Fisheries Research 211 (2019) 231–237

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Sub-lethal responses of mahseer (*Tor khudree*) to catch-and-release recreational angling

Shannon D. Bower[a,d,*], Neethi Mahesh, Rajeev Raghavan[b,d], Andy J. Danylchuk[c], Steven J. Cooke[a]

[a] Fish Ecology and Conservation Physiology Laboratory, Department of Biology, Carleton University, 1125 Colonel By Dr., Ottawa, ON, K1S 5B6, Canada
[b] Department of Fisheries Resource Management, Kerala University of Fisheries and Ocean Studies, Kochi, 682 506, Kerala, India
[c] Department of Environmental Conservation, University of Massachusetts Amherst, 160 Holdsworth Way, Amherst, MA, 01003, USA
[d] Mahseer Trust, c/o The Freshwater Biological Association, East Stoke River Laboratory, Wareham, Dorset, BH20 6BB, United Kingdom

ARTICLE INFO

Handled by: Guest Editor

Keywords:
Best practices
Fish conservation
Indian fisheries
Mahseer
Recreational fisheries

ABSTRACT

Fishes exhibit a range of biological responses to the process of catch-and-release recreational angling. In the last decade, research has begun to consider how such fisheries interactions alter the behaviour (e.g., movement, feeding activity, reproduction) of fish upon release. In this study, we assessed reflex impairment and then affixed radio telemetry transmitters to 34 blue-finned mahseer (*Tor khudree*) angled on the Cauvery River, India, between February and May of 2015. We then tracked their movements over two time scales: continuously for 90 min post-release, and hourly over a 24 h period. When testing reflex impairment, mahseer were more likely to first lose orientation, followed by loss of tail grab response, then loss of regular operculum beats. Neither reflex impairment nor time taken for fish to swim away from the release site varied significantly with air exposure or handling time. Similarly, movement rates of mahseer were consistent amongst tagging periods. However, trends did indicate that larger fish subject to longer angling and handling times took longer to leave the release site, moved less during the initial release period, and moved less over a 24 h cycle. We recommend that anglers view impairment of multiple reflexes in blue-finned mahseer as an indication that caution in handling is warranted. We also recommend further study of size- and age-based differences in mahseer behaviour, including specific research on responses of trophy-sized mahseer to catch-and-release angling. Our work contributes to the understanding of sublethal behavioural consequences of catch-and-release while generating some of the first information to guide development of best practice guidelines for those catching and releasing blue-finned mahseer.

1. Introduction

Many anglers around the world practice catch-and-release (C&R), as an estimated two-thirds of ~47 billion fish caught during recreational fishing activities per year are released back into the water (Cooke and Cowx, 2004). Defined as 'the act of returning a fish to the water after capture, presumably unharmed' (Arlinghaus et al., 2007), the success of C&R as a conservation strategy is highly dependent on the degree of physiological disturbance (including injury) experienced by fishes during capture and handling. The level of physiological disturbance can range from mild physiological stress from which fish recover to severe physiological impairment which leads to post-release mortality (see reviews by Cooke and Suski, 2005; Arlinghaus et al., 2007). 'Sub-lethal consequences' refers to outcomes experienced by fishes that, while not resulting in death, do result in physiological or behavioural changes over the short to long-term (Cooke et al., 2002). These consequences can include increased susceptibility to post-release predation (a lethal outcome) through alterations in movement, changes in migration, feeding, or parental care patterns, and changes in habitat associations (Thorstad et al., 2003; Hanson et al., 2007; Suski et al., 2007; Klefoth et al., 2008). There is growing recognition that behavioural outcomes for animals that interact with humans can be used as objective assessments of animal condition needed to understand consequences of human activities on wildlife (Sutherland, 1998; Caro, 1999). Behavioural outcomes can also be used to identify opportunities to improve welfare of animals (Swaisgood, 2007).

Notwithstanding some inherent drawbacks to the approach, including challenges establishing control groups and accounting for

* Corresponding author at: Natural Resources and Sustainable Development, Department of Earth Sciences, Uppsala University, Cramérgatan 3, Visby, 621 57, Sweden.

E-mail address: Shannon.Bower@carleton.ca (S.D. Bower).

https://doi.org/10.1016/j.fishres.2018.11.004
Received 15 November 2017; Received in revised form 1 November 2018; Accepted 3 November 2018
Available online 26 November 2018
0165-7836/

