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ARTICLE

Air Exposure, Fight Times, and Deep-Hooking Rates of Steelhead Caught in Idaho Fisheries

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Abstract
Potential effects of air exposure and fight times on fish caught and released by anglers have been increasingly studied in recent years, yet little is known about how long anglers actually fight the fish and expose them to air before releasing them. In the present study, air exposure and fight times were measured for anglers catching and releasing fish in popular steelhead *Oncorhynchus mykiss* fisheries in Idaho, and other relevant factors were also recorded such as fishing gear (fly or nonfly), occurrence of anglers photographing their catch, landing method (with net or by hand), and whether the fish was hooked deeply. A total of 432 steelhead were observed being landed, from which 395 fight times and 251 air exposure times were recorded. The longest interval of air exposure for all steelhead caught and released averaged 28.1 s (95% CI, 25.9–31.3 s), and the vast majority of anglers (88%) held steelhead out of water for less than 60 s. Air exposure was not significantly different by gear type but was estimated to be 1.69 times longer if the angler took a photo of their catch; anglers using flies were 58% more likely to photograph their catch than nonfly anglers. Fight time averaged 130 s (95% CI, 119.3–140.7 s) and differed significantly by gear type, with fly anglers taking an estimated 1.54 times longer to land fish than nonfly anglers. Deep-hooking rates were 0% for fly and bait and/or jig terminal tackle and 1% for lures. In the context of previous studies that have measured postrelease mortality of caught-and-released salmonids, the effects of these fight and air exposure times and deep-hooking rates in Idaho steelhead fisheries are likely negligible.

Potential effects of catch-and-release angling on fish mortality have been the subject of extensive research for decades (see reviews by Wydoski 1977 and Muoneke and Childress 1994), and concerns over sublethal physiological effects and general fish welfare are growing areas of research (e.g., Davie and Kopf 2006; Huntingford et al. 2006; Arlinghaus et al. 2007; Cooke and Sneddon 2007). Aspects of catch-and-release angling shown to affect postrelease performance and survival include (among others) terminal tackle type (bait, lure, fly: Hunsaker et al. 1970), fish handling (fight time and air exposure: Schisler and Bergersen 1996), and environmental conditions (e.g., water temperature: Klein 1966; capture depth: Rogers et al. 1986).

Of these factors affecting postrelease performance of caught-and-released fish, the effect of air exposure and fight times has received the most attention in recent fisheries literature (reviewed in Cook et al. 2015) and popular

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culture (e.g., see www.keepemwet.org). Early studies conducted on hatchery Rainbow Trout *Oncorhynchus mykiss* suggested that air exposure and fight times greatly elevated mortality rates for fish (Ferguson and Tufts 1992; Schisler and Bergersen 1996). However, more recent research suggests that, for most salmonid species, unless released fish are exposed to the air for a prolonged period, and such air exposure is coupled with other stressors (i.e., high temperatures), long-term impacts are rarely life-threatening (Schreer et al. 2005; Donaldson et al. 2010, 2014; Raby et al. 2013; Gale et al. 2014). Nevertheless, some state fisheries management agencies have enacted regulations prohibiting air exposure of caught-and-released fish for some species. For example, in Washington State, it is unlawful to completely remove salmon, steelhead (anadromous Rainbow Trout), or Bull Trout *Salvelinus confluentus* from the water if the angler intends to release the fish. With regard to fight time, exhaustive exercise has been implicated as having negative consequences for caught-and-released fish (Ferguson and Tufts 1992; Schreer et al. 2001), but as with air exposure, such impacts typically do not materialize unless fight times or simulated exercise are extreme.

Considering the breadth of research on the effects of various levels of air exposure and fight time on caught-and-released fish, surprisingly little information exists about how anglers actually play and release fish. In Idaho, covert angler observations at several lake and river fisheries revealed that trout anglers held fish out of water for an average for 26 s before releasing them, and only 4% of anglers holding fish out of water for >60 s (Lamansky and Meyer 2016). In the same study, fight times averaged 53 s. Another recent study showed that trout caught and released were exposed to air for an average of 19 s, while fight times averaged 40 s (Roth et al. 2018a). Although such fight and air exposure times are unlikely to impact the mortality of caught-and-released trout, the extent to which these findings relate to sport fisheries for anadromous fishes is unknown, particularly regarding the larger fish size and potentially longer fight times. Our primary study objective was to evaluate fight and air exposure times in a popular catch-and-release steelhead fishery in Idaho.

