North American Journal of Fisheries Management

ISSN: 0275-5947 (Print) 1548-8675 (Online) Journal homepage: http://www.tandfonline.com/loi/ujfm20

Use of a Statewide Angler Tag Reporting System to Estimate Rates of Exploitation and Total Mortality for Idaho Sport Fisheries

Kevin A. Meyer & Daniel J. Schill

North American Journal of Fisheries Management 34:1145–1158, 2014

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1080/02755947.2014.951803

ARTICLE

Use of a Statewide Angler Tag Reporting System to Estimate Rates of Exploitation and Total Mortality for Idaho Sport Fisheries

Kevin A. Meyer* and Daniel J. Schill
Idaho Department of Fish and Game, 1414 East Locust Lane, Nampa, Idaho 83686, USA

Abstract

From 2006 to 2009, 18,712 fish were tagged and released in 45 tagging events using nonreward and high-reward T-bar anchor tags to estimate the rate of exploitation (*u*) by anglers in various Idaho fisheries. In total, 3,100 nonreward tags and 592 high-reward tags were reported by anglers. Annual *u* was adjusted for tag loss, tagging mortality, and angler tag reporting rate. Tag loss, estimated by double-tagging a subsample of fish, varied greatly among species; tag loss was lowest for Yellow Perch *Perca flavescens* (1.1% in year 1 and 4.5% in year 2) and crappies *Pomoxis* spp. (2.9% and 4.8%) and was highest for Largemouth Bass *Micropterus salmoides* (14.8% and 30.3%), Walleyes *Sander vitreus* (11.4% and 43.2%), and Smallmouth Bass *M. dolomieu* (10.5% and 41.6%). Short-term (7–33-d) mortality averaged about 1% for both hatchery and wild fish. The nonreward-tag reporting rate averaged 54.5% across all species and years. Adjusted *u* averaged 19.4% (range = 2.0–44.3%) and was generally highest for crappies (mean = 28.7%) and Smallmouth Bass (22.0%) and lowest for wild trout (9.5%). Estimates of total annual mortality (*A*), based on the difference in tag returns between years 1 and 2, were plausible for some species but were unusually high for other species, especially Smallmouth Bass and wild trout. The implausibility of some estimates of *A* probably resulted from a combination of factors, including the reduced vulnerability of larger, older fish to angling, which would have caused a reduction in tag returns in year 2, likely due to a shift in fish behavior or habitat preference as tagged fish grew in size. Our results demonstrate the utility of using the high-reward tagging method to estimate *u* for fisheries under a variety of circumstances, but fisheries managers should use caution in attempting to simultaneously estimate *A* from the tag returns.

Mortality assessment is an essential part of fish population management (Allen and Hightower 2010) because mortality rates can have important influences on the abundance, size structure, recruitment, and growth of fish populations (Ricker 1975). However, estimating the various components of mortality in fish populations is often challenging due to sampling limitations and an inability to fully meet the assumptions of various estimation procedures (Miranda and Bettoli 2007).

Estimation of exploitation rate (*u*; i.e., the proportion of harvestable-sized fish that are removed from a population annually via fishing) has been a hallmark of fishery management for over 50 years. Perhaps the most straightforward technique for estimating *u* is to determine the ratio of fish harvested during the fishing season to population size at the start of the season; however, except in small populations, difficulties in measuring population size often preclude this approach (Miranda et al. 2002). A more commonly employed technique for estimating *u* consists of releasing a known number of marked fish with tags, relying on anglers to return the tags, and calculating the proportion harvested (Pollock et al. 2001).

Several authors have provided a sizeable list of assumptions associated with this approach (e.g., Ricker 1975; Pollock et al. 2001; Miranda et al. 2002), and violation of any of these assumptions can render the estimates of *u* unreliable unless the resulting bias is accounted for. In particular, violations of the tag loss, tagging mortality, and tag reporting rate assumptions are sometimes evaluated empirically and corrected for directly in exploitation tagging studies (Pollock et al. 2001; Miranda

*Corresponding author: kevin.meyer@idfg.idaho.gov
Received December 23, 2013; accepted July 21, 2014

et al. 2002). For example, tag loss can be directly estimated by releasing double-tagged fish. Immediate or delayed tagging mortality can be minimized by gentle handling and capture techniques, instituting favorable holding and tagging environments, and choosing the appropriate tag for the size and species of fish (Nielsen 1992). Even if these procedures are followed, tagging may still cause some mortality, usually in the short term, and this can be estimated with holding experiments wherein tagged fish as well as untagged control fish are held in an ambient environment (such as a net-pen) for one to several days, after which their relative survival is compared (Nielsen 1992; Pollock et al. 2001). Tag reporting rate can be evaluated by releasing both nonreward and high-reward tags and comparing their relative returns (e.g., Nichols et al. 1991; Meyer et al. 2012a).