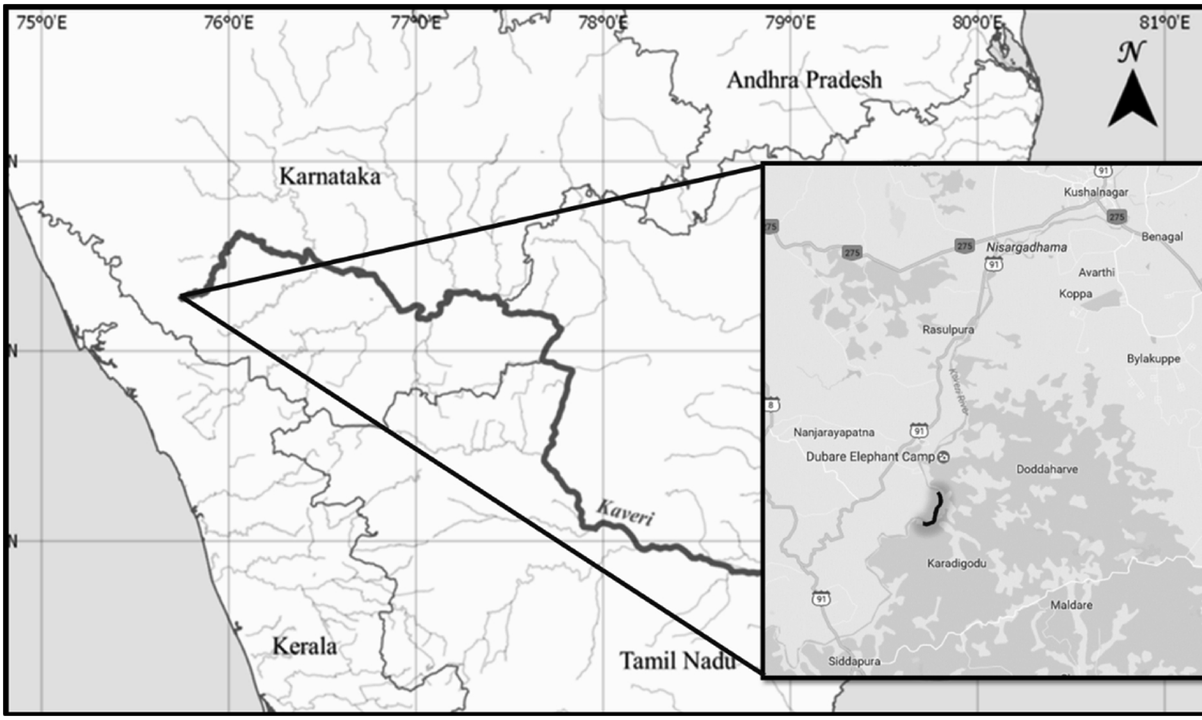

Fig. 1. Map indicating the location of the Cauvery River in South India, with the location of the field site in Valnur, Coorg emphasized in black (inset).

additional stress and mortality through the tagging process, biotelemetry is an ideal method for examining sub-lethal consequences of C&R on released fishes (Donaldson et al., 2008). Using radio telemetry, the movement of released fishes in various conditions can be remotely tracked without the need for further contact or handling. By comparing movement rates among groups (e.g., Lennox et al., 2015) or among tagging dates (e.g., Klefoth et al., 2008), the degree of increase or decrease in movement according to key angling variables, such as extended angling and air exposure times, can be measured and inferences made about sub-lethal effects of C&R. Individual sub-lethal effects may result in population-level disturbances, depending on parameters such as the amount of angling pressure and population size (Skomal, 2007), though drawing tangible linkages to population-level cascades is challenging due to the compounding factors influencing fish survival and fitness over time (Cooke et al., 2013). Regardless of challenges in gathering evidence connecting to population processes, maximizing the welfare and survival of fish from C&R is important for ensuring the sustainability of this common and socioeconomically valuable practice.

The mahseer recreational fishery in India was first documented as early as the 12th century (Nautiyal, 2014). Indian mahseer populations consist of eight valid species, five of which are endangered in their native ranges, including the two most popular game species *Tor khudree* (blue-finned mahseer; Raghavan, 2011) and *Tor putitora* (golden mahseer; Jha and Rayamajhi, 2010). Declines in the size and abundance of these target species were noted by anglers during the 1970s, leading to the formation of angling conservation groups and coalitions (e.g., Wildlife Association of South India [WASI], Coorg Wildlife Society [CWS]) who established angling camps and began collecting catch data (Pinder and Raghavan, 2013). Such groups promoted C&R fishing and hired local fishers to act as guides and guards of river reaches they managed (Gupta et al., 2015). Despite the cultural and recreational importance of these species, however, data deficiencies surrounding basic biology and ecology of mahseer are widespread (Raghavan et al., 2011; Pinder and Raghavan, 2013) and many questions about the suitability of the species for C&R remain.

A previous study examining the immediate responses of blue-finned mahseer to C&R indicated that while post-release mortality was likely to be low, extended angling times resulted in physiological stress responses such as significant increases in blood lactate, and air exposure led to increased reflex impairment (Bower et al., 2016). These results suggest that C&R activities may lead to sub-lethal consequences in blue-finned mahseer. Our team used radio telemetry to identify the presence of any sub-lethal consequences arising as a result of C&R activities in the mahseer recreational fishery of the Cauvery River, in Karnataka, India. Our objective for this study therefore, was to use changes in post-release movement rates as a proxy for sub-lethal disturbances to determine whether differences in key angling variables (angling time, handling time, air exposure) resulted in significant changes to post-release movement rates in *T. khudree* as a result of C&R. To our knowledge, this was the first freshwater biotelemetry study conducted in India.

2. Methods

2.1. Study site

Permission to conduct this study was sought and granted at four levels. We are grateful to the Animal Care Committee of Carleton University (Protocol 101845), the High Commission of India for granting a research visa based on study protocols, and Dr. Ramakrishna of the Karnataka Fisheries Department and the Fisheries Subcommittee of the Coorg Wildlife Society for allowing our team to conduct this work.

The Cauvery River runs 800 km from its headwaters in Talakaveri to the Bay of Bengal, through the Indian states of Karnataka, Tamil Nadu, Kerala, and Puducherry. The depth of the river fluctuates strongly according to monsoon period, with the shallowest depths and warmest temperatures closest to the study site typically occurring through the months of March to June (mean temperature = 28 °C) and the coolest temperatures and deepest water occurring during monsoon months from July to September (mean temperature = 24 °C; Central Water Commission, 2012). This study took place in Valnur, Coorg (Karnataka, India) along a 4 km stretch of the Cauvery River controlled by the Coorg Wildlife Society (CWS; Fig. 1) from February 19 – April 24, 2015. Mean water temperatures during this study were 27 ± 2 °C (range = 22 °C – 30 °C).

2.2. Angling and tagging procedures

Blue-finned mahseer (N = 34, total length [TL] range: 200–1050 mm) were angled throughout the study period using mid- and heavy-weight conventional rods and reels. Mahseer were caught using lures such as plastic shads and crankbaits and ragi (a flour paste bait mixture), commonly used methods in the area. In all cases, hook numbers were reduced such that lures and bait approaches made use of a single hook, however, in-line J hooks (Mustad Kaiju, 2/0) were used for lures while slightly offset hooks (Mustad Big Red, 2/0) were used for ragi bait. Angling time was recorded as the amount of time (s) taken from hook set to the removal of fish from the water. Air exposure time was recorded as the amount of time (s) taken from the removal of fish from the water to the placement of fish in the trough for tagging. Handling time was recorded as the amount of time (s) taken to process the fish from trough placement to release, including hook removal, the tagging process, and the assessment of reflex impairment (Davis, 2010) immediately prior to and after tagging. Reflex indicators were measured as a proxy for impairment in this study, as previous studies have indicated these indicators are highly predictive of post-release behavioural impairment and post-release mortality (e.g., Raby et al., 2012; Brownscombe et al., 2013). Three reflex indicators were measured on two occasions in order to separate impairment arising from angling from that of the combination of angling and tagging: ‘tail grab’, the presence of a burst swim response to being gripped by the caudal peduncle; ‘operculum beats’, the presence of steady (as opposed to irregular) operculum beats; and, ‘orientation’, the presence of the ability for the fish to right itself when placed upside down in water. A commonly used fourth indicator, ‘body flex’, the presence of torso flexion in the fish when gripped along the dorsoventral axis, was not used in this study as prior research on this species validating reflex impairment assessment for this species noted the overall lack of body flex responses in the species (see Bower et al., 2016).

