








# Understanding the consequences of intermittent and repeated air exposure events on Bluegill in the context of recreational fishing

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## ABSTRACT

**Objective:** It is common for recreational anglers to expose fish to air during handling and admiration, leading to a variety of sublethal consequences, with potential for mortality if thresholds are exceeded. To date, however, there has been no research on the extent to which intermittent air exposure versus a single continuous air exposure period affects fish condition or survival. The objective of our study was to address that issue using Bluegill *Lepomis macrochirus* as a model by assessing the effect of different durations of intermittent air exposure periods on their immediate reflex impairment prior to release and their short-term survival.

**Methods:** We angled Bluegill and exposed them to nine different air exposure treatments (including relevant controls), some with even intermittent air exposure (e.g., 10 s water/air) and others with uneven intermittent air exposure (e.g., 90 s air/10 s water), until a total of 180 s of air exposure was achieved. We then tested each fish for equilibrium status, immediate and delayed (12 h later) burst reflex response, and mortality over a 12-h holding period.

**Results:** The control fish had negligible reflex impairments, whereas the fish that were exposed to air had consistent reflex impairment independent of the air exposure regime. Additionally, smaller fish were more prone to mortality, suggesting that more care needs to be given to smaller Bluegill (total length <150 mm) during a capture event.

**Conclusions:** These results suggest that accumulated air exposure of 180 s, even if intermittent, can cause reflex impairment in Bluegill. Our work also suggests that there is functionally no difference between continuous and intermittent air exposure in the context that was assessed here.

**KEYWORDS:** air exposure, catch and release, fish behavior, recreational fishing

## LAY SUMMARY

Anglers have wondered whether a helpful practice in an angling event is to intermittently immerse fish in water after they are exposed to air. We found that for Bluegill, there were no benefits from intermittently immersing the fish in water and that smaller Bluegill should be handled with more care.

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## INTRODUCTION

An estimated 47 billion fish are caught worldwide annually by recreational anglers (Cooke & Cowx, 2004). Among these, an estimated two-thirds of the captured fish are released (Cooke & Cowx, 2004) due to a variety of reasons, including angler conservation ethic and compliance with regulations (Arlinghaus et al., 2007). For catch-and-release angling to be an effective management strategy, it is assumed that the released fish survive with negligible or short-lived sublethal effects (Cooke & Schramm, 2007; Cooke & Suski, 2005; Muoneke & Childress, 1994). Captured fish accrue some level of injury (e.g., hook wounds; Meka, 2004) and stress (e.g., exhaustion from the fight; LaRochelle et al., 2025) from being angled, and some fish die (Arlinghaus et al., 2007; Muoneke & Childress, 1994). Given the popularity of recreational angling and the number of fish that are caught and released, a growing body of scientific evidence is informing anglers about the best practices to reduce adverse effects on individual fish (Brownscombe et al., 2017).

Air exposure is one of the most commonly occurring stressors during an angling event due to hook removal, weighing and measuring fish, and the general admiration of the fish (Cook et al., 2015; Cooke & Suski, 2005; Ferguson & Tufts, 1992). Air exposure can also be influenced by angler experience (e.g., Mullen et al., 2020), hooking location (Cooke & Danylchuk, 2020), hook type (Cooke et al., 2022), and unhooking method (Vermaire et al., 2025). Although there are many aspects of a catch-and-release event that can be detrimental to fish, air exposure has received notable attention (Cook et al., 2015). Air exposure contributes to acidosis (Ferguson & Tufts, 1992; Suski et al., 2004), reduces gas exchange (Ferguson & Tufts, 1992), increases the likelihood of cardiovascular consequences (Cooke et al., 2001), increases recovery times (Cooke et al., 2004; Suski et al., 2004), and elevates the accumulation of damaging metabolites (Suski et al., 2004). Furthermore, during air exposure, physical damage occurs when the gill lamellae collapse and the gill filaments adhere together (Ferguson & Tufts, 1992).

All of the above effects of air exposure can contribute to impaired reflexes (e.g., Gingerich et al., 2007; Robichaud et al., 2024) and swimming performance (e.g., Schreer et al., 2005) that can contribute to postrelease mortality (e.g., as a result of hypoxia or postrelease predation). Research has revealed a wide range of impairments in locomotion and even fitness (e.g., Arlinghaus et al., 2009; Cooke et al., 2000, 2013; Danylchuk et al., 2007). It is common for air exposure to reduce postrelease locomotor activity, which has negative implications for predator avoidance (Arlinghaus et al., 2009; Cooke & Philipp, 2004; Davis & Parker, 2004; Mesa, 1994; Rapp et al., 2014; Schreer et al., 2005; Thompson et al., 2008). Furthermore, prolonged air exposure can induce behavioral changes that diminish the quality of the parental care that is provided to broods, thus having negative implications for recruitment (Cooke et al., 2002; Gingerich et al., 2007; Hanson et al., 2007).

In some instances, anglers may re-immerses fish underwater in between periods of air exposure, assuming that this will counter some of the negative effects of air exposure events. Although many studies have quantified the effects of air exposure on fish (Cook et al., 2015), no study has examined the consequences of repeated intermittent air exposure relative to continuous air exposure. The objective of our study was to

assess the effect of different durations of intermittent air exposure periods on the immediate and delayed reflex impairment prior to release and survival after release in Bluegill *Lepomis macrochirus*. We used Bluegill as a model species because they are a popular centrarchid species that is targeted by recreational anglers across North America (Quinn & Paukert, 2009).