Once the above corrections are accounted for, annual rates of exploitation by anglers can be estimated. However, because of difficulties in (1) meeting the necessary assumptions to reliably estimate u from tag returns or (2) estimating the departure from these assumptions, it has been suggested that biologists avoid directly estimating u altogether in favor of indirect population monitoring methods, such as analyzing angler catch rates, fish size, fish growth, and recruitment variability (Miranda et al. 2002). This recommendation was also based on the perception that a large financial investment would typically be required for field tagging and reward tag payments, although others have argued that this perception is based on little evidence and that high-reward tagging studies should not be dismissed out of hand as being too expensive (Pollock et al. 2001; also see Walters and Martell 2004).

Estimates of u that incorporate corrections for tag loss, tagging mortality, and tag reporting rate have error that is propagated with each applied correction, perhaps accounting for the observation that confidence bounds for such estimates are seldom reported in the literature (Miranda et al. 2002). Although simulation or resampling techniques can be used to develop such confidence bounds (e.g., Miranda et al. 2002; Isermann et al. 2005), a simpler approach for most fishery managers would be to use straightforward mathematical formulas that account for the error propagation (McFadden 1961; Yates 1980). The primary aim of the present study was therefore to evaluate whether results from a statewide angler tag reporting system in Idaho (presented by Meyer et al. 2012a) could produce precise estimates of u (corrected for tag loss, tagging mortality, and tag reporting rate) for a variety of Idaho sport fisheries.

By itself, an estimate of annual u—even with precise error bounds—may or may not be adequate for use in evaluating a fishery management program. Unless the evaluation was initially designed only to quantify the return rates of stocked fish (e.g., Koenig and Meyer 2011) or unless an estimated u for a wild stock is clearly low, additional mortality components (e.g., total or natural mortality) are often needed for a more refined fishery assessment. Often, this is accomplished by estimating total mortality using catch curves (Miranda and Bettoli 2007). However, catch curves have their own set of assumptions that may be difficult to substantiate or correct (for example, the assumption that the catch is not size selective), and substantial effort is needed to collect the necessary data (Walters and Martell 2004). Alternatively, if u is estimated with angler tag returns and if the tag returns are monitored for two full years, then total annual mortality (A) can be simply estimated by comparing the tag returns in year 2 to those in year 1 (McCammon and LaFaunce 1961; Ricker 1975) after adjusting for any additional tag loss in the second year relative to the first. This method also relies on meeting several important assumptions, some of which can be evaluated empirically. For example, vulnerability to angling is assumed to be constant over all ages and sizes of fish in the harvestable population. However, if vulnerability to angling declines as the fish grow to larger sizes and become more difficult to catch, then tag returns in year 2 would likely be biased low and estimates of total mortality would be inflated. Another important assumption is that the tag reporting rate does not differ between years. A secondary objective of this study was to calculate tag-derived estimates of A and determine whether the assumptions of this method (particularly the assumption of equal vulnerability to catch by anglers) were adequately supported by the data.

METHODS

Fish tagging.—From 2006 to 2009, Idaho Department of Fish and Game (IDFG) personnel tagged 18,712 fish distributed across 45 tagging events (Table 1). This study included a variety of species: White Crappie *Pomoxis annularis*, Black Crappie *Pomoxis nigromaculatus*, Largemouth Bass *Micropterus salmoides*, Smallmouth Bass *Micropterus dolomieu*, Yellow Perch *Perca flavescens*, Walleye *Sander vitreus*, and several species of trout, including Rainbow Trout *Oncorhynchus mykiss*, Brook Trout *Salvelinus fontinalis*, Cutthroat Trout *O. clarkii*, and Rainbow Trout × Cutthroat Trout hybrids. White Crappies and Black Crappies were combined in this study because they often occur in sympatry in Idaho waters and anglers do not distinguish between species.