Immediately after the first reflex assessment (reflex 1), landed mahseer were measured for TL (mm) and injury score, followed by the tagging procedure. While submerged in a water-filled trough with head covered, fish were affixed with one of two radio tags, depending on fish size (Advanced Telemetry Systems Inc., Seattle, USA, models F1970 [4.3 g] for fish > 450 mm TL and F1930 [2.4 g] for fish < 450 mm TL). Tags were placed dorsally, to the rear of the dorsal fin such that the antennae would not impede water flow. Fixation of the tags required using two hollow 1.5 in. 18 gauge needles to pierce dorsal musculature. Coated 0.8 mm wires attached to the radio tag were fed through the hollow needles and stoppered on the opposite side (as in Lennox et al., 2015). After tagging, mahseer were measured for a second reflex impairment score (reflex 2) and released. On release, the time taken for each fish to move 1 m, 5 m, and 10 m (referred to hereafter as ‘swim away times’) from the release site was recorded (s).

2.3. Tracking procedures

All fish were tracked from a walking trail immediately adjacent to the river using a handheld receiver (Communications Specialists, Inc., Orange, USA, model R-1000) and short, three-element handheld antenna. Fish positions were determined using successive gain reductions whereby the gain was reduced each time a position was pinpointed, until the most accurate position could be determined. Once identified, positions were recorded using a handheld GPS unit (Garmin Ltd., Schaffhausen, Switzerland, model GPSMAP 60cx) to within ± 5 m. This technique resulted in an established river position along the Y-axis (river length), but not along X- or Z- axes (river width or depth). To facilitate the comparison of distance measurements, positions were recorded using the Universal Transverse Mercator (UTM) system. These positions were later translated into standard latitudinal and longitudinal coordinates for mapping fish movements.

Bettoli and Osborne (1998) noted that mortality estimates in telemetry studies typically use stationary tags as a proxy for mortality. In this study, it was necessary to consider that tag loss or removal was also a possible explanation for stationary tags as a tag shedding rate has not been established for mahseer species. All tags that became stationary (N = 4) were attached to fish that had demonstrated no or very low reflex impairment and had shown movement consistent with live fish for days prior to cessation of movement. Additionally, of the four stationary tags that occurred in this study two occurred on the first two fish tagged, which were tagged using a weaker set of pliers, suggesting stationary positions were possibly caused by tag loss and not mortality (for an example of similar challenges in acoustic telemetry, see Yergey et al., 2012). Furthermore, of the two remaining stationary tags, one became stationary after witnessing a destructive fishing event using dynamite and the other tag was traced to a local midden, suggesting harvest was a possible outcome for these fish. Despite searching the areas for days, no dead fish were found and the tags could not be recovered. Thus, while it is not possible to rule out the possibility of mortality, we strongly suspect that any mortality that occurred did not occur as a result of either the C&R or tagging process.

On occasions where tags demonstrated no movement after four days, the fish were tracked multiple times daily to confirm that a stationary position was indeed occurring. If tags continued to demonstrate zero movement for three additional days (a total of seven days), the tag was considered lost and data was not analyzed from the initial point of movement cessation onwards. As such, tag loss did not interfere with post-release tracking or diel movement tracking sessions as no fish lost tags during the immediate post-release period, and fish demonstrating a permanently stationary position indicating tag loss were not included in diel movement tracking sessions.

2.3.1. Post-release tracking

Immediately after release, mahseer were tracked over a 90 min period, with positions established every five min. If released mahseer established a stationary location prior to the end of the 90 min tracking period, tracking continued until the end of the 90 min period (19 positions, including the initial release site). If released mahseer continued to move actively throughout the 90 min tracking period, tracking continued until a stationary period was established and confirmed (i.e., at least three measurements in the same location). Post-release tracking periods vary in the literature, e.g., up to 60 min to observe post-release predation in *Albula vulpes* (Danylchuk et al., 2007). In our study, post-release tracking periods were constrained by the time of day. On seven occasions, tracking during the initial release period was shorter than 90 min due to the arrival of dusk on the river (1900 h), which posed a safety hazard as elephant traffic was very common in the study reach at nightfall. However, on all but one occasion, fish tracked during twilight had established a stationary period prior to cessation of tracking.

2.3.2. Diel movement tracking

Mahseer were tracked over a full 24 h period on two occasions. Fish were located each hour over the course of a 24 h period, however, due to the presence of elephant traffic we were forced to cease tracking on three occasions and resume coverage of the 24 h period on a subsequent date when sufficient personnel were available to assist. The difficulty of tracking the river reach safely at night meant it was not possible to track each fish every hour (though positions were obtained for each fish throughout the 24 h period, for example, for some fish a data point may be missing for 0400 h, but positions for 0300 h and 0500 h were recorded). As a result, the average number of data points per fish in the diel movement portion of the study was 19 (range = 7 h – 23). As the river reach studied was too long to enable the tracking all of the study fish each hour, we opted to separate tracking sessions into two river reaches. The first reach was tracked on March 19th, March 29th, and

April 4th, 2015. The second reach was tracked on April 16th, April 17th, and April 23rd, 2015.