## METHODS

### Study site and fish capture

This study was conducted at the Queen's University Biological Station (QUBS), located on Lake Opinicon, Ontario, Canada (44°34'N, 76°19'W), from June 7 to 12, 2024. The surface water temperatures during the study period ranged from 21°C to 23.5°C. Lake Opinicon is a mesotrophic lake with an average depth of 2.5 m and a maximum depth of approximately 11 m that hosts a variety of commonly targeted species, including Bluegill. Bluegill for this study were collected via angling from boats in shallow water (<2 m) using medium action spinning rods, size 6–8 hooks, and small artificial maggots as bait. Air exposure was limited to <10 s during hook removal, and fight times were <20 s. This research was conducted under a Scientific Collection Permit that was authorized by the Ontario Ministry of Natural Resources, and all the described methodologies adhered to animal care protocols that were approved by Carleton University.

After capture, the fish were immediately placed into coolers or live wells that were filled with ambient water and remained on the boat for a short time (<1 h) before being transported back to QUBS for acclimation. Upon arrival at QUBS, the fish were released into a 150-gal (approximately 568 L) trough that contained an air stone for oxygenation and allowed to acclimate for 30 min prior to testing. At any point during the experiment, there were fewer than 30 fish released into the trough. During acclimation, the water was replaced every 10 min to maintain water temperature and quality (within similar parameters of lake water temperature and quality). Any fish that were identified as hybrids (Bluegill × Pumpkinseed *Lepomis gibbosus*) that took longer than 10 s to land (see Gingerich et al., 2007), that were under 130 mm (to test for most commonly recreationally angled sizes), that displayed visible bleeding, or that were hooked in any areas other than the upper and lower outer jaw (Cooke et al. 2003) were excluded from this study.

### Treatments and reflex testing

The sampled fish were randomly assigned to one of nine possible air exposure treatments (simulating potential air exposure intervals typically experienced during angling events) in which the order was standardized and repeated to control for bias. Other than the first treatment (no air exposure), air exposure measures were repeated until a total of 180 s of air exposure was achieved (to simulate approximate maximum handling times that may occur during an angling event).

1. 0 s air exposure (i.e., control)
2. 180 s continuous air exposure
3. 10 s air/water (10 s of air exposure, followed by 10 s of water exposure, 10 s of air exposure, and 10 s of water exposure until the fish was exposed to air 18 times)

4. 30 s air/water (30 s of air exposure, followed by 30 s of water exposure, 30 s of air exposure, 30 s of water exposure, 30 s of air exposure, 30 s of water exposure, 30 s of air exposure, 30 s of water exposure, and 30 s of air exposure)
5. 60 s air/water (60 s of air exposure, followed by 60 s of water exposure, 60 s of air exposure, 60 s of water exposure, and 60 s of air exposure)
6. 90 s air/water (90 s of air exposure, followed by 90 s of water exposure and 90 s of air exposure)
7. 90 s air/10 s water (90 s of air exposure, followed by 10 s of water exposure and 90 s of air exposure)
8. 90 s air/30 s water (90 s of air exposure, followed by 30 s of water exposure and 90 s of air exposure)
9. 90 s air/60 s water (90 s of air exposure, followed by 60 s of water exposure and 90 s of air exposure).

During trials, each fish was held out of the water using a small, standard 20.3-cm net to reduce human contact while also alleviating the potential for dropping the fish. After each trial, the fish were immediately tested for the two reflexes: equilibrium and burst escape response (i.e., tail grab; [Lennox et al., 2024](#)). The equilibrium test was conducted by turning the fish upside down and recording whether the fish could right itself within 3 s (see [Hussey et al., 2025](#)). The burst escape test was conducted by grabbing the tail of the fish and assessing its ability to quickly propel itself and escape on the first grab (see also, [Hussey et al., 2025](#)). Being binary responses, both of these variables were recorded as yes (0) or no (1). After these two initial tests, the fish were measured for total length (mm) and tagged with a T-anchor tag (Floy Manufacturing) while being held in a water-filled trough, thus not further exposing these individuals to air. After the initial assessment, the fish were moved into a holding pen (dimensions: 175 × 85 × 125 cm, with 1.5 × 1.5-cm gaps in the mesh) inside the lake for approximately 12 h (maximum density of the fish was approximately 100 fish). The fish were returned to the lake to simulate a catch-and-release event where fish would be released back into the lake. Once the 12-h period was over, the fish were removed from the holding pen and quickly transferred back into an aerated trough and assessed again for their burst. During this process, any mortalities (i.e., fate) were recorded (as a yes or no response). Any fish that were moribund (in poor condition as evidenced by loss of skin and gill color as well as lethargy) were also euthanized and considered to be dead. The scores of the initial equilibrium and burst response tests were combined to create a composite score of the overall reflex score of each fish ([Davis, 2007, 2010](#)). This composite score was then divided by two to generate the mean reflex score, where a score of 0 was representative of fish that were not impaired and a score of 1 represented fully impaired fish. A second tail grab response was assessed after an overnight holding period to assess the possibility that fish experienced delayed mortality that did not initially occur.