Wild fish were generally collected by using a boat-mounted electrofisher (settings were 300–600-V DC, 60 Hz, and 4–7-ms pulse width, producing a 25–40% duty cycle and an average output of 1–5 A). During electrofishing, fish were captured and placed in a live well in small quantities until they were tagged and released near the point of capture. Wild trout were also captured at weirs. Hatchery trout that were used in this study were raised to catchable size (i.e., about 250 mm TL), netted out of the raceway, tagged, and held in a pen within the raceway until stocking (usually 1–3 d later).

All fish were anesthetized with spearmint oil (Danner et al. 2011) and measured for TL (nearest mm); fish were then tagged with T-bar anchor tags that were fluorescent orange, 70 mm in total length (51 mm of tubing), and treated with algaecide. Tags were labeled on two sides, with one side stating the agency and phone number and the other side listing a tag number and

TABLE 1. Summary of nonreward and high-reward tags released from 2006 to 2009 and returned by anglers for each of 45 fish tagging events in Idaho.

				Nonreward tags					High-reward tags		
					Reported[a]			Harvested			Angler nonreward-tag
Year	Water body	Species	Origin	Released	Total	Year 1	Year 2	in year 1	Released	Reported	reporting rate (±90% CI)
2006	Brownlee Reservoir	Crappies	Wild	449	111	78	28	62	41	14	72.4 ± 33.8
2007	Brownlee Reservoir	Crappies	Wild	399	108	97	9	67	42	20	56.8 ± 22.8
2008	Brownlee Reservoir	Crappies	Wild	379	73	63	9	48	40	19	40.5 ± 17.2
2009	Brownlee Reservoir	Crappies	Wild	398	85	79	5	69	42	16	56.1 ± 25.1
2006	C.J. Strike Reservoir	Crappies	Wild	210	54	42	7	26	18	6	77.1 ± 54.6
2007	C.J. Strike Reservoir	Crappies	Wild	366	113	71	34	46	40	12	102.9 ± 51.4
2008	C.J. Strike Reservoir	Crappies	Wild	382	110	79	25	57	40	18	64.0 ± 26.8
2009	C.J. Strike Reservoir	Crappies	Wild	380	112	98	13	84	38	26	43.1 ± 15.4
2006	Mann Lake	Crappies	Wild	252	111	84	12	64	25	18	61.2 ± 25.6
2006	Ben Ross Reservoir	Largemouth Bass	Wild	108	13	9	2	5	16	5	38.5 ± 33.3
2007	Ben Ross Reservoir	Largemouth Bass	Wild	227	47	36	8	6	24	13	38.2 ± 19.7
2006	Pend Oreille River	Largemouth Bass	Wild	332	94	75	12	33	33	25	37.4 ± 13.8
2006	Brownlee Reservoir	Smallmouth Bass	Wild	392	92	89	1	35	38	22	40.5 ± 15.8
2007	Brownlee Reservoir	Smallmouth Bass	Wild	399	80	79	1	37	42	15	56.1 ± 26.0
2008	Brownlee Reservoir	Smallmouth Bass	Wild	382	109	107	2	57	40	18	63.4 ± 26.5
2009	Brownlee Reservoir	Smallmouth Bass	Wild	342	51	50	1	25	36	14	38.3 ± 19.0
2006	Cascade Reservoir	Smallmouth Bass	Wild	106	12	10	2	6	2	1	22.6 ± 38.8
2006	C.J. Strike Reservoir	Smallmouth Bass	Wild	292	90	87	1	29	29	14	63.8 ± 30.2
2007	C.J. Strike Reservoir	Smallmouth Bass	Wild	379	144	142	1	61	40	19	80.0 ± 32.1
2008	C.J. Strike Reservoir	Smallmouth Bass	Wild	381	92	91	1	41	40	19	50.8 ± 21.1
2009	C.J. Strike Reservoir	Smallmouth Bass	Wild	381	104	104	1	61	42	22	52.1 ± 20.1
2007	Dworshak Reservoir	Smallmouth Bass	Wild	383	96	87	8	40	40	22	45.6 ± 17.7
2006	Milner Reservoir	Smallmouth Bass	Wild	401	134	132	2	26	40	22	60.8 ± 23.0
2009	Oakley Reservoir	Walleye	Wild	224	39	32	7	24	24	6	69.6 ± 50.2
2007	Salmon Falls Creek Reservoir	Walleye	Wild	559	123	72	41	45	42	14	66.0 ± 30.6
2009	Cascade Reservoir	Yellow Perch	Wild	379	61	44	18	37	40	11	58.5 ± 31.5
2006	Coeur d'Alene River	Rainbow Trout, Cutthroat Trout, and hybrids	Wild	78	11	10	1	4	10	4	35.3 ± 33.9
2007	Henry's Lake	Cutthroat Trout and hybrids	Wild	669	18	12	5	6	75	4	50.4 ± 45.9
2006	Moyie River	Rainbow Trout and Brook Trout	Wild	374	16	14	2	7	29	3	41.4 ± 42.8

TABLE 1. Continued.