2.4. Data management and statistical analyses

Due to the non-normal distributions commonly associated with small sample size, non-parametric analyses were preferentially applied, however all variables were examined for homogeneity of variance and/or residual distribution prior to testing using Shapiro-Wilks test, Levene's test, or residual plots. Any variables displaying non-normal distribution were then transformed if parametric testing was indicated.

2.4.1. Angling variable analyses

Reflex scores 1 and 2 were compared using an Exact McNemar test to identify any significant differences between the two scores, as significant differences would suggest that the tagging process led to significantly more impairment than the angling process alone. To perform this test, reflex scores were reduced to a binary frequency (where 0 indicated 'unimpaired' and 1 indicated 'impaired') to increase power because so few mahseer generated impairment scores. We then used general linear regression models (logistic regression) to examine any significant contributions of angling variables (angling time, log air exposure time) to the reduced reflex 1 score and handling time to the reduced reflex 2 score. General linear models were used to determine whether increases in the angling variables (angling time, handling time, log air exposure) resulted in significant increases or decreases in release variables (all swim away times). General linear models were also used to evaluate whether the presence or absence of impairment (using reflex 2 scores) resulted in significant increases or decreases in swim away times.

2.4.2. Tracking variable analyses

Total distance travelled (m) by individual fish during all tracking periods was calculated as a sum of the distances travelled from previous coordinates to account for fish movement in upstream and downstream directions (hereafter referred to as 'total distance'). For example, a fish that travelled upstream by 50 m after release, before travelling downstream by a 100 m and then returning to the original release site would register a total travel distance of 200 m despite the net movement over the tracking period being 0 m. Similarly, a ratio measurement of total distance travelled (m) by the amount of time spent tracking (min; hereafter referred to as 'ratio distance') was developed to account for differences in the number of tracking measurements taken.

Post-release tracking variables were measured as: the distance travelled (m) over the first five min post-release, the distance travelled (m) over the first ten min post-release, ratio distance (m/min), and the longest distance travelled (m) between tracking measurements over the post-release period. Angling variables (angling time, air exposure time, handling time) and reflex scores were used as independent variables in general linear models respectively to identify any significant contributions to post-release tracking variables.

We generated descriptive statistics for the diel movement tracking sessions to identify time-based patterns of movement in *T. khudree*. Diel movement variables included the distance travelled per hr (m) and the longest distance covered between measurements per session (m). A general linear model was applied to determine the effect of tag days (the number of days since tagging and release) on mahseer movements as measured by distance travelled per hr (m) and the longest distance covered between measurements per session (m). All data are presented as mean ± standard deviation unless otherwise specified. All analyses were performed in R (version 3.3.3, © 2016, The R Foundation for Statistical Computing, Vienna, Austria).

3. Results

Blue-finned mahseer angled during this study (N = 34) ranged from 200 to 1050 mm TL (mean = 597 mm TL, SD = 189 mm). Of these, 15 mahseer were caught using single-hook lures such as plastic shads and crankbaits, and the remainder were caught using ragi (a flour paste bait mixture) on a single hook. All angled fish were hooked in the corner or centre of the mouth, and no fish in this study were deeply-hooked or foul-hooked, both of which are uncommon in this fishery (S. Bower, personal observation). Of the total number of fish caught and tagged (N = 34), four fish demonstrated stationary positions and tracking was discontinued as per the above protocol for stationary tags. Additionally, no tagged fish were recaptured during the study period.

3.1. Angling variables

Angling times ranged from 104 s to 1020s, with a mean of 362 ± 40 s. Handling times varied over a similar duration, ranging from 170 s to 1054s (mean = 539 ± 40 s), while air exposure ranged from 0 s to 149 s (mean = 30 ± 6 s). Angling time and handling time demonstrated a stronger linear relationship with 1 m and 5 m swim away times than air exposure, however logistic regression analysis indicated that neither increased angling time, handling time, nor log air exposure resulted in significant reflex impairment (angling time, $z = 0.76$, df = 32, p = 0.45; handling time, $z = -0.35$, df = 32, p = 0.72; log air exposure, $z = 0.89$, df = 32, p = 0.38; TL, $z = 1.12$, df = 32, p = 0.26).

3.2. Reflex impairment scores

Reflex 1 scores showed that six of 34 fish exhibited impairment (18%). Of these, five mahseer demonstrated impairment in one reflex (four lost orientation, one lost tail grab) and one mahseer demonstrated impairment in two reflexes (orientation and tail grab). Reflex 2 scores showed that seven of 34 fish exhibited impairment (21%). Of these, four demonstrated impairment in a single reflex (two lost orientation, one each lost tail grab and operculum beats) and three demonstrated impairment in two reflexes (all three lost orientation and tail grab). Of the six fish demonstrating impairment at the reflex 1 time point, two fish did not demonstrate impairment during the reflex 2 assessment, three fish demonstrated the same degree of impairment in both scores, and one fish demonstrated impairment in an additional reflex measurement (tail grab, in addition to orientation). Three fish that did not exhibit impairment during reflex 1 measurements exhibited impairment in reflex 2. There was no significant difference in impairment frequency between reflex 1 and reflex 2 scores (McNemar's $\chi^2 = 0.06$, df = 1, p = 0.81).

3.3. Post-release tracking period

Immediately after release, 29 mahseer were tracked over a 90 min period, with positions established every five min. All tagged mahseer reached the 10 m swim away distance in under a minute (Table 1). All but four tagged mahseer (14%) completed the 1 m swim away distance in fewer than 15 s and all but five mahseer (17%) completed the 5 m swim away distance in under 20 s. Values for the 10 m swim away time were slightly more dispersed, however only six fish (21%) required longer than 20 s to reach this distance.

The distances travelled by mahseer were higher in the first five min

Table 1
Mean, median, and range of swim away times, taken for release mahseer to travel 1 m, 5 m, and 10 m distances from the release site.

	Mean	Median	Smallest Value	Largest Value
Swim Away 1 m (s)	6 s ± 2 s	2 s	1 s	38 s
Swim Away 5 m (s)	8 s ± 2 s	4 s	2 s	42 s
Swim Away 10 m (s)	12 s ± 2 s	7 s	3 s	47 s

Table 2
Mean (± standard deviation), median, and range values for tracking variables during the initial post-release tracking period (90 min).