#### Statistical analysis

All statistical analyses occurred in Rstudio (2024.04.2+764; Posit Team) via R version 4.4.0 (R Core Team) and all figures were made using the *ggplot2* package ([Wickham, 2016](#)). A

one-way ANOVA was used to assess whether there were any differences in total length of Bluegill across all treatments in the study. Four different binomial regression models were fit with fate, tail grab, equilibrium, and the second tail grab as the response variables. Following this, Tukey's post hoc tests using the *glht* function from the *multcomp* package ([Hothorn et al., 2008](#)) were used to further assess the significant differences among predictor variables in these models. The first model with fate as the response variable was fit with treatment, total length, and reflex score as the predictor variables. Next, the burst escape response was fit with treatment and the total length of Bluegill as the predictor variables. Treatment, total length, and burst escape were the predictor variables in the model with equilibrium as the response variable. The final model had the second burst escape as the response variable and was fitted with treatment, total length, tail grab, and equilibrium as the predictor variables.

Similarly, the reflex scores were fit as a response variable in an ordinal logistic regression using the *clm* function from the *ordinal* package ([Christensen, 2023](#)). The reflex score models used treatment and total length as the predictor variables. Following this, a Tukey's post hoc test using the *pairs* function from the *emmeans* package ([Lenth, 2024](#)) was used to further assess the differences in reflex scores within significant predictors.

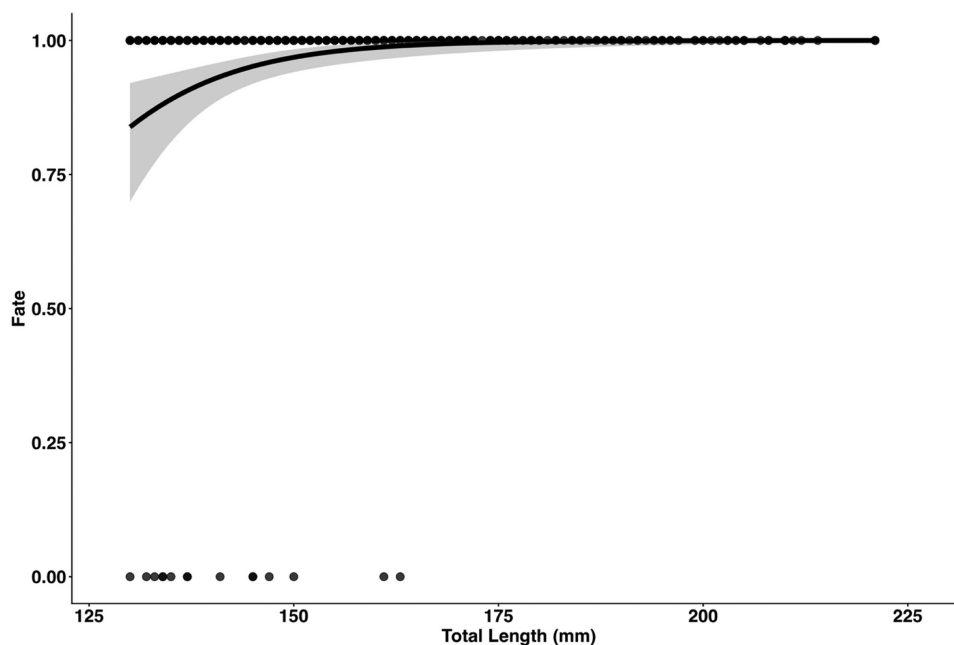
## RESULTS

We captured 458 Bluegill ([mean ± SD] total length = 161 ± 20 mm, range = 130–221 mm) for this study. The size of fish was similar among the nine treatments ( $F_{4,49} = 0.372, P = 0.935$ ; [Table 1](#)). At the conclusion of the study, 15 of the 458 Bluegill were categorized as mortalities. The fate (i.e., survival) of Bluegill was not influenced by treatment ( $\chi^2 = 12.061, P = 0.149$ ) or by the reflex impairment level of the fish ( $\chi^2 = 0.888, P = 0.642$ ). Only the total length of the Bluegill had an influence on the fate of the fish ( $\chi^2 = 20.756, P < 0.001$ ), where fish < 145 mm were more susceptible to being classified as mortalities at the conclusion of the 12-h holding period ([Figure 1](#)).

The tail grab test was not significantly influenced by the total length of the Bluegill ( $\chi^2 = 1.414, P = 0.234$ ) but was significantly influenced by the air exposure treatment ( $\chi^2 = 66.049, P < 0.001$ ). The burst escape response (i.e., tail grab) was significantly less impaired for control fish than for the fish in all the other treatments, and there were no differences among the air exposure treatments for burst escape scores ([Table 2](#); [Figure 2](#)). Equilibrium was not significantly influenced by the total length of Bluegill ( $\chi^2 = 0.005, P = 0.946$ ) or by the treatment ([Figure 3](#);  $\chi^2 = 13.361, P = 0.100$ ). The equilibrium of Bluegill was, however, significantly influenced by the burst escape response ( $\chi^2 = 19.885, P < 0.001$ ), where equilibrium tended to be impaired when the burst escape response was also impaired. For the second burst escape test, total length ( $\chi^2 = 0.347, P = 0.556$ ), initial burst escape response ( $\chi^2 = 1.524, P = 0.217$ ), and equilibrium ( $\chi^2 = 2.868, P = 0.090$ ) did not have an influence on the impairment level. The treatment had a significant influence on the second burst escape response ( $\chi^2 = 16.837, P = 0.032$ ); however, the post hoc test did not identify any differences among the treatments ([Table 3](#); [Figure 4](#)).