				Nonreward tags							
					Reported[a]			Harvested	High-reward tags		Angler nonreward-tag
Year	Water body	Species	Origin	Released	Total	Year 1	Year 2	in year 1	Released	Reported	reporting rate (±90% CI)
2006	South Fork Snake River	Rainbow Trout	Wild	243	48	35	8	10	25	4	123.5 ± 105.7
2007	South Fork Snake River	Rainbow Trout and hybrids	Wild	521	72	55	9	29	48	12	55.3 ± 28.4
2006	Williams Lake	Rainbow Trout	Wild	226	40	27	10	21	24	11	38.6 ± 21.6
2007	Williams Lake	Rainbow Trout	Wild	228	20	15	2	10	31	6	45.3 ± 34.7
2008	Anderson Ranch Reservoir	Rainbow Trout	Hatchery	606	26	23	3	20	63	6	45.0 ± 33.6
2007	Boise River	Rainbow Trout	Hatchery	380	89	89	0	45	39	18	50.7 ± 21.6
2006	Cascade Reservoir	Rainbow Trout	Hatchery	755	27	25	2	18	80	4	71.5 ± 63.0
2006	Chesterfield Reservoir	Rainbow Trout	Hatchery	378	38	29	9	17	40	12	33.5 ± 18.3
2007	Glendale Reservoir	Rainbow Trout × Cutthroat Trout hybrid	Hatchery	379	87	86	1	64	39	22	40.7 ± 16.0
2006	Lake Walcott	Rainbow Trout	Hatchery	698	86	53	23	44	95	22	53.2 ± 20.9
2007	Little Wood Reservoir	Rainbow Trout × Cutthroat Trout hybrid	Hatchery	378	6	5	0	5	40	3	21.2 ± 24.6
2006	Lucky Peak Reservoir	Rainbow Trout	Hatchery	380	42	39	2	30	40	4	110.5 ± 95.1
2007	Mann Creek Reservoir	Rainbow Trout	Hatchery	380	76	70	5	66	40	15	53.3 ± 24.8
2006	Mann Lake	Rainbow Trout	Hatchery	343	58	56	0	36	40	9	75.2 ± 44.3
2007	North Fork Payette River	Rainbow Trout	Hatchery	670	53	53	0	31	72	14	40.7 ± 20.1
2008	Ririe Reservoir	Cutthroat Trout	Hatchery	380	29	18	10	10	40	8	38.2 ± 25.1
	Total			16,948	3,100	2,651	343	1,564	1,764	592	54.5 ± 4.0

[a] For reported tags, year 1 + year 2 does not always equal the total because some of the reported tags could not be assigned to a year.

reward amount if applicable. Tags were either nonreward or high reward. High-reward tags were equally split between values of US$100 and $200, both of which have recently been shown to elicit 100% tag reporting by anglers (Meyer et al. 2012a). High-reward tags made up about 10% of the total number of tags released for each tagging event. All species were tagged just below the dorsal fin as recommended by Guy et al. (1996). To reduce the rate of tagging mortality, individual fish were evaluated (up to the point of release) in terms of whether they were unfit for this study due to visible signs of stress from capture and handling procedures (Nielsen 1992). Because we were primarily interested in estimating exploitation, fish that were selected for tagging were always of harvestable size based on angler interest and angling regulations, except at one study location (i.e., Largemouth Bass at Ben Ross Reservoir) where angler catch of sub-harvestable-sized fish was also of interest.

Meyer et al. (2012a) provided a more detailed summary of the tag reporting system used in this study. Briefly, a website and toll-free automated telephone hotline were established through which anglers could voluntarily report tags, although some tags were mailed to or dropped off at IDFG offices. In addition, informational posters and stickers were distributed to IDFG license vendors, regional offices, and sporting goods stores to publicize tagging efforts, explain how the information was being used, and provide tag return instructions. No other information was provided to anglers, and signs were not posted at individual water bodies so that site-specific estimates of u in the future would not require labor-intensive sign maintenance activity at each water body where tags are released.