In addition to air exposure and fight time, terminal gear type and anatomical hooking location also affect the survival of caught-and-released fish (Bendock and Alexandersdottir 1993; Vincent-Lang 1993; Lindsay et al. 2004; Nelson et al. 2005; Cowen et al. 2007), though other factors such as hook size and type, species, fish size, and capture conditions may also play a role because they directly influence hooking location. Bait fishing generally results in higher rates of deep hooking, which more often injures vital internal organs or gills and frequently leads to higher rates of catch-and-release mortality (Wydoski 1977; Muoneke and Childress 1994). Because deep hooking is the main driver in hooking mortality (Wydoski 1977; Muoneke and Childress), our second study objective was to use angler observations noted above to evaluate deep-hooking rates by steelhead anglers using bait or other terminal tackle.

METHODS

The Clearwater River, its north and south tributary forks, the Little Salmon River, and the Salmon River are all popular steelhead fisheries in Idaho. In these waters, anglers may only harvest steelhead that have a clipped adipose fin, indicating they are of hatchery origin; otherwise, the fish must be released. The only gear restriction on these waters is that only single-pointed barbless hooks are allowed when fishing for steelhead on the South Fork Clearwater River.

We observed anglers fishing for steelhead in all of these fisheries. At most sites, observations were made covertly because we assumed that angler behavior might be affected by the close presence of state agency staff. However, some observations on the South Fork Clearwater River were overt; i.e., they were collected opportunistically during an unrelated program involving volunteer steelhead broodstock collection by anglers. During these instances, anglers were fishing for their own personal enjoyment and potential harvest and also assisting with occasional broodfish collection. The overt observations used in our analysis did not include any of the fish collected for broodstock. Covert observations of anglers were conducted with binoculars from inconspicuous locations or directly by observers posing as anglers.

When a fish was hooked, we used a stopwatch or smartphone timer to measure the duration (in seconds) it took from initial hookup to landing of the fish. At times, the initial hookup was not observed, so fight times were not recorded for those fish. Once landed, we timed how long the fish was exposed to air before being released. Occasionally, fish were put back in the water and then re-exposed to air one or two times. These occurrences accounted for 14% of observations and 7% of all air exposure and did not affect model variables included in our results or our conclusions. Thus, for the purposes of analysis, we used only the longest air exposure interval. During each fish landing event, we also noted various associated factors that might influence fight times and air exposure, including the type of fishing gear used (fly, lure, bait), the method used to land the fish (with net, by hand), and whether a photograph of the fish was taken.

All nonfly fishing tackle, such as beads, yarn, or bait drifted with or without a bobber, was fished very similarly and was not always distinguishable at a distance by anything other than the rod type and technique used, so they were combined into a nonfly gear category. Even though lures are fished distinctively, they were also included in the nonfly gear category because rods used to fish with lures are very similar to those used with other nonfly gear and would be expected to have a similar effect on fight times. Thus, for fishing gear type used, we report either fly fishing or nonfly fishing when we tested the effects on fight time and air exposure.

Water bodies were considered separately in this analysis due to differences that could contribute to variation in the data. For example, on the North Fork Clearwater River, many anglers fish either from the Ahsahka Bridge or from the wall below Dworshak Dam, targeting fish returning to Dworshak Hatchery. At both locations, anglers are fishing 10–20 m above the surface of the water, which (1) precludes fly anglers from fishing those locations and (2) greatly extends the fight time because the angler is required to walk across the bridge or wall and climb down a series of stairs to reach the water and land a hooked fish. Thus, observations collected at the bridge and dam were treated as a site separate from the remaining observations on the North Fork Clearwater River and other sites. In the interest of collecting independent observations, we did not knowingly collect more than one observation per angler each day.

Hooking location data, collected only on the South Fork Clearwater River, were recorded for overt observations but could not be determined for covert observations; we assumed that anglers could not influence their hooking location based on their awareness of a nearby state agency staff member. Hooking location was recorded as deep (i.e., either in the gills or more deeply hooked), mouth (i.e., in the corner of the mouth or anything inside the mouth but not deep hooked), or foul hooked (i.e., on the outside of the body). For hooking location, gear was categorized into either bait and/or jigs, lures, or flies because of suspected differences among terminal tackle types (Wydoski 1977; Muoneke and Childress 1994).