Tracking Variables	Mean	Median	Smallest Value	Largest Value
Distance travelled in first 5 minutes (m)	33 ± 8	18	0	164
Distance travelled in first 10 minutes (m)	47 ± 9	28	0	200
Ratio Distance (m/min)	12 ± 2	11	0	26
Longest distance travelled between measurements (m)	65 ± 8	51	0	164

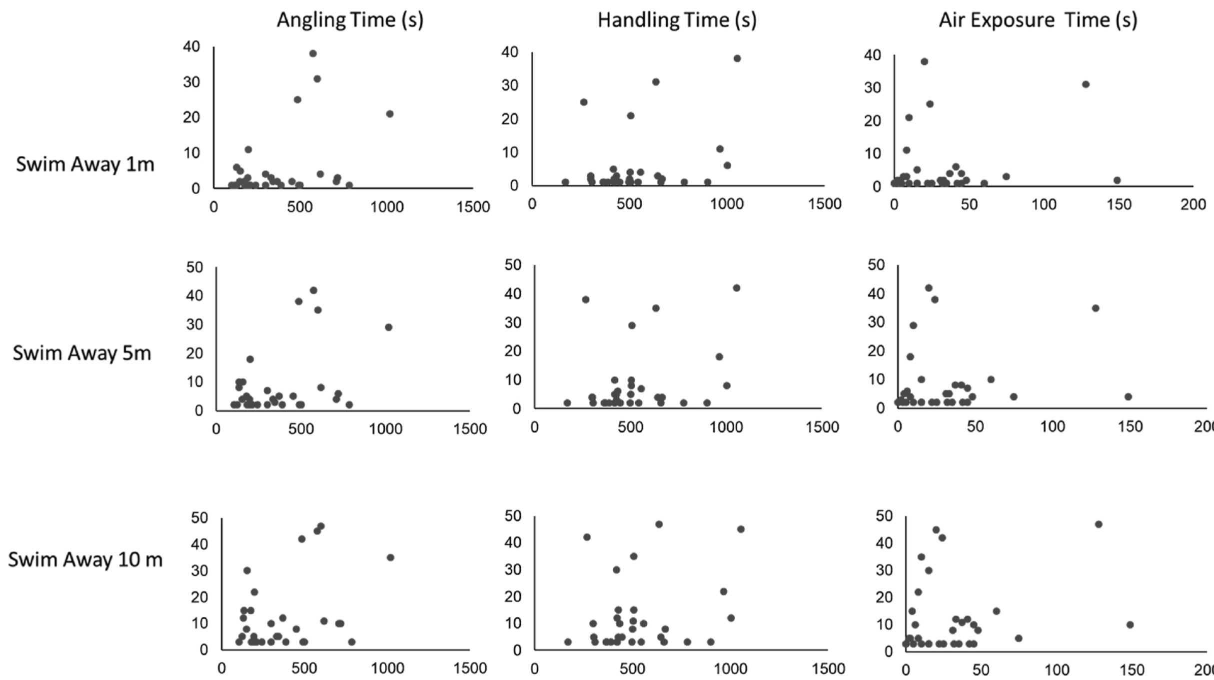

Fig. 2. Linear plots, including trendlines, of angling variables: angling time (s), handling time (s), and air exposure time (s); and swim away times: the time taken to travel 1 m, 5 m, and 10 m away from the release site.

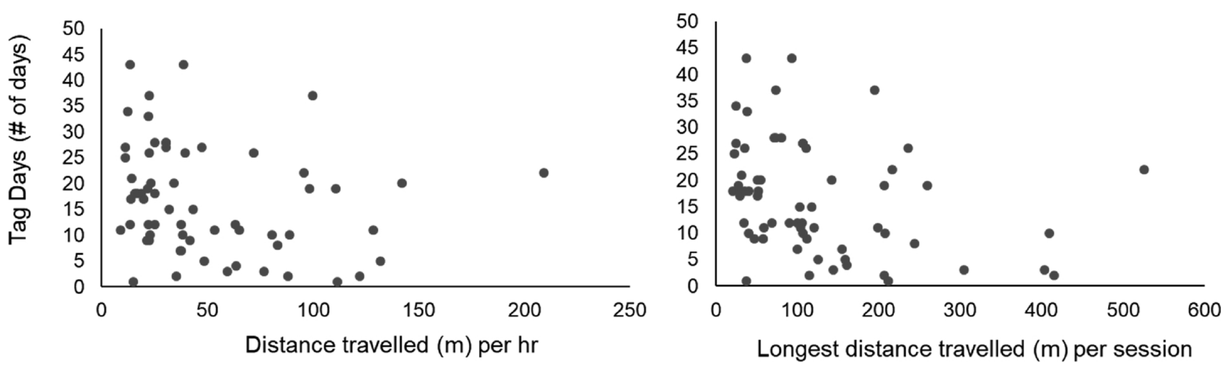

Fig. 3. Relationship between the linear distance travelled (m) per hour and the number of days since tagging is shown at left, and the relationship between the longest distance travelled (m) during the tagging sessions and the number of days since tagging is shown at right. Slightly negative trends in both images demonstrate that fish with fewer tag days moved more and exhibited longer travel distances, however neither of these relationships were statistically significant.

post-release than for ten min post-release (Table 2). Both initial measurements (5 min and 10 min post-release) demonstrated higher rates of movement than subsequent measurements, as indicated by ratio distance. In 29% of released fish, the longest distance measured during the travel period occurred during the first 10 min of tracking (largest value, Table 2). Movement patterns post-release were not significantly correlated with angling metrics, including angling time, handling time, and air exposure, nor was reflex 2 a significant predictor of increased or decreased movement. Slightly negative linear relationships were noted in visualizations suggesting increasing TL as a predictor of decreasing movement rates, however, these trends were not statistically significant either (Fig. 2).

