon reasonable request.

Declarations

Ethics approval All procedures used in this research were approved by UMass IACUC, protocol 2013–0031, and under a research permit from the Republic of Kiribati.

Conflict of interest The authors declare no competing interests.

Dedication This paper is dedicated to Mr. Moanafua 'Moana' Kofe—fishing guide at Ikari House. Moana was instrumental in the development of the giant trevally fishery on Kiritimati and actively participated in this study.

References

Abdussamad EM, Kasim HM, Balasubramanian TS (2008) Distribution, biology, and behaviour of the giant trevally, Caranx ignobilis-a candidate species for mariculture. Bangladesh F Fish Res 12:89–94

Arlinghaus R, Cooke SJ, Lyman J, Policanksy D, Schwab A, Suski CD, Sutton SG, Thorstad EB (2007) Understanding the complexity of catch-and-release in recreational fishing: an integrative synthesis of global knowledge from

historical, ethical, social and biological perspectives. Rev Fish Sci Aquac 15:75–167. https://doi.org/10.1080/10641260601149432

Barnett A, Abrantes KG, Baker R, Diedrich AS, Farr M, Kuilboer A, Mahony T, McLeod I, Moscardo G, Prideaux M, Stoeckl N, van Luyn A, Sheaves M (2016) Sportfisheries, conservation and sustainable livelihoods: a multidisciplinary guide to best practice. Fish Fish 17:696–713. https://doi.org/10.1111/faf.12140

Bartholomew A, Bohnsack JA (2005) A review of catch-and-release angling mortality with implications for no-take reserves. Rev Fish Biol Fish 15:129–154. https://doi.org/10.1007/s11160-005-2175-1

Barton B (2002a) Stress in fishes: a diversity of responses with particular reference to changes in circulating corticosteroids. Integr Comp Biol 42(3):517–525. https://doi.org/10.1093/icb/42.3.517

Barton BA, Morgan JD, Vijayan MM, Adams SM (2002b) Physiological and condition-related indicators of environmental stress in fish. Biological Indicators of Aquatic Ecosystem Stress 111-148

Berry FH, Smith-Vaniz WF, Moberly JB (1981) Identification of trevallys or crevalles (genus *Caranx*) of the Indian and Pacific Oceans. International Game Fish Association, Fort Lauderdale, FL

Bower SD, Danylchuk AJ, Raghavan R, Danylchuk SC, Pinder AC, Cooke SJ (2016) Rapid assessment of the physiology impacts cause by catch-and-release angling on blue-finned mahseer (*Tor* sp.) of the Cauvery River, India. Fish Manage Ecol 23:208–217. https://doi.org/10.1111/fme.12135

Bower SD, Mahesh N, Raghavan R, Danylchuk AJ, Cooke SJ (2019) Sub-lethal response of (*Tor khudree*) to catch-and-release recreational angling. Fish Res 211:231–237. https://doi.org/10.1016/j.fishres.2018.11.004

Brownscombe JW, Thiem JD, Hatry C, Cull F, Haak CR, Danylchuk AJ, Cooke SJ (2013) Recovery bags reduce post-release impairments in locomotory activity and behavior of bonefish (*Albula* spp.) following exposure to angling-related stressors. J Exp Mar Biol Ecol 440:207–215. https://doi.org/10.1016/j.jembe.2012.12.004

Brownscombe JW, Griffin LP, Gagne T, Haak CR, Cooke SJ, Danylchuk AJ (2015) Physiological stress and reflex impairment of recreationally angled bonefish in Puerto Rico. Environ Biol Fishes 98:2287–2295. https://doi.org/10.1007/s10641-015-0444-y

Brownscombe JW, Danylchuk AJ, Chapman JM, Gutowsky LFG, Cooke SJ (2017) Best practices for catch-and-release recreational fisheries – angling tools and tactics. Fish Res 186(3):693–705. https://doi.org/10.1016/j.fishres.2016.04.018

Brownscombe JW, Lennox RJ, Danylchuk AJ, Cooke SJ (2018) Estimating fish swimming metrics and metabolic rates with accelerometers: the influence of sampling frequency. J Fish Biol 93:207–214. https://doi.org/10.1111/jfb.13652

Christensen R (2023) _ordinal- regression models for ordinal data_. R Package version 2023.12-4.