The data collected on air exposure and fight time represented time-to-event data that conformed to an exponential distribution, so we used accelerated failure time models to evaluate the factors affecting each response variable (Therneau and Grambsch 2000; Therneau 2015); air exposure and fight time were modeled separately. Accelerated failure time models designate a family of models that can be generalized to include covariates on the air exposure or fight time function (Kalbfleisch and Prentice 2002). Candidate models included water, gear type, photo taken (yes or no), observer status (covert or overt), landing method (net or hand), and whether the fish was harvested (only fight time models) as factors potentially affecting air exposure or fight time. We considered photographing and harvest separately in candidate fight time models as surrogates for fish size, under the rationale that the larger a fish is, the more likely it is to be photographed or harvested. Candidate models were evaluated using Akaike's information criterion corrected for small sample size (AIC_c; Burnham and Anderson 2002). Once exponentiated, coefficients in the accelerated failure time models are multiplicative. For instance, if the coefficient for when a photo was taken was 1.5 for a given air exposure model, this means air exposure was 1.5 times longer for photographed fish than for those not photographed. We used leave-one-out cross validation to evaluate the predictive performance of each model and reported the mean error for each candidate model. Program R was used for all data analyses (R Development Core Team 2011).

RESULTS

From September 2016 to April 2017, we observed a total of 432 steelhead caught, of which 293 were released. We recorded 395 fight times and 251 air exposure times. The longest interval of air exposure for caught-and-released steelhead averaged 28.1 s (95% CI, 25.9–31.3 s), and the vast majority of anglers (88%) held fish out of water for less than 60 s. Only 14% (mean, 13.3 s) and 3% (7.6 s) of anglers held fish out of water for two and three separate intervals. The average fight time was 130 s (95% CI, 119.3–140.7 s; Table 1).

The top three air exposure models included either photographing, gear type and photographing, or both terms including an interaction (Table 2). Of these factors, photographing had the strongest effect, and air exposure time was estimated at 1.69 times (95% CI, 1.26–2.27) longer if the fish was photographed (Table 3). This effect appeared stronger for anglers using nonfly gear, as inferred by the inclusion of a gear × photo interaction term in one of the top three models. However, the gear and gear × photo interaction terms both had coefficients with 95% CIs that overlapped 1, indicating their effects were not significant. Nevertheless, fly anglers photographed their catch significantly more often (38%) than did nonfly anglers (24%) ($\chi^2 = 5.19$, df = 1, $P = 0.02$). Anglers on the South Fork Clearwater River, the only water with covert and overt observations, held fish out of the water an estimated 1.57 times (95% CI, 1.09–2.28) longer when they did not know they were being observed by agency staff.

Candidate fight time models that included gear type, water body, landing method, and either harvest or photo best supported our data (Table 4). However, the best model included just gear type and waterbody as predictors of fight time (Table 5). When fly gear was used, anglers fought fish for an estimated 1.54 times longer than when nonfly gear was used, after we accounted for differences in waterbody (Table 5). Although waterbody was included in the top model, coefficients for each waterbody had CIs

TABLE 1. Summary statistics of air exposure to steelhead and fight times by anglers in five Idaho rivers, including sample size (n), mean, range, and 95% CIs for gear types (fly and nonfly), observer status (covert and overt), and whether the angler photographed their catch.

Gear type	n	Mean	Range	95% CI
Air exposure (s)				
Total	251	28.1	0–185	3.2
Fly[a]	47	22.4	0–89	5.9
Nonfly[a]	204	29.4	0–185	3.7
Covert[b]	50	36.4	0–109	8.0
Overt[b]	102	23.2	2–60	2.8
Photo	75	37.9	0–129	6.4
No photo	176	24.1	0–185	3.5
Fight time (s)				
Total	395	130.4	5–900	10.7
Fly[a]	70	169.8	13–765	31.1
Nonfly[a]	234	93.2	5–575	9.9
Covert[b]	47	74.16	5–494	26.2
Overt[b]	171	113.2	6–765	15.3
Photo	70	140.0	17–519	24.5
No photo	234	101.9	5–765	12.1

[a]Air exposure and fight times for nonfly gear include fish caught from the South Fork Clearwater and Little Salmon rivers only.