3.4. Diel movement tracking period

Over the 24 h tracking periods, 28 released mahseer (mean tag days = 16 ± 1, range = 1 tag day – 43 tag days) were tracked for an average of 19 h (range = 7 h – 23 h). The mean distance mahseer travelled per session was 376 m ± 38 m (range = 25 m – 1221 m), with a mean distance per hr of 50 m/hr ± 5 m/hr (range = 9 m/hr – 209 m/hr). There were three peaks of movement over the 24 h time period, as measured by the longest distance travelled between measurements (m): one peak occurring in the late morning (0800 h – 1000 h), one peak occurring in the late afternoon (1400 h – 1900 h), and a smaller peak during the middle of the night (0200 - 0400 h). Plots of the data suggested that there was a negative linear relationship between tag days and both dependent variables (distance travelled per hr [m], longest distance travelled between measurements per session [m]) such that fish with fewer tag days moved more, but these relationships were not statistically significant (Fig. 3).

4. Discussion

The results of this study provide important considerations for angling and handling behaviours and offer the first glimpse into post-release movement patterns of the blue-finned mahseer. We found that post-release movement patterns were not significantly correlated with angling metrices, despite the extreme nature of the angling and handling when combined with the tagging process and the wide range of angling, handling, and air exposure times. Studies examining the consequences of C&R are an integral part of proactive fisheries management (Cooke and Schramm, 2007), particularly when C&R fisheries target endangered or migratory species and species prone to post-release predation (e.g., Thorstad et al., 2004; Danylchuk et al., 2007). Sub-lethal disturbances and post-release behaviour are understudied components of C&R (Cooke et al., 2013) that should be considered important research for the management of any species whereby C&R activities are presented as a conservation strategy.

That none of the angling variables were significant predictors of reflex or behavioural impairment suggest that further research to identify factors or interactive influences that contribute to relative changes in stress response among mahseer is warranted. There were no significant differences between reflex 1 scores (accounting for reflex impairment arising from the angling process, including air exposure) and reflex 2 scores (accounting for reflex impairment arising from the combination of the angling and handling process, including tagging) in this study. While this suggests that blue-finned mahseer were not significantly more impaired by the handling and tagging process than by the angling process, the impairment rate (18% for reflex 1, 21% for reflex 2) confirms that angling activities are stressors for this species. As our angling and handling times were all within what would be considered reasonable, “real world” timelines for blue-finned mahseer of similar size, it is reasonable to conclude that use and promotion of best practices that minimize angling and handling time, such as choosing appropriate gear to minimize unnecessarily fight times (Cooke and Suski, 2005) and handling fish properly to reduce stress (e.g, minimize air exposure, Cook et al., 2015) should also be recommended for this species.

Using reflex impairment indicators to predict mortality and measure impairment in fishes allows researchers to gather data quickly and with minimal disturbance (Cooke et al., 2012), and can also be valuable to anglers. For both reflex 1 and reflex 2 scores measured in this study, impairment in mahseer appeared to follow a pattern such that orientation was typically the first reflex lost. Mahseer that exhibited impairment in two reflexes lost orientation and tail grab. This finding accords with previous research on the same species (*T. khudree*, Bower et al., 2016) and other species (e.g., *Albula vulpes*, Brownscombe et al., 2013), and may be of particular value to anglers, who may use the combined loss of orientation and tail grab as an indicator that a mahseer they have caught is likely to be impaired and should be handled and released with caution and care. For example, anglers who note the impairment of both reflexes should consider foregoing photo-taking, or at minimum ensure that the process is brief and occurs with the fish submerged in water.

Angling and handling time showed a positive linear relationship with swim away times, particularly the time taken to swim 1 m and 5 m away from the release site. This relationship was not statistically significant once fish length was controlled for, which suggests, intuitively, that larger fish were subjected to longer angling and handling times, and took longer to leave the release site. Similarly, while mahseer tended to be most active in the first ten min post-release, a slightly negative trend between post-release movement rates and total length indicated that larger fish moved less during the first ten min post-release. This suggests that while post-release behaviour alterations are minor under similar conditions, they do occur and may be more pronounced in larger mahseer. Anecdotally, trophy-sized mahseer are also the most likely to suffer from post-release predation by crocodiles (Aiyappa C.P., personal communication).

That mahseer moved more in the earlier post-release period (i.e., the first 10 min) is consistent with the results of a study by Thorstad et al. (2003), who found that the post-release period for two large cichlid species on the Zambezi River featured increased movement rates compared to post-recovery movement rates. Only two fish larger than 15 kg were landed during this study, but this finding combined with anecdotal suggestions that post-release predation of large mahseer is a possibility lends support to the need for further study exploring the responses and fate of trophy-sized mahseer post-release, as these fish are the most highly-prized and sought after by local anglers, and are likely the most highly fecund.

The diel movement tracking sessions included mahseer tagged from one to 43 days previously, and this period likely covers the return to metabolic and behavioural baseline (pre-angling). Though a recovery profile for mahseer has yet to be generated, recovery profiles for other species have found that blood lactate returns on baseline levels in hours, not days, depending on conditions (e.g., approximately 6 h in rainbow trout [*Oncorhynchus mykiss*] held in still water and approximately 4 h for rainbow trout held in flowing water, Milligan et al., 2000). In simulated recreational angling captures where fish were exercised to exhaustion, heart rates of adult migrating coho salmon (*Onchorhynchus kisutch*) required 16 h to return to baseline levels compared to 7.6 h after simulated beach seining (Donaldson et al., 2010). Results of analysis of the diel movement tracking period suggested that fish with fewer tag days moved more over the course of 24 hs than fish tagged less recently (also consistent with Thorstad et al., 2003). As with the findings of the immediate post-release period, these results were not statistically significant once fish length was accounted for. This may indicate that differences in movement are linked more to size- or age-based behavioural differences than to C&R activities. We acknowledge that the study took place over a single season, suggesting that this study would fail to pick up longer term variation that could arise resulting from changes in temperature regime, or other long-term patterns (e.g., as seen in salmonids, Raby et al., 2016). However, we specifically chose to conduct this study during the most extreme of the annual conditions (highest air and water temperatures, combined with lowest flows) for this reason. Given the lack of evidence of sub-lethal consequences arising from combined C&R and tagging activities during the time of year with highest water temperatures and lowest flows, we feel it is reasonable to conclude that these findings could be considered a conservative estimate of blue-finned mahseer responses to similar angling practices at other times of year in the Cauvery River.