**Table 1.** Total length (mm) of Bluegill for each treatment.

Treatment	<i>n</i>	Mean length (mm)	SD ± (mm)	Minimum length (mm)	Maximum length (mm)	Number of dead fish after 12 h ( <i>n</i> )
0 s air	51	160	19	130	214	1
10 s water/90 s air	51	162	20	130	221	1
10 s water/air	51	158	20	130	202	3
180 s air	51	161	21	130	221	4
30 s water/90 s air	51	161	21	130	211	0
30 s water/air	51	163	21	132	221	1
60 s water/90 s air	50	163	23	130	212	2
60 s water/air	51	162	22	130	210	0
90 s water/air	51	164	19	130	210	3

**Figure 1.** Logistic regression showing the probability that Bluegill survive after various air exposure treatments (represented with the 1) as length increases.

Finally, the overall reflex score was not significantly influenced by the total length of the Bluegill ( $\chi^2 = 0.906$ ,  $P = 0.341$ ) but was influenced by the treatment ( $\chi^2 = 37.255$ ,  $P < 0.001$ ). Control fish had significantly lower reflex impairment scores than did all the air-exposed fish, regardless of the air exposure regime (Table 3; Figure 5). Reflex scores did not vary among the other treatments (Table 4; Figure 5).

## DISCUSSION

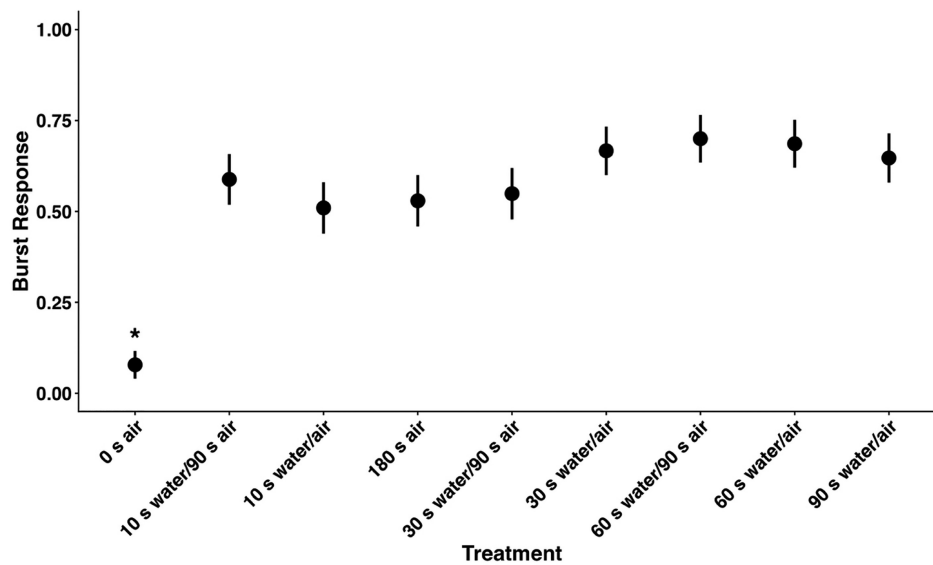
In this study, air exposure across treatments led to reflex impairments regardless of the type of intermittent treatment (whether it was equal amounts of time exposed to air and water or timing differed). It is well known that the duration of air exposure during an angling event is one of the most significant stressors and determinants of the eventual fate of fish that are intended for release, and the research has shown a wide range of adverse effects, including impairments in swimming performance and locomotion (e.g., Cooke et al., 2000; Davis & Parker, 2004; Gingerich et al., 2007; LaRochelle et al., 2021; Robichaud

et al., 2024; Schreer et al., 2005; Thompson et al., 2008), physiological disturbances (Arlinghaus et al., 2009; Barton, 2002; Cooke et al., 2013; Rapp et al., 2014), cognitive impairments (Chhor et al., 2022), and fitness reductions (Cooke & Philipp, 2004; Cooke et al., 2002; Hanson et al., 2007). Mortality has also been documented as a result of extended air exposure (e.g., Arlinghaus & Hallermann, 2007; Broadhurst et al., 2012; Chiamonte et al., 2017; Ferguson & Tufts, 1992).

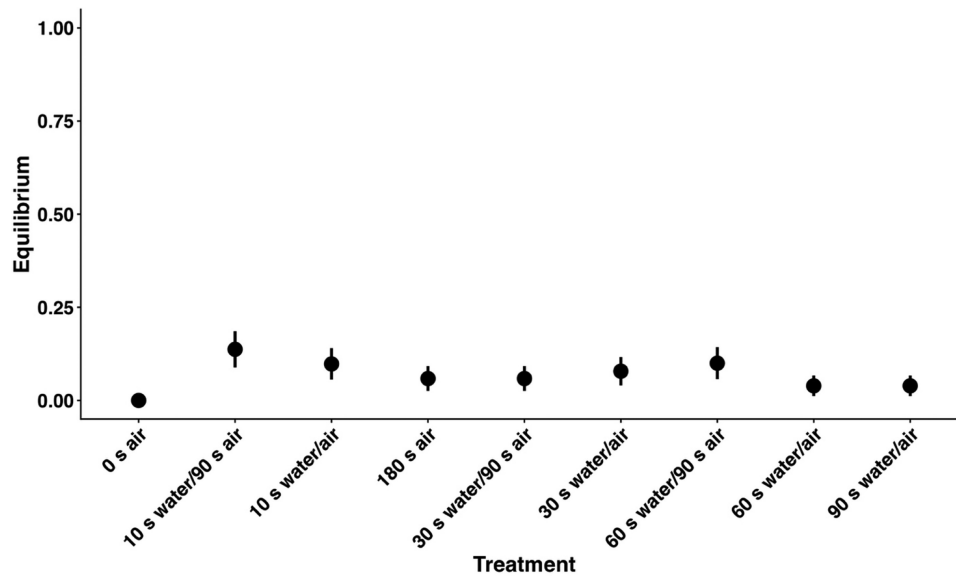
We pursued this question after being asked repeatedly by anglers if returning fish to the water, “reset” their ability to air expose the fish again. These reports were based on anecdotal informal interactions (e.g., on social media, at tackle shops, at outdoor shows) rather than via a formal survey process. Although it is unknown to what extent these practices were being suggested among angler circles, there have long been popular or widespread use of other poor practices under the guise of improving fish welfare that have been disproven (e.g., carbonated beverages to stop bleeding; Trahan et al., 2021; live-well additives to reduce stress and improve recovery; LaRochelle et al., 2024). Thus, practices or suggestions of