Cook KV, Lennox RJ, Hinch SG, Cooke SJ (2015) Fish out of water: how much air is too much? Fish 40(9):452–461. https://doi.org/10.1080/03632415.2015.1074570

Cooke SJ, Suski CD (2005) Do we need species-specific guidelines for catch-and-release recreational angling to effectively conserve diverse fishery resources? Biodivers Conserv 14:1195–1209. https://doi.org/10.1007/s10531-004-7845-0

Cooke SJ, Raby GD, Donaldson MR, Hinch SG, O'Connor CM, Arlinghaus R, Danylchuk AJ, Hanson KC, Clark TD, Patterson DA (2013) The physiological consequences of catch-and-release angling: perspectives on experimental design, interpretation, extrapolation and relevance to stakeholders. Fish Manage Ecol 20:268–287. https://doi.org/10.1111/j.1365-2400.2012.00867.x

Daly R, Filmalter JD, Daly CAK, Bennett RH, Pereira MAM, Mann BQ, Dunlop SW, Cowley PD (2019) Acoustic telemetry reveals multi-seasonal spatiotemporal dynamics of giant trevally Caranx ignobilis aggregation. Mar Ecol Prog Ser 621:185–197. https://doi.org/10.3354/meps12975

Daly R, Filmalter JD, Peel LR, Mann BQ, Lea JSE, Clarke CR, Cowley PD (2021) Ontogenetic shifts in home range size of a top predatory reef-associated fish (*Caranx ignobilis*): implications for conservation. Mar Ecol Prog Ser 664:165–182. https://doi.org/10.3354/meps

Danylchuk AJ, Cooke SJ, Goldberg TL, Suski CD, Murchie KL, Danylchuk SE, Shultz AD, Haak CR, Brooks EJ, Oronti A, Koppelman JB, Philipp DP (2011) Aggregrations and offshore movements as indicators of spawning activity of bonefish (*Albula vulpes*) in the The Bahamas. Mar Biol 158:1981–1999

Danylchuk SC, Danylchuk AJ, Cooke SJ, Goldberg TL, Koppelman J, Philipp DP (2007) Effects of recreational angling on the post-release behavior and predation of bonefish (Albula vulpes): the role of equilibrium status at the time of release. J Exp Mar Biol Ecol 346(1–2):127–133. https://doi.org/10.1016/j.jembe.2007.03.008

Danylchuk AJ, Suski CD, Madelman JW, Murchie KJ, Haak CR, Brooks AM, Cooke SJ (2014) Hooking injury, physiological status and short-term mortality of juvenile lemon sharks (*Negaprion bevirostri*) following catch-and-release recreational angling. Conserv Physiol 2(1):cot036. https://doi.org/10.1093/conphys/cot036

Danylchuk AJ, Danylchuk SC, Kosiarski A, Cooke SJ, Huskey B (2018) Keepemwet fishing – an emerging social brand for disseminating best practices for catch-and-release in recreational fisheries. Fish Res 205:52–56. https://doi.org/10.1016/j.fishres.2018.04.005

Danylchuk AJ, Griffin LP, Lawrence M, Danylchuk SC, Brighton E, Fordham G, Curd G, Simpson K, Merwe DV, Cooke SJ (2024) Physiological response of milkfish (*Chanos chanos*) to capture in a fly fishing catch-and-release recreational fishery. Fish Manage Ecol 32(3):e12741. https://doi.org/10.1111/fme.12741

Davis MW (2010) Fish stress and mortality can be predicted using reflex impairment. Fish Fish 11:1–11. https://doi.org/10.1111/j.1467-2979.2009.00331.x

Farmer BM, Wilson SK (2011) Diet of finfish targeted by fishers in North West Australia and the implications for trophic cascades. Environ Biol Fish 91:75–81. https://doi.org/10.1007/s10641-010-9761-3

Fedler T (2014) Economic impacts of flats fishing in Belize. Vero Beach, FL

Gaffney R (2000) Evaluation of the status of the recreational fishery ulua in Hawai'I, and recommendations for future management. Hawaii Department of Land and Natural Resources, Division of Aquatic Resources Technical Report 2-20