[b]Air exposure and fight times for covert and overt observations include the South Fork Clearwater River only.

TABLE 3. Coefficients and 95% CIs for the most highly supported accelerated failure time models used to estimate air exposure times for steelhead caught and released in five Idaho rivers. Fly gear and no photo taken are the reference categories for gear and photo taking. Coefficient estimates are interpreted as multiplicative of each parameter relative to the reference category.

Coefficient	Estimate	95% CI
Air exposure ~ Photo		
(Intercept)	22.66	19.36–26.53
Photo (yes)	1.69	1.26–2.27
Air exposure ~ Photo + Gear		
(Intercept)	18.61	13.74–25.19
Gear (nonfly)	1.28	0.92–1.77
Photo (yes)	1.69	1.26–2.26
Air exposure ~ Photo + Gear + Photo × Gear		
(Intercept)	20.92	14.54–30.10
Gear (non-fly)	1.10	0.74–1.65
Photo (yes)	1.16	0.63–2.14
Gear (nonfly) × Photo (yes)	1.61	0.80–3.23

that overlapped a value of 1, suggesting there was no significant difference from the reference waterbody. Fight times measured on the South Fork Clearwater River were also affected by observer status (covert–overt), but the effect was opposite to that from air exposure. Fight times measured covertly were 0.61 (95% CI, 0.43–0.85) times as long as those collected overtly.

Hooking location was determined for 188 fish, which comprised 49 caught by bait and/or jig, 99 caught by lure, and 40 caught by fly fishing. Deep-hooking rates were 0% for bait–jigs, 1% for lures, and 0% for flies. Foul-hooking rates were much higher for lures (40%) than for flies (7.5%) or bait–jigs (4%).

DISCUSSION

Our finding that most Idaho anglers exposed caught-and-released steelhead to <30 s of air concurs with previous studies on trout anglers, which also showed that, on average, fish were exposed to <30 s of air before being released (Lamansky and Meyer 2016; Roth et al. 2018a, 2018b). In contrast, our average fight time of 120 s was two- to threefold longer than that found in previous studies on trout that reported mean fight times of 53 s (Lamansky and Meyer 2016) and 40 s (Roth et al. 2018a, 2018b). This disparity was most likely related to the size of the fish being caught (i.e., adult steelhead are an order of magnitude heavier than most resident adult trout),

TABLE 2. Comparison of accelerated failure time models that estimate air exposure times of steelhead caught and released in five Idaho rivers. Degrees of freedom (df), Akaike's information criteria (AIC_c), change in AIC_c value (ΔAIC_c), AIC_c weights, and mean error from leave-one-out cross validation were used to select top models from a set of candidate models. Variables considered in the models included fishing gear type, whether the angler photographed their catch, waterbody, and whether the observer was covert.

Model	df	AIC_c	ΔAIC_c	AIC_c weight	Mean error
Photo	2	1,867.2	0.00	0.291	16.74
Photo + Gear	3	1,867.2	0.03	0.286	16.48
Photo + Gear + Photo × Gear	4	1,867.5	0.37	0.242	16.56
Water	6	1,868.3	1.15	0.164	16.27
Photo + Gear + Photo × Gear + Water + Water × Gear	14	1,873.1	5.98	0.015	15.98
Gear	2	1,878.3	11.11	0.001	17.07
Intercept	1	1,878.4	13.59	0.001	17.21

TABLE 4. Comparison of accelerated failure time models used to estimate fight times of steelhead caught and released in five Idaho rivers. Degrees of freedom (df), Akaike's information criteria (AIC_c), change in AIC_c value (ΔAIC_c), AIC_c weights, and mean error from leave-one-out cross-validation were used to select top models from a set of candidate models. Variables considered in the models included fishing gear type, whether the angler photographed their catch, waterbody, whether the observer was covert, landing method, and whether the fish was harvested.