**Table 2.** Tukey’s post hoc results of the immediate burst response (i.e., tail grab) reflex impairment of Bluegill between the various treatments. The significant difference in burst response across the treatments is represented by the bold text.

Comparison	Estimate	SE	Z ratio	P
0 s air–10 s air/90 s water	−2.837	0.594	−4.775	<b>&lt;0.001</b>
0 s air–10 s water/air	−2.497	0.592	−4.220	<b>&lt;0.001</b>
0 s air–180 s air	−2.591	0.592	−4.375	<b>&lt;0.001</b>
0 s air–30 s water/90 s air	−2.671	0.593	−4.507	<b>&lt;0.001</b>
0 s air–30 s water/air	−3.180	0.601	−5.294	<b>&lt;0.001</b>
0 s air–60 s water/90 s air	−3.339	0.607	−5.504	<b>&lt;0.001</b>
0 s air–60 s water/air	−3.265	0.603	−5.416	<b>&lt;0.001</b>
0 s air–90 s water/air	−3.099	0.599	−5.176	<b>&lt;0.001</b>
10 s water/90 s air–10 s water/air	0.340	0.400	0.849	0.995
10 s water/90 s air–180 s air	0.246	0.400	0.615	1.000
10 s water/90 s air–30 s water/90 s air	0.167	0.401	0.416	1.000
10 s water/90 s air–30 s water/air	−0.342	0.412	−0.830	0.996
10 s water/90 s air–60 s water/90 s air	−0.502	0.421	−1.194	0.958
10 s water/90 s air–60 s water/air	−0.428	0.415	−1.030	0.983
10 s water/90 s air–90 s water/air	−0.262	0.409	−0.640	0.999
10 s water/air–180 s air	−0.094	0.397	−0.236	1.000
10 s water/air–30 s water/90 s air	−0.173	0.398	−0.435	1.000
10 s water/air–30 s water/air	−0.682	0.410	−1.665	0.768
10 s water/air–60 s water/90 s air	−0.842	0.419	−2.011	0.536
10 s water/air–60 s water/air	−0.768	0.413	−1.859	0.642
10 s water/air–90 s water/air	−0.602	0.407	−1.478	0.642
180 s air–30 s water/90 s air	−0.080	0.398	−0.200	1.000
180 s air–30 s water/air	−0.588	0.410	−1.437	0.884
180 s air–60 s water/90 s air	−0.748	0.418	−1.789	0.690
180 s air–60 s water/air	−0.674	0.413	−1.633	0.787
180 s air–90 s water/air	−0.508	0.407	−1.250	0.945
30 s water/90 s air–30 s water/air	−0.509	0.410	−1.241	0.948
30 s water/90 s air–60 s water/90 s air	−0.669	0.419	−1.597	0.807
30 s water/90 s air–60 s water/air	−0.595	0.413	−1.438	0.883
30 s water/90 s air–90 s water/air	−0.429	0.407	−1.053	0.981
30 s water/air–60 s water/90 s air	−0.160	0.429	−0.373	1.000
30 s water/air–60 s water/air	−0.086	0.424	−0.202	1.000
30 s water/air–90 s water/air	0.080	0.418	0.192	1.000
60 s water/90 s air–60 s water/air	0.074	0.433	0.171	1.000
60 s water/90 s air–90 s water/air	0.240	0.426	0.563	1.000
60 s water/air–90 s water/air	0.166	0.421	0.394	1.000



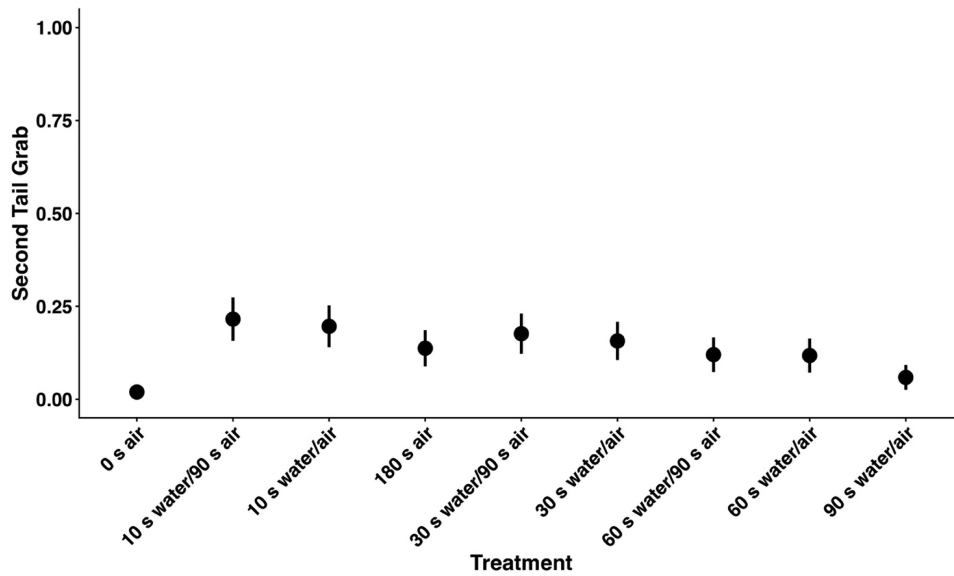
**Figure 2.** Mean and standard error for the burst response (tail grab reflex test) of Bluegill for each treatment. Scores of 0 represent fish that are not impaired, whereas a score of 1 represents a lack of response to the tail grab test. Groups that are significantly different are represented with the asterisk.