5. Conclusion

The conservation value of considering sub-lethal consequences of fisheries interactions is particularly important for recreationally fished species that are considered threatened. While *T. khudree* are listed as “endangered” in their native range (Raghavan, 2011), it is important to note that the study group represents a stocked population, one that has possibly contributed to the decline of another native mahseer species in the Cauvery River (Pinder et al., 2015). However, as wild populations of *T. khudree* face marked decline in their native range (Raghavan, 2011), these hatchery-bred specimens may be the only closely-related stable population. As such, the research conducted on this species is valuable to understanding mahseer responses to C&R under similar conditions but should not be applied to all mahseer species without similar study. Our work indicates that behavioural consequences of C&R activities to blue-finned mahseer were not distinguishable despite wide-ranging differences in angling time, handling time, and air exposure time. However, the slight negative (though not significant in this study) trends in decreased movement post-release for larger blue-finned mahseer also indicate that mahseer behaviour after release may be influenced by size, suggesting research on behavioural consequences of C&R should include studies of trophy-sized mahseer.

Improved understanding of habitat use and behavioural responses to key threats such as fragmentation and stocking regimes can help to predict population-level responses to ongoing changes in the environment (Sutherland, 1998). Identifying typical patterns of movement after C&R activities in mahseer not only helps to support sustainable management of this species from a fisheries perspective, but also provides valuable baseline data to support such a behavioural conservation approach.

Acknowledgements

Bower is supported by a Mitacs Globalink Research Award, Too Big to Ignore (TBTI), and the Ontario Graduate Scholarship fund. Cooke is supported by NSERC and the Canada Research Chairs Program. Danylchuk is supported by the < GS5 > National Institute of Food and Agriculture, U.S. Department of Agriculture < GS5 > , the < GS6 > Massachussetts Agriculture Experiment Station < GS6 > , and < GS7 > the Department of Environmental Conservation < GS7 > . We would also like to extend our sincere gratitude to the Karnataka Fisheries Department and the members and governing council, including the Fishing Subcommittee, of the Coorg Wildlife Society for their support and cooperation throughout this study. In particular, the support of the chairman of the Fishing Subcommittee, Aiyappa C.P., and that of Shyam Aiyappa, Sandeep Chakrabarti, Derek D'Souza, and Raja P.K. were integral to the success of this research. We also greatly appreciate the efforts of volunteer anglers who assisted with data collection throughout the project, including Ambily Nair, Alexis Greenwood, Marcus Greenwood, Saravanan Shanmugam, Raghuram Gopalakrishnan, Yohann De Souza, Dayan Mandappa, Bopanna Pattada, Ajay Bopanna Kodandera, Vinnay Appanna, Jagrath Belliapa Chendanda, Maya D'Souza, and Devaiah Chendanda. It was an honour to spend time on the river with all of you.

References

Arlinghaus, R., Cooke, S.J., Lyman, J., Policansky, D., Schwab, A., Suski, C., Sutton, S.G., Thorstad, E.B., 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. 15 (1-2), 75–167.

Bettoli, P.W., Osborne, R.S., 1998. Hooking mortality and behavior of striped bass following catch and release angling. N. Am. J. Fish. Manag. 18 (3), 609–615.

Bower, S.D., Danylchuk, A.J., Raghavan, R., Clark-Danylchuk, S.E., Pinder, A.C., Cooke, S.J., 2016. Rapid assessment of the physiological impacts caused by catch-and-release angling on blue-finned mahseer (*Tor* sp.) of the Cauvery River, India. Fish. Manag. Ecol. 23 (3-4), 208–217.

Brownscombe, J.W., Thiem, J.D., Hatry, C., Cull, F., Haak, C.R., Danylchuk, A.J., Cooke, S.J., 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.

Caro, T., 1999. The behaviour–conservation interface. Trends Ecol. Evol. 14 (9), 366–369.

Central Water Commission, 2012. Hydrological Data Directorate, Information Systems Organization, Water Planning & Projects Wing. Central Water Commission, New Delhi 680 pp.

Cook, K.V., Lennox, R.J., Hinch, S.G., Cooke, S.J., 2015. Fish out of water: how much air is too much? Fisheries 40 (9), 452–461.

Cooke, S.J., Schreer, J.F., Dunmall, K.M., Philipp, D.P., 2002. Strategies for quantifying sub-lethal effects of marine catch-and-release angling: insights from novel freshwater applications. American Fisheries Society Symposium 121–134.

Cooke, S.J., Cowx, I.G., 2004. The role of recreational fishing in global fish crises. BioScience 54 (9), 857–859.

Cooke, S.J., Suski, C.D., 2005. Do we need species-specific guidelines for catch-and-release recreational angling to effectively conserve diverse fishery resources? Biodivers. Conserv. 14 (5), 1195–1209.

Cooke, S.J., Schramm, H.L., 2007. Catch-and-release science and its application to conservation and management of recreational fisheries. Fish. Manag. Ecol. 14 (2), 73–79.

Cooke, S.J., Hinch, S.G., Donaldson, M.R., Clark, T.D., Eliason, E.J., Crossin, G.T., Raby, G.D., Jeffries, J.M., Lapointe, M., Miller, K., Patterson, D.A., Farrell, A.P., 2012. Conservation physiology in practice: how physiological knowledge has improved our ability to sustainably manage Pacific salmon during up-river migration. Philos. Trans. R. Soc. B: Biol. Sci. 367 (1596), 1757–1769.

Cooke, S.J., Donaldson, M.R., O'connor, C.M., Raby, G.D., Arlinghaus, R., Danylchuk, A.J., Hanson, K.C., Hinch, S.G., Clark, T.D., Patterson, D.A., Suski, C.D., 2013. The physiological consequences of catch-and-release angling: perspectives on experimental design, interpretation, extrapolation and relevance to stakeholders. Fish. Manag. Ecol. 20 (2-3), 268–287.