Model	df	AIC_c	ΔAIC_c	AIC_c weight	Mean error
Gear + Water	6	4,432.6	0.00	0.511	65.16
Gear + Water + Landing method	7	4,434.5	1.95	0.193	65.26
Gear + Water + Landing method + Harvest	8	4,434.7	2.16	0.174	65.01
Gear + Water + Landing method + Photo	8	4,435.4	2.87	0.122	65.24
Water	5	4,464.2	31.63	0	70.13
Gear	2	4,485.9	53.38	0	77.89
Photo	2	4,487.4	54.79	0	77.28
Intercept	1	4,490.5	57.92	0	78.24
Landing method	2	4,492.2	59.67	0	78.36

TABLE 5. Coefficients and 95% CIs for the most highly supported accelerated failure time model used to estimate fight times for steelhead caught and released in five Idaho rivers. Coefficient estimates are interpreted as multiplicative of each parameter relative to the reference category. Fly gear and the Clearwater River were the reference categories for gear and water. LS = Little Salmon River, NFBD = North Fork Clearwater River dam wall and bridge fisheries, NFCLW = North Fork Clearwater River, SFCLW = South Fork Clearwater River. No fight times were measured for steelhead caught in the Salmon River, so this water was not included in the model selection.

Parameter	Coefficient	95% CI
Fight – Gear + Water		
Intercept	251.59	119.23–530.91
Gear (Nonfly)	0.46	0.35–0.60
Water (LS)	0.55	0.26–1.18
Water (NFBD)	1.69	0.82–3.49
Water (NFCLW)	1.55	0.71–3.40
Water (SFCLW)	0.70	0.35–1.43

though fight times for Cutthroat Trout *O. clarkii* in Yellowstone National Park (102 s: Schill et al. 1986) were similar to the steelhead fight times in the present study. Such short air exposure and fight time intervals suggest that most anglers are inherently conscientious of the negative impact that prolonged air exposure or exhaustive exercise can have on caught-and-released fish, although some anglers may also operate under the assumption that prolonging fight time increases the likelihood that a hooked fish will escape being landed.

Though survival of caught-and-released steelhead was not estimated in the present study, results of nearly all previous salmonid studies suggest that the air exposure and fight times reported herein would result in little to no mortality for trout and salmon in freshwater (Table 6). One notable exception is a laboratory study in which hatchery Rainbow Trout were chased in a hatchery raceway for 10 min and exposed to air for 30 or 60 s to simulate a catch-and-release event (Ferguson and Tufts 1992). Though significant mortality (38–72%) of fish exposed to air was observed, even the fish not exposed to air (but still exercised) experienced 12% mortality, and the 10 min of exhaustive exercise was not representative of fight times observed in actual angling scenarios (Schill et al. 1986; Lamansky and Meyer 2016; Roth et al. 2018a, 2018b). Furthermore, the test fish were cannulated and sampled for blood up to five times throughout the experiment, which may have exacerbated treatment effects. In a contrasting example of hardiness to handling stress, 75% of Pink Salmon *O. gorbuscha* exposed to 16 min of air and 100% of them exposed to 8 min of air survived and spawned successfully (Raby et al. 2013). In the context of these and many other studies, the fight times and air exposure times observed in the present study likely have negligible population-level effects in Idaho steelhead fisheries.

While hooking mortality was not estimated in the present study, deep-hooking rates were lower (≤1%) than those reported in previous studies on anadromous salmonids. For example, Chinook Salmon *O. tshawytscha* in the Willamette River, Oregon, experienced a 13% deep-hooking rate (esophagus–stomach, gills), which included deep-hooking rates of 15% for bait anglers and 3% for anglers using spinners (Lindsay et al. 2004). Chinook Salmon in the Yakima River, Washington, experienced an 8% deep-hooking rate, and 99% of the anglers fished with bait (Fritts et al. 2016). The discrepancy between these previous studies and our results may be caused by disparate foraging behavior between species during upstream spawning migrations. Indeed, adult steelhead are generally not believed to feed in freshwater before they spawn (Penney and Moffitt 2014), whereas Chinook Salmon can forage occasionally during their upstream migration (Garner et al. 2009). Because deep hooking by anglers is most

TABLE 6. Summary of previous studies testing exercise (fight times), air exposure, water temperatures, and sample sizes (*n*) for various salmonids, with resulting mortality rates.