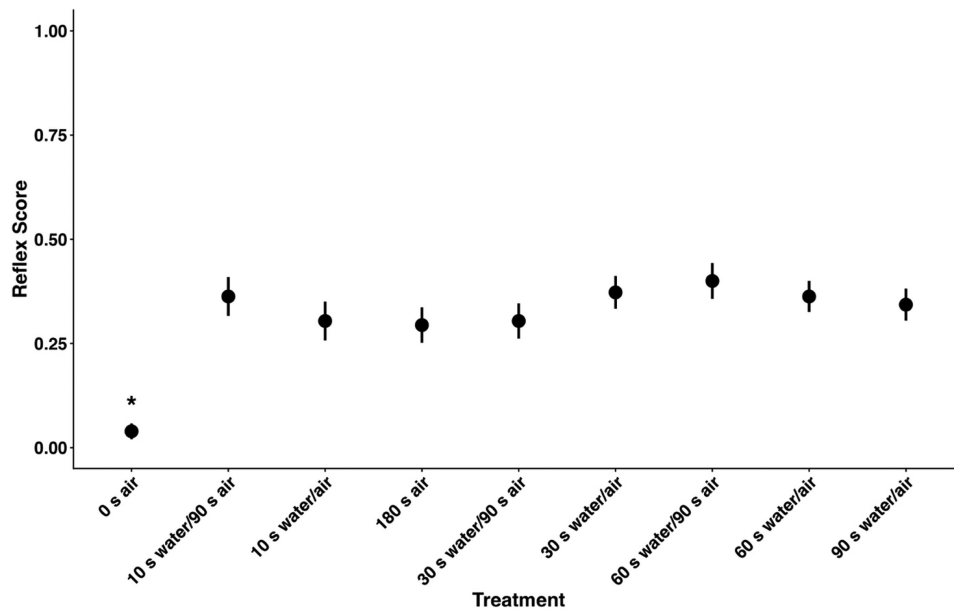
**Figure 3.** Mean and standard error for the equilibrium score of Bluegill for each treatment. Scores of 0 represent fish that are not impaired, whereas a score of 1 represents a lack of response to the equilibrium test.

**Table 3.** Tukey's post hoc results of the comparison in the burst response (i.e., tail grab) reflex impairment of Bluegill across the various treatments performed 12 h after air exposure.

Comparison	Estimate	SE	Z ratio	P
0 s air–10 s air/90 s water	2.351	1.080	2.176	0.403
0 s air–10 s water/air	2.297	1.081	2.125	0.438
0 s air–180 s air	1.893	1.100	1.721	0.718
0 s air–30 s water/90 s air	2.188	1.086	2.015	0.514
0 s air–30 s water/air	1.989	1.097	1.812	0.657
0 s air–60 s water/90 s air	1.632	1.120	1.457	0.866
0 s air–60 s water/air	1.687	1.117	1.511	0.841
0 s air–90 s water/air	0.928	1.187	0.782	0.997
10 s water/90 s air–10 s water/air	−0.054	0.497	−0.108	1.000
10 s water/90 s air–180 s air	−0.458	0.536	−0.854	0.995
10 s water/90 s air–30 s water/90 s air	−0.163	0.507	−0.322	1.000
10 s water/90 s air–30 s water/air	−0.362	0.520	−0.697	0.999
10 s water/90 s air–60 s water/90 s air	−0.719	0.560	−1.285	0.930
10 s water/90 s air–60 s water/air	−0.664	0.560	−1.185	0.956
10 s water/90 s air–90 s water/air	−1.423	0.691	−2.058	0.483
10 s water/air–180 s air	−0.404	0.543	−0.744	0.998
10 s water/air–30 s water/90 s air	−0.109	0.515	−0.212	1.000
10 s water/air–30 s water/air	−0.309	0.530	−0.583	1.000
10 s water/air–60 s water/90 s air	−0.666	0.570	−1.167	0.960
10 s water/air–60 s water/air	−0.610	0.568	−1.073	0.976
10 s water/air–90 s water/air	−1.369	0.698	−1.961	0.553
180 s air–30 s water/90 s air	0.295	0.551	0.536	1.000
180 s air–30 s water/air	0.096	0.565	0.170	1.000
180 s air–60 s water/90 s air	−0.261	0.603	−0.433	1.000
180 s air–60 s water/air	−0.205	0.600	−0.342	1.000
180 s air–90 s water/air	−0.965	0.725	−1.331	0.916
30 s water/90 s air–30 s water/air	−0.199	0.537	−0.371	1.000
30 s water/90 s air–60 s water/90 s air	−0.556	0.577	−0.964	0.988
30 s water/90 s air–60 s water/air	−0.501	0.574	−0.872	0.994
30 s water/90 s air–90 s water/air	−1.260	0.703	−1.792	0.671
30 s water/air–60 s water/90 s air	−0.357	0.586	−0.609	1.000
30 s water/air–60 s water/air	−0.301	0.584	−0.516	1.000
30 s water/air–90 s water/air	−1.060	0.712	−1.490	0.851
60 s water/90 s air–60 s water/air	0.056	0.621	0.090	1.000
60 s water/90 s air–90 s water/air	−0.703	0.742	−0.948	0.989
60 s water/air–90 s water/air	−0.759	0.739	−1.027	0.982