Danylchuk, S.E., Danylchuk, A.J., Cooke, S.J., Goldberg, T.L., Koppelman, J., Philipp, D.P., 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), 127–133.

Davis, M.W., 2010. Fish stress and mortality can be predicted using reflex impairment. Fish Fish. 11 (1), 1–11.

Donaldson, M.R., Arlinghaus, R., Hanson, K.C., Cooke, S.J., 2008. Enhancing catch and release science with biotelemetry. Fish Fish. 9 (1), 79–105.

Donaldson, M.R., Clark, T.D., Hinch, S.G., Cooke, S.J., Patterson, D.A., Gale, M.K., Frappell, P.B., Farrell, A.P., 2010. Physiological responses of free-swimming adult coho salmon to simulated predator and fisheries encounters. Physiol. Biochem. Zool. 83 (6), 973–983.

Gupta, N., Bower, S.D., Raghavan, R., Danylchuk, A.J., Cooke, S.J., 2015. Status of recreational fisheries in India: development, issues, and opportunities. Rev. Fish. Sci. Aquac. 23 (3), 291–301.

Hanson, K.C., Cooke, S.J., Suski, C.D., Philipp, D.P., 2007. Effects of different angling practices on post-release behaviour of nest-guarding male black bass, *Micropterus* spp. Fish. Manag. Ecol. 14, 141–148.

Jha, B.R., Rayamajhi, A., 2010. *Tor putitora*. The IUCN Red List of Threatened Species 2010. e.T166645A6254146. https://doi.org/10.2305/IUCN.UK.2010-4.RLTS.T166645A6254146.en. Downloaded on 30 August 2017.

Klefoth, T., Kobler, A., Arlinghaus, R., 2008. The impact of catch-and-release angling on short-term behaviour and habitat choice of northern pike (*Esox lucius L.*). Hydrobiologia 601 (1), 99–110.

Lennox, R.J., Uglem, I., Cooke, S.J., Næsje, T.F., Whoriskey, F.G., Havn, T.B., Ulvan, E.M., Solem, O., Thorstad, E.B., 2015. Does catch-and-release angling alter the behavior and fate of adult Atlantic Salmon during upriver migration? Trans. Am. Fish. Soc. 144 (2), 400–409.

Milligan, C.L., Hooke, G.B., Johnson, C., 2000. Sustained swimming at low velocity following a bout of exhaustive exercise enhances metabolic recovery in rainbow trout. J. Exp. Biol. 203 (5), 921–926.

Nautiyal, P., 2014. Review of the art and science of indian mahseer (Game fish) from nineteenth to twentieth century: road to extinction or conservation? Proc. Natl. Acad. Sci. India Sect. B: Biol. Sci. 84 (2), 215–236.

Pinder, A.C., Raghavan, R., 2013. Conserving the endangered mahseers (*Tor* spp.) of India: the positive role of recreational fisheries. Curr. Sci. 104 (11), 1472–1475.

Pinder, A.C., Raghavan, R., Britton, J.R., 2015. The legendary hump-backed mahseer *Tor* sp. of India's River Cauvery: an endemic fish swimming towards extinction? Endanger. Species Res. 28 (1), 11–17.

Raby, G.D., Casselman, M.T., Cooke, S.J., Hinch, S.G., Farrell, A.P., Clark, T.D., 2016. Aerobic scope increases throughout an ecologically relevant temperature range in coho salmon. J. Exp. Biol. 219 (12), 1922–1931.

Raby, G.D., Donaldson, M.R., Hinch, S.G., Patterson, D.A., Lotto, A.G., Robichaud, D., et al., 2012. Validation of reflex indicators for measuring vitality and predicting the delayed mortality of wild coho salmon bycatch released from fishing gears. J. Appl. Ecol. 49 (1), 90–98.

Raghavan, R., 2011. *Tor khudree*. The IUCN Red List of Threatened Species 2011. e.T169609A6653249. https://doi.org/10.2305/IUCN.UK.2011-1.RLTS.T169609A6653249.en. Downloaded on 30 August 2017.

Raghavan, R., Ali, A., Dahanukar, N., Rosser, A., 2011. Is the Deccan Mahseer, Tor khudree (Sykes, 1839)(Pisces: cyprinidae) fishery in the Western Ghats Hotspot sustainable? A participatory approach to stock assessment. Fish. Res. 110 (1), 29–38.

Skomal, G.B., 2007. Evaluating the physiological and physical consequences of capture on post-release survivorship in large pelagic fishes. Fish. Manag. Ecol. 14 (2), 81–89.

Suski, C.D., Cooke, S.J., Danylchuk, A.J., O'Connor, C.M., Gravel, M.A., Redpath, T., Hanson, K.C., Gingerich, A.J., Murchie, K.J., Danylchuk, S.E., Koppelman, J.B., Goldberg, T.L., 2007. Physiological disturbance and recovery dynamics of bonefish (Albula vulpes), a tropical marine fish, in response to variable exercise and exposure to air. Comp. Biochem. Physiol., Part A: Mol. Integr. Physiol. 148 (3), 664–673.

Sutherland, W.J., 1998. The importance of behavioural studies in conservation biology. Anim. Behav. 56 (4), 801–809.

Swaisgood, R.R., 2007. Current status and future directions of applied behavioral research for animal welfare and conservation. Appl. Anim. Behav. Sci. 102 (3), 139–162.

Thorstad, E.B., Næsje, T.F., Fiske, P., Finstad, B., 2003. Effects of hook and release on Atlantic salmon in the River Alta, northern Norway. Fish. Res. 60 (2), 293–307.

Thorstad, E.B., Hay, C.J., Næsje, T.F., Chanda, B., Økland, F., 2004. Effects of catch-and-release angling on large cichlids in the subtropical Zambezi River. Fish. Res. 69 (1), 141–144.

Yergey, M.E., Grothues, T.M., Able, K.W., Crawford, C., DeCristofer, K., 2012. Evaluating discard mortality of summer flounder (Paralichthys dentatus) in the commercial trawl fishery: developing acoustic telemetry techniques. Fish. Res. 115, 72–81.