Species	Temperature (°C)	Fight time (s)	Air exposure (s)	Mortality (%)	*n*	Reference
Rainbow Trout *Oncorhynchus mykiss*	8–10	600	0	12	6	Ferguson and Tufts (1992)
	8–10	600	30	38	8	
	8–10	600	60	72	7	
Brook Trout *Salvelinus fontinalis*	10	30	0	0	12	Schreer et al. (2005)
	10	30	30	0	12	
	10	30	60	0	12	
	10	30	120	0	12	
Coho Salmon *O. kisutch*	8	180	0	0	12	Donaldson et al. (2010)
		180	60	0	13	
Pink Salmon *O. gorbuscha*	13.2	180	0	0	29	Raby et al. (2013)
	13.2	180	60	0	29	
	13.2	10	0	0	29	
	11.9	0	60	0	20	
	11.9	0	120	0	20	
	11.9	0	240	0	20	
	11.9	0	480	0	20	
	11.9	0	960	25	20	
Chum Salmon *O. keta*	11.8	180	0	0	29	
	11.8	180	60	0	29	
	11.8	10	0	0	29	
Cutthroat Trout *O. clarkii*	10–13	17	0	32	110	Roth et al. (2018b)[a]
		17	30	43	110	
		17	60	39	108	
Bull Trout *S. confluentus*	9–14	16	0	48	92	
		14	30	41	94	
		14	60	36	92	
Rainbow Trout		16	0	37	103	
		13	30	42	106	
		15	60	49	113	
Pink Salmon	11–12	180	60	0	44	Donaldson et al. (2014)
Sockeye Salmon *O. nerka*	11–12	180	60	0	66	

[a]Mortality estimates from Roth et al. (2018b) were calculated from relative survival estimates reported for captured-marked-and recaptured fish.

strongly associated with fish attempting to swallow bait attached to a hook (Wydoski 1977; Muoneke and Childress 1994), fish that actively attempt to swallow food are inherently more likely to be deep hooked by bait anglers.

Fly fishing is usually regarded as resulting in higher catch-and-release survival than bait or lure fishing due to lower deep-hooking rates (Hunsaker et al. 1970) and perceived reduced handling stress. In the present study, fly anglers took considerably longer to land steelhead, exposed fish to similar air durations, were more likely to hold a fish out of water for photographing, and did not deep hook fish less often compared with those using other terminal tackle. These results suggest that fish caught and released by fly anglers in Idaho steelhead fisheries may experience more stressful handling conditions (primarily in the form of extended fight time) than fish caught by nonfly anglers. Extended fight time by fly anglers should not be surprising given that fishing rods used with bait, bobbers, and lures typically have much greater resistance and strength than fly rods used in similar fisheries. However, it should be noted that these differences, though statistically significant, are likely not biologically meaningful in the context of postrelease mortality rates or population-level impacts.

Our study confirms the importance of covertly collecting observational data on anglers in order to not bias their behavior. As suspected, anglers held fish out of the water for less time when the data were overtly collected, presumably because they were aware that their behavior was observable to agency staff. Until the study by Lamansky and Meyer (2016), previous studies that reported fight times and air exposure times had only included anglers participating in a particular study (e.g., Landsman et al. 2011). Surprisingly, covertly collected fight times were shorter than overt observations, perhaps because most overt observations were of anglers who were cooperating with biologists for hatchery broodstock collection. This situation may have placed greater importance on carefully landing the fish, making the anglers more conscious not to hurry the capture, thereby slightly prolonging the process. A limitation of this interpretation is that we assume bias due to the presence of an observer affects a typical recreational angler similar to an angler who is voluntarily assisting biologists collecting broodstock.

The results of this study add to previous work (Lamansky and Meyer 2016; Roth et al. 2018a, 2018b) suggesting that anglers in many Idaho fisheries already minimize stress on caught-and-released fish by fighting fish quickly and minimizing air exposure times. Even when anglers photographed their catch, the air exposure times we observed were not consistent with values expected to result in reduced survival. We therefore see no benefit from imposing air exposure fishing regulations in these types of fisheries. Angling interest is already declining nationwide (Maillet et al. 2017), and formally banning the practice of photographing or admiring a fish out of water before releasing it may negatively impact angler satisfaction and ultimately angler recruitment, especially considering the rise in smartphone camera and social media use. No scientific study has demonstrated that air exposure times and handling methods typical in catch-and-release fisheries have negative impacts on fish populations, and efforts to regulate air exposure distract attention from more important and legitimate negative impacts to managed fisheries, such as overharvest, habitat alterations, invasive species, and climate change.

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