**Figure 4.** Mean and standard error for the second tail grab (burst response score) of Bluegill for each treatment tested 12 h after air exposure. Scores of 0 represent fish that are not impaired, whereas a score of 1 represents a lack of response to the tail grab test.



**Figure 5.** Mean and standard error for the total reflex impairment level of Bluegill for each treatment. Scores of 0 represent fish that are not impaired, whereas a score of 1 indicates full impairment. Groups that are significantly different are represented with the asterisk.

practices should be tested to dispel and prevent the spread of misinformation. Our work revealed that in the context studied here (Bluegill at moderate water temperatures), there was no apparent benefit from immersing the fish in water between air exposure events. To be clear, there was no harm induced by putting the fish back in water (based on the end points used here; mortality, burst response, etc.), but there was also no benefit.

It is widely accepted that angled fish should be exposed to as little air as possible (e.g., <10 s; Cook et al., 2015; Twardek et al., 2018, for steelhead *Oncorhynchus mykiss*; Brownscombe et al., 2022, for Brook Trout *Salvelinus fontinalis*), although these thresholds may differ for more sensitive species (e.g.,

European Grayling *Thyllumus thymallus*; Lennox et al., 2016) and those that may be more robust, such as Common Carp *Cyprinus carpio* (Rapp et al., 2014) or Bluegill. As a result, future studies should test various intermittent air-exposure intervals that cumulate to different total air exposure times (e.g., instead of 180 s total air exposure like in this study, comparing 30, 60, and 120 s, of total air exposure). Furthermore, although the end points measured here revealed no benefit of holding fish in water between subsequent air exposure periods, there may be benefits or costs that we failed to quantify. For example, one might surmise that keeping the fish wet is good for the skin, mucous, and eyes, potentially preventing drying

**Table 4.** Tukey's post hoc results of the total immediate reflex impairment level of Bluegill across the various treatments. Significant responses in reflex impairment levels among the treatments are represented by the bolded text.

Comparison	Estimate	SE	Z ratio	P
0 s air–10 s air/90 s water	–3.048	0.594	–5.133	<b>&lt;0.001</b>
0 s air–10 s water/air	–2.605	0.592	–4.399	<b>&lt;0.001</b>
0 s air–180 s air	–2.616	0.589	–4.438	<b>&lt;0.001</b>
0 s air–30 s water/90 s air	–2.685	0.589	–4.558	<b>&lt;0.001</b>
0 s air–30 s water/air	–3.179	0.590	–5.388	<b>&lt;0.001</b>
0 s air–60 s water/90 s air	–3.340	0.595	–5.611	<b>&lt;0.001</b>
0 s air–60 s water/air	–3.129	0.588	–5.316	<b>&lt;0.001</b>
0 s air–90 s water/air	–2.996	0.588	–5.096	<b>&lt;0.001</b>
10 s water/90 s air–10 s water/air	0.444	0.400	1.110	0.973
10 s water/90 s air–180 s air	0.432	0.395	1.095	0.975
10 s water/90 s air–30 s water/90 s air	0.363	0.394	0.921	0.992
10 s water/90 s air–30 s water/air	–0.131	0.393	–0.332	1.000
10 s water/90 s air–60 s water/90 s air	–0.292	0.400	–0.729	0.998
10 s water/90 s air–60 s water/air	–0.081	0.391	–0.206	1.000
10 s water/90 s air–90 s water/air	0.052	0.391	0.133	1.000
10 s water/air–180 s air	–0.012	0.394	–0.030	1.000
10 s water/air–30 s water/90 s air	–0.081	0.393	–0.205	1.000
10 s water/air–30 s water/air	–0.574	0.394	–1.459	0.874
10 s water/air–60 s water/90 s air	–0.736	0.401	–1.833	0.660
10 s water/air–60 s water/air	–0.524	0.392	–1.339	0.920
10 s water/air–90 s water/air	–0.391	0.391	–1.001	0.986
180 s air–30 s water/90 s air	–0.069	0.388	–0.177	1.000
180 s air–30 s water/air	–0.563	0.388	–1.448	0.879
180 s air–60 s water/90 s air	–0.724	0.396	–1.828	0.663
180 s air–60 s water/air	–0.512	0.386	–1.326	0.924
180 s air–90 s water/air	–0.380	0.386	–0.984	0.987
30 s water/90 s air–30 s water/air	–0.494	0.388	–1.273	0.939
30 s water/90 s air–60 s water/90 s air	–0.655	0.395	–1.656	0.773
30 s water/90 s air–60 s water/air	–0.444	0.386	–1.149	0.967
30 s water/90 s air–90 s water/air	–0.311	0.385	–0.807	0.997
30 s water/air–60 s water/90 s air	–0.162	0.394	–0.410	1.000
30 s water/air–60 s water/air	0.050	0.385	0.130	1.000
30 s water/air–90 s water/air	0.183	0.385	0.475	1.000
60 s water/90 s air–60 s water/air	0.212	0.392	0.539	1.000
60 s water/90 s air–90 s water/air	0.344	0.392	0.878	0.994
60 s water/air–90 s water/air	0.133	0.383	0.347	1.000

and any associated tissue damage. Conversely, putting the fish back in water may require more handling and struggling by the fish, yielding potential skin damage, physiological exhaustion, and stress related to longer retention times. We, therefore, encourage additional research exploring various physical and physiological impediments during intermittent air exposure treatments to further tease out best practices.