Gingerich A, Cooke SJ, Hanson KC, Donaldson MR, Hasler CT, Suski CD, Arlinghaus R (2007) Evaluation of the interactive effects of air exposure duration and water temperature on the condition and survival of angled and released fish. Fish Res 86:169–178. https://doi.org/10.1016/j.fishres.2007.06.002

Glass J, Daly R, Cowley P, Post D (2020) Spatial trophic variability of a coastal apex predator, the giant trevally Caranax ignobilis, in the western Indian Ocean. Mar Ecol Prog Ser 694:195–208. https://doi.org/10.3354/meps13305

Gleiss AC, Wilson RP, Shepard ELC (2011) Making overall dynamic body acceleration work: on the theory of acceleration as a proxy for energy expenditure. Methods Ecol Evol 2(1):23–33. https://doi.org/10.1111/j.2041-210X.2010.00057.x

Griffin LP, Adam P-A, Fordham G, Curd G, McGarigal C, Narty C, Norgués J, Rose-Innes K, Merwe DV, Danylchuk SC, Cooke SJ, Danylchuk AJ (2021) Cooperative monitoring program for a catch-and-release recreational fishery in the Alphonse Island group, Seychelles: from data deficiencies to the foundation for science and management. Ocean Coast Manage 210:105681. https://doi.org/10.1016/j.ocecoaman.2021.105681

Griffin LP, Fordham G, Curd G, Narty C, Adam P-A, Brownscombe JW, Cooke SJ, Danylchuk AJ (2022) 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. Fish Res 252:106337. https://doi.org/10.1016/j.fishres.2022.106337

Halsey LG, Shepard ELC, Quintana F, Laich AG, Green JA, Wilson RP (2009) The relationship between oxygen consumption and body acceleration in a range of species. Comp Biochem Physiol A Mol Integr Physiol 152(2):197–202. https://doi.org/10.1016/j.cbpa.2008.09.021

Holder PE, Wood CM, Lawrence MJ, Clark TD, Suski CD, Weber JM, Danylchuk AJ, Cooke SJ (2022) Are we any closer to understanding why fish can die after severe exercise? Fish Fish 23:1400–1417. https://doi.org/10.1111/faf.12696

Hothorn T, Bretz F, Westfall P (2008) Simultaneous inference in general parametric models. Biom J 50(3):346–363. https://doi.org/10.1002/bimj.200810425

Hussey J, LaRochelle L, Danylchuk AJ, Danylchuk SC, Cooke BWC, Cooke JTH, Cooke CJA, Cooke SJ (2025) Influence of four hook types across four hook removal tools, including bare hands, on the effectiveness of hook removal and reflex impairment of Bluegill (*Lepomis macrochirus*) captured from a lake in Eastern Ontario. Fish Manag Ecol 32(3):e12672. https://doi.org/10.1111/fme.12672

Janak JM, Brown RS, Colotelo AH, Pflugrath BD, Stephenson JR (2012) The effects of neutrally buoyant, externally attached transmitters in swimming performance and predator avoidance of juvenile Chinook salmon. Trans Am Fish Soc 141:1424–1432. https://doi.org/10.1080/00028487.2012.688915

Kieffer JD (2000) Limits to exhaustive exercise in fish. Comp Biochem Physiol A Mol Integr Physiol 126:161–179. https://doi.org/10.1016/S1095-6433(00)00202-6

LaRochelle L, Bernardi J, Madden JC, Brownscombe JW, Goodenough AM, Danylchuk AJ, Cooke SJ (2025a) Effects of recreational fishing gear type on reflex impairment and post-release swimming activity of Smallmouth Bass. Fish Manage Ecol 32(2):e12776. https://doi.org/10.1111/fme.12776

LaRochelle L, Griffin LP, Brownscombe JW, Elvidge CK, Hasler CT, Robichaud JA, Madden JC, Landsman SJ, Raoult V, Danylchuk AJ, Cooke SJ (2025b) On the behaviour of fish released following fisheries capture: methods, endpoints, and consequences. Rev Fish Sci Aquac 33(4):629–656. https://doi.org/10.1080/23308249.2025b.2518167