Estimating tag reporting rate.—The angler tag reporting rate (λ) was estimated using the reporting rate of nonreward tags relative to that of high-reward tags (Pollock et al. 2001):

$$\lambda = \frac{R_r}{R_t} \div \frac{N_r}{N_t},$$

where R_t and R_r are the numbers of nonreward tags released and reported, respectively; and N_t and N_r are the numbers of high-reward tags released and reported. Although in some instances anglers did release fish with tags intact, this usually only occurred for nonreward tags because anglers were required to turn in (not just report) high-reward tags before payment could be issued. Consequently, we only counted a reported tag once so that λ would not be biased by the fact that nonreward tags were much more likely to be reported multiple times. Variance in λ was calculated according to Henny and Burnham (1976) as

$$\mathrm{Var}(\lambda) = \lambda^2 \times \left[\frac{1}{R_r} + \left(\frac{\lambda}{R_r}\right)^2 \times \left(\frac{R_t}{N_t}\right)^2 \times N_r\right].$$

From the estimate of variance, we calculated 90% CIs. Reporting rates were estimated for each tagging event, but data were also pooled by species across all tagging events to create mean λ for each species (see Meyer et al. 2012a).

Estimates of nonreward-tag reporting rate theoretically should range between 0% and 100%. However, individual estimates of nonreward-tag reporting rates can exceed 100% by chance due to small numbers of tags for individual tagging events and the random nature of anglers' encounters with tagged fish. As a hypothetical example, if 100 nonreward tags and 10 high-reward tags are released in a water body and if anglers report 11 nonreward tags and 2 high-reward tags, then the estimated nonreward-tag reporting rate for this tagging event would be (11/100)/(2/10) = 0.55, or 55%. However, because of small sample sizes for individual tagging events, anglers might—by chance alone—encounter high-reward tags a bit less often than they probabilistically should have. In this example, if anglers had encountered and reported only one high-reward tag, the resulting nonreward-tag reporting rate would be 110%. Clearly, this result does not mean that anglers were more willing to report nonreward tags than high-reward tags in this instance, but rather it reflects chance variation in tag encounters by anglers and the small sample sizes on which reporting rates were based for individual tagging events. Consequently, estimates of u based on λ from individual tagging events were considered less reliable, and herein we only present estimates based on mean λ for each species (also see Meyer et al. 2012a).

Estimating tag loss.—To estimate the rate of tag loss, more than half of the tagged fish (nonreward and high-reward tags) were double-tagged with a "secondary" nonreward tag. Tag loss rate (Tag_l) was estimated as

$$Tag_l = \left(\frac{n_{DT1}}{2 \times n_{DT2}}\right) \times \left(\frac{n_{DT1}}{2 \times n_{DT2}}\right)^2,$$

where n_{DT1} is the number of double-tagged fish for which anglers reported that only a single tag was present, and n_{DT2} is the total number of double-tagged fish reported, whether one tag or both tags were present. The second part of the equation accounts for fish that lost both tags and therefore had no chance of being reported (Miranda et al. 2002). Sample size was not adequate to estimate Tag_l at each water body, so data were pooled to develop one estimate of Tag_l for each species. Tag loss was estimated separately for year 1 (i.e., tags returned within 1 year of the tagging event) and year 2 (i.e., tags returned after year 1 but before 2 years had expired since the tagging event). Variance was calculated according to the formula given by Fleiss (1981):

$$\mathrm{Var}(Tag_l) = \sqrt{\frac{PQ}{n}},$$

where P is Tag_l, Q is $1 - P$, and n is the number of double-tagged fish that were reported by anglers (multiplied by 2). From the estimate of variance, we calculated 90% CIs. The secondary nonreward tags were returned by anglers at the same rate as the primary nonreward tags; thus, to simplify analyses and to help meet the assumption of independence in tag reporting, secondary tags were used only to estimate Tag_l and were not considered when estimating λ. For each species, we calculated the year-1 Tag_l for larger-sized fish (i.e., those above the median TL) and smaller-sized fish (below the median), and we used a paired *t*-test (α = 0.10, with each species treated as the sampling unit) to evaluate whether tag loss appeared to be related to fish size.