Although it is important to determine maximum air exposure thresholds, it is also important to note that anglers may expose fish to air for longer than the 180 s tested in this study. Prolonged air exposure can result because of difficulty with hook removal (Hussey et al., 2025), using differing gear types, or as anglers hold fish for pictures or admiration, among other factors (Brownscombe et al., 2017; Gingerich et al., 2007; Lamansky & Meyer, 2016; LaRochelle et al., 2023). Additionally, many Bluegill displayed a burst response (second tail grab) after being held overnight and were not impaired even if they failed the first burst escape or equilibrium test. This result suggests that these Bluegill recovered overnight or that thresholds for stress could be higher for Bluegill than other popularly angled species (it is well known that some salmonids

display high mortality when being handled and air exposed, especially at high water temperatures; Ferguson & Tufts, 1992; Robichaud et al., 2024), although there are no measures comparing these species. Even for a hardier species such as Bluegill, and despite some potential overnight recovery from the stress of initial capture, resubmerging these fish did not reduce the adverse effects of air exposure (as observed during the initial equilibrium and burst response tests). Thus, for other species that are less tolerant of capture and handling, this could have even larger implications. This supports the notion that there should be species-specific recommendations targeting more sensitive species or that we should exercise caution for air exposure of all species during an angling event.

Environmental factors such as water temperature, air temperature (e.g., subfreezing), and periods of high winds could influence how fish respond to different durations of air exposure (Forgues et al., 2022). Because our study was conducted in the span of 6 d in the early summer during relatively stable weather conditions, the water and air temperatures did not vary considerably over that period (only by 2.5°C). There have been many studies that found that anaerobic exercise during elevated

temperatures led to greater reflex impairment and mortality (e.g., Brownscombe et al., 2022; Gingerich et al., 2007; Meyer et al., 2023; Robichaud et al., 2024). Although far fewer studies have examined best practices for fish during winter temperatures (below 0°C), LaRochelle et al. (2021) suggested that fish exposed to winter air and wind chill can alter fish locomotor activity postrelease, possibly due to freezing of outer extremities such as gills and fins. In this case, submersing fish intermittently could be beneficial to reduce the potential of freezing and desiccation. Combining air exposure and temperatures is a logical next step for intermittent and repeated air exposure testing given the breadth of literature on the relationship between continuous air exposure, environmental temperatures, and sublethal or lethal effects.

In our study, smaller fish were more likely to die during the 12-h holding period after being exposed to various combinations of air and water exposure. Further work should explore holding the fish longer (~48 h) to explore the delayed effects of intermittent air exposure on fish. Although the results in this study highlight the potential acute impairments that intermittent air exposure may have on smaller fish, it is important to also point out that these longer term effects may be exacerbated for larger fish, as there has been a substantial amount of research linking larger body size to increased energy expenditure, slower recovery times, swimming activity deviations, and ultimately mortality (e.g., Broadhurst et al., 2012; Brownscombe et al., 2022; Casselberry et al., 2024; Cooke et al., 2002; LaRochelle et al., 2023, 2025; Thorstad et al., 2003). This can be an issue in many recreational fisheries where the focus on catching trophy-sized fish may exacerbate these issues (e.g., longer fight times). Events such as tournaments, which largely focus on catching the largest fish, are increasing in popularity (Driscoll et al., 2012). Our results also suggest that fish of all sizes should be given due care because it is difficult to control which fish sizes are captured. This may be especially true for heavily targeted fish such as Bluegill, where many fish are released (Coble, 1988).

### Conclusions and future directions

Although our understanding of how air exposure affects a variety of popularly angled fish species is broad, no studies have explored whether intermittent or repeated air exposure events result in better outcomes for released fish than continuous air exposure. This study was conducted as a result of suggestions from anglers that intermittent air exposure events may result in better welfare outcomes for fish and may reduce lethal or sublethal stressors postrelease. Our study found that reflex responses did not vary between any intermittent treatment and that the only predictors for reflex impairment were total cumulative time exposed to air (180 s) and body size (for delayed mortality). As a result, we conclude that under the conditions explored here (i.e., moderate temperatures) with a 180-s air exposure time, there is no difference in the outcome regardless of whether Bluegill are exposed to air continuously or intermittently. We recommend that Bluegill of all sizes should be handled quickly with minimal air exposure. Moreover, future work needs to explore longer term effects (>48 h) on fish. Additionally, we emphasize that intermittent and repeated air exposure experiments should be explored further under different water and air temperatures, with different cumulative air exposure times (to develop minimum

and maximum thresholds) and across more species to fully grasp what best practices and recommendations should be given across different contexts.

### DATA AVAILABILITY

Data are available upon request.

### ETHICS STATEMENT

This research followed all ethics protocols outlined by the Carleton University Research Ethics Board (Cooke Umbrella C&R Protocol—2024).

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### CONFLICTS OF INTEREST

None declared.

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