Lédée EJI, Heupel MR, Tobin AJ, Simpfendorfer CA (2015) Movements and space use of giant trevally in coral reef habitats and the importance of environmental drivers. Anim Biotelemetry 3:1–14. https://doi.org/10.1186/s40317-015-0024-0

Lennox RJ, Donaldson MR, Raby GD, Cook KV, LaRochelle L, Madden JC, Cooke SJ, Patterson DA, Hinch SG (2024) Using vitality indicators to predict survival of aquatic animals released from fisheries. Conserv Physiol 12(1):coae034. https://doi.org/10.1093/conphys/coae034

Lenth R (2024) _emmeans: estimated marginal means, aka least-squares means_. R Package Version 1(10):2

Lyle JM, Moltschaniwskyj NA, Morton AJ, Brown IW, Mayer D (2007) Effects of hooking damage and hook type on post-release survival of sand flathead (*Platycephalus bassensis*). Mar Freshw Res 58:445–453. https://doi.org/10.1071/MF06233

McCleave JD, Stred KA (1975) Effect of dummy telemetry transmitters on stamina of Atlantic salmon (*Salmo salar*) smolts. J Fish Res Board Can 32:559–563. https://doi.org/10.1139/f75-071

McLeod P (2016) GT: a flyfisher's guide to giant trevally. Merlin Unwin Books, United Kingdom

Meka JM, Margraf FJ (2007) Using a bioenergetic model to assess growth reduction from catch-and-release fishing and hooking injury in rainbow trout, *Oncorhynchus mykiss*. Fish Manage Ecol 14(2):131–139. https://doi.org/10.1111/j.1365-2400.2007.00533.x

Meyer CG, Holland KN, Papastamatiou YP (2007) Seasonal and diel movements of giant trevalley *Caranx ignobilis* at remote Hawaiian atolls: implications for the design of Marine Protected Areas. Mar Ecol Prog Ser 333:15–25. https://doi.org/10.3354/meps333013

Milligan CL (1996) Metabolic recovery from exhaustive exercise in rainbow trout. Comp Biochem Physiol A Mol Integr Physiol 113(1):51–60

Ostrand KG, Cooke SJ, Wahl DH (2004) Effects of stress on largemouth bass reproduction. N Am J Fish Manag 24:1038–1045. https://doi.org/10.1577/M02-154.1

Papastamatiou YP, Meyer CG, Kosaki RK, Wallsgrove NJ, Popp BN (2015) Movements and foraging of predators associated with mesophotic coral reefs and their