Estimating tagging mortality.—To estimate tagging mortality (Tag_m), we used the same electrofishing methodology as above to capture wild Smallmouth Bass, Largemouth Bass, crappies, and trout at several water bodies. Fish were placed in 1-m^3, wire-mesh cages at a density of 28–80 fish/m^3 and were lowered to the bottom in 3–10 m of water ($n = 9$ holding trials with wild fish). Half of the fish were tagged and the other half were untagged; tagged and untagged fish were held in the same cage for each trial. Short-term mortality of tagged and untagged fish was estimated as the proportion of fish alive at 1 d or 7 d after initial capture. For hatchery trout, short-term mortality was estimated by tagging fish in raceways and holding them in 6.8-m^3 pens (at a density of 74 fish/m^3) for 22–33 d ($n = 5$ holding trials with hatchery fish).

Estimating angler exploitation.—Unadjusted *u* was calculated as the number of nonreward-tagged fish that were reported as harvested within 1 year of the tagging event, divided by the number of fish that were released with nonreward tags for the tagging event. All anglers that reported a tag were asked whether they had intentionally planned to harvest the fish they were reporting or whether they only harvested the fish because it had a tag. We asked this question because a small proportion of anglers indicated confusion as to whether tag reporting was mandatory or voluntary and whether the tag was removable without killing the fish. Few anglers reported that they had only harvested their fish because the fish was tagged; however, assuming these data were accurate, a small proportion of the total number of tagged fish were harvested "unintentionally," and those fish were not included in the calculation of *u*.

Adjusted *u* (u') incorporated λ, Tag_l, and Tag_m and was estimated using the formula

$$u' = \frac{u}{\lambda(1 - Tag_l)(1 - Tag_m)},$$

where *u* is the unadjusted annual exploitation rate (Allen and Hightower 2010). For each tagging event, we estimated u' using the mean λ for the appropriate species. Variance for u' was calculated using the approximate formulas for the variance of products and the variance of ratios (Yates 1980):

$$\mathrm{Var}(x \times y) = x^2 \times \mathrm{Var}(y) + y^2 \times \mathrm{Var}(x)$$

and

$$\mathrm{Var}(x/y) = \left(\frac{x}{y}\right)^2 \times \left[\frac{\mathrm{Var}(x)}{x^2} + \frac{\mathrm{Var}(y)}{y^2}\right],$$

where *x* and *y* are independent components of the formula for u' (each with their own variance, as established in earlier equations) being multiplied or divided by one another. These variance estimators account for uncertainty due to the number of tags at large, such that precision is improved at higher sample sizes. From these results, we derived 90% CIs for u'. Estimates of u' were compared across species and years by using ANOVA with α = 0.10.

The rate of catch-and-release angling occurring in these fisheries was estimated in the same way as for u' except that in the numerator (i.e., *u*), the number of nonreward-tagged fish reported as harvested within 1 year of the tagging event was replaced with the number reported as *not* harvested. As with estimates of u', for each tagging event we estimated the rate of catch and release by using only the mean λ for the appropriate species.

Estimating total annual mortality.—Total annual mortality rate (*A*) was estimated as

$$A = 1 - \frac{R_{r(y2)}}{R_{r(y1)}},$$

where $R_{r(y2)}$ is the number of nonreward tags reported by anglers in year 2 and $R_{r(y1)}$ is the number of nonreward tags reported in year 1 (Ricker 1975; Miranda and Bettoli 2007). The estimation of *A* had several important assumptions that we could evaluate empirically. One assumption was that λ did not differ between years, and our results support this assumption (see below; also see Meyer et al. 2012a). Another assumption was that λ did not differ between larger-sized and smaller-sized fish because as fish grew in size from year 1 to year 2, a change in λ caused by fish growth would cause the likelihood of tags being returned by anglers in year 2 to differ from the likelihood in year 1, thereby invalidating the estimate of *A*. This assumption was evaluated by splitting fish of each species into groups of larger-sized fish (i.e., those above the median) and smaller-sized fish (those below the median) and comparing λ between the two groups with a paired *t*-test (α = 0.10, treating each species as the sampling unit). Hatchery trout were excluded from these analyses since they were all stocked at essentially the same size. If Tag_l was different between larger- and smaller-sized fish, this would have been corrected for by the additional tag loss adjustment we had already made for year-2 tag returns, but as noted above we did evaluate whether fish size affected tag loss.