potential for linking ecological habitats. Mar Ecol Prog Ser 521:155–170. https://doi.org/10.3354/meps11110
Peake S, McKinley RS, Scruton DA, Moccia R (1997) Influence of transmitter attachment procedures on swimming performance of wild and hatchery-reared Atlantic salmon smolts. Trans Am Fish Soc 126(4):707–714
Pelzman RJ (1978) Hooking mortality of juvenile largemouth bass: *Micropterus salmoides*. Calif Fish Game 64:185–188
R Core Team (2024) R: a language and environment for statistical computing_. R Foundation for Statistical Computing, Vienna, Austria
Richard A, Dionne M, Wang J, Bernatchez L (2013) Does catch and release affect the mating system and individual reproductive success of wild Atlantic salmon (*Salmo salar* L.)? Mol Ecol 22:187–200. https://doi.org/10.1111/mec.12102
RStudio Team (2024) RStudio: Integrated Development for R. RStudio, PBC, Boston, MA
Shepard ELC, Wilson RP, Quintana F, Laich AG, Liebsch N, Albareda DA, Halsey LG, Gleiss A, Morgan DT, Myers AE, Newman C, Macdonald DW (2008) Identification of animal movement patterns using tri-axial accelerometry. Endanger Species Res 10:47–60. https://doi.org/10.3354/esr00084
Skomal GB (2007) Evaluating the physiological and physical consequences of capture on post-release survivorship in large pelagic fishes. Fish Manage Ecol 14:81–89. https://doi.org/10.1111/j.1365-2400.2007.00528.x
Stoot LJ, Cairns NA, Cull F, Taylor JJ, Jeffrey JD, Morin F, Mandelman JW, Clark TD, Cooke SJ (2014) Use of portable blood physiology point-of-care devices for basic and applied research on vertebrates – a review. Conserv Physiol 2(1):cou011. https://doi.org/10.1093/conphys/cou011
Sudekum AE, Parrish JD, Radtke RL, Ralston S (1991) Life history and ecology of large jacks in undisturbed, shallow, oceanic communities. Fish Bull 89:493–513
Talbot FH, Williams F (1956) Sexual colour differences in *Caranx ignobilis* (Frosk.). Nature 178:934. https://doi.org/10.1038/178934a0
Therneau T, Atkinson B (2023) _rpart: recursive partitioning and regression trees_. R Package Version 4(1):23
Thompson LA, Cooke SJ, Donaldson MR, Hanson KC, Gingerich A, Klefoth T, Arlinghaus R (2008) Physiology, behavior, and survival of angled and air-exposed Largemouth Bass. N Am J Fish Manag 28(4):1059–1068. https://doi.org/10.1577/M07-079.1
Thorstad EB, Næsje TF, Fiske P, Finstad B (2003) Effects of hook and release on Atlantic salmon in the River Alta, northern Norway. Fish Res 60:293–307. https://doi.org/10.1016/S0165-7836(02)00176-5
Trahan A, Chhor AD, LaRochelle L, Danylchuk AJ, Cooke SJ (2021) Influence of artificial lure hook type on hooking characteristics, handling, and injury of angled freshwater gamefish. Fish Res 243:106056. https://doi.org/10.1016/j.fishres.2021.106056
Verschuuren B, Zylstra M, Yunupingu B, Verschoor G (2015) Mixing waters: cross cultural approach to developing guidelines for fishers and boaters in the Dhimurru Indigenous Protected Area. Parks Aust 21:73–88
Wang Y, Wilkie MP, Heigenhauser GJF, Wood CM (1994) The analysis of metabolites in rainbow trout white muscle: a comparison of different sampling and processing methods. J Fish Biol 45:1587–1596. https://doi.org/10.1111/j.1095-8649.1994.tb00950.x
Wells RM, Baldwin J (2006) Plasma lactate and glucose flushes following burst swimming in silver trevally (Pseudocaranx limbatus: Carangidae) support the "releaser" hypothesis. Comp Biochem Physiol A 143(3):347–352. https://doi.org/10.1016/j.cbpa.2005.12.015
Wells RM, McIntyre RH, Morgan AK, Davie PS (1986) Physiological stress responses in big gamefish after capture: observations on plasma chemistry and blood factors. Comp Biochem Physiol A 84(3):565–571. https://doi.org/10.1016/0300-9629(86)90366-X
Wendelaar Bonga SE (1997) The stress response in fish. Physiol Rev 77(3):591–625. https://doi.org/10.1152/physrev.1997.77.3.591
White AJ, Schreer JF, Cooke SJ (2008) Behavioral and physiological responses of the congeneric largemouth (*Micropterus salmoides*) and smallmouth bass (*M. dolomieu*) to various exercise and air exposure durations. Fish Res 89:9–16. https://doi.org/10.1016/j.fishres.2007.08.008
Whitney NM, White CF, Anderson PA, Hueter RE, Skomal GB (2017) The physiological stress response, postrelease behaviour, and mortality of blacktip (*Carcharhinus limbatus*) caught on circle and J-hooks in the Florida recreational fishery. Fish Bull 4:532–544
Williams F (1958) Fishes of the family Carangidae in British East African waters. Ann Mag Nat Hist 13:369–430. https://doi.org/10.1080/00222935808651147
Wood CM (1991) Acid-base and ion balance, metabolism, and their interactions, after exhaustive exercise in fish. J Exp Biol 160:285–308. https://doi.org/10.1242/jeb.160.1.285
Wood AL, Butler JRA, Sheaves M, Wani J (2013) Sport fisheries: opportunities and challenges for diversifying coastal livelihoods in the Pacific. Mar Policy 42:305–314. https://doi.org/10.1016/j.marpol.2013.03.005