Another important assumption for estimating *A* was that vulnerability to angling was not size dependent. To assess whether estimates of *A* were potentially impaired by size dependence in fish vulnerability to anglers, each fish with a nonreward tag was considered the sampling unit; fish TL at tagging was binned into 50-mm size-groups, and dummy variables were used to define whether a fish was caught and reported by an angler (1) or not (0). We used ANOVA ($\alpha = 0.10$) to evaluate whether the proportion of tagged fish caught by anglers varied between size-groups. To minimize any bias that fish growth might have on this analysis, we limited returns to those occurring within 1 year of tagging.

A final assumption was that Tag_l in year 2 was not higher than that in year 1. We expected that this assumption would be violated because regardless of whether or not Tag_l was size dependent, tags were more likely to have fallen off by the end of year 2 than by the end of year 1. To account for this, we adjusted our estimates of A by enlarging the total number of year-2 tag returns by the amount of additional tag loss in year 2 relative to year 1, which standardized the effect of tag loss on tag returns between years. A second adjustment to A was made to account for those anglers who had (1) "unintentionally" harvested a fish only because it had a tag, and otherwise would have released the fish; or (2) removed and reported the tag but released the fish. These tagged fish were not incorporated into estimates of u', but they were also unavailable to anglers the next year, which could have lowered tag returns in year 2. We derived 90% CIs for A by using the above-mentioned formulas from Yates (1980).

We used an α value of 0.10 for all statistical significance tests and for calculating CIs. This less-stringent significance level (compared to the more standard use of $\alpha = 0.05$) was adopted to balance type I and type II errors in our statistical tests (Cohen 1990; Stephens et al. 2005) and because IDFG fish managers were content with the tradeoff of having more precision in the estimates of u and A at the expense of less confidence in the estimates.

RESULTS

In total, 16,948 fish with nonreward tags and 1,764 fish with high-reward tags were released, and anglers reported 3,100 nonreward tags and 592 reward tags (Table 1). Nonreward-tag reporting rate averaged 54.5 ± 4.0% (weighted mean ± 90% CI) across all species and years, with individual estimates varying from 21.2% to over 100% (Table 1). There was no apparent variation in tag reporting rates over time, with weighted means of 53, 56, 50, and 56% from 2006 to 2009. A paired t-test indicated that the tag reporting rate did not differ between the larger-sized fish (mean = 55.8%) and smaller-sized fish (mean = 53.5%; $t = 1.14$, df = 5, $P = 0.31$).

Average Tag_l (weighted mean ± 90% CI) across all species was 8.2 ± 0.7% in year 1 and 17.8 ± 2.3% in year 2 (Table 2). Tag loss varied among species and was lowest for Yellow Perch (1.1 ± 1.9% in year 1; 4.5 ± 3.7% in year 2) and crappies (2.9 ± 1.1%; 4.8 ± 3.1%) and was highest for Largemouth Bass (14.8 ± 5.1%; 30.3 ± 11.9%), Walleyes (11.4 ± 5.2%; 43.2 ± 12.8%), and Smallmouth Bass (10.5 ± 1.5%; 41.6 ± 14.3%). A paired t-test indicated that Tag_l in the first year after release did not differ between the larger-sized fish

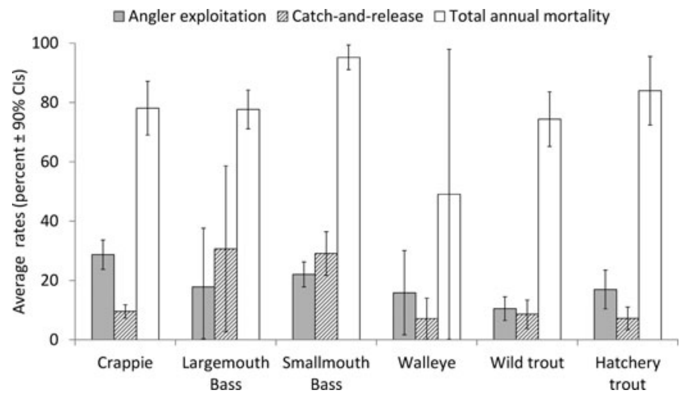

FIGURE 1. Estimates of mean (± 90% CI) annual rates (%) of exploitation by anglers (adjusted), catch-and-release angling, and total mortality summarized by species.

(mean = 8.6%) and smaller-sized fish (mean = 7.8%; $t = 1.47$, df = 5, $P = 0.20$).

Tagging mortality (Tag_m) was low (i.e., < 5%) for all trials (Table 3). Mean short-term (i.e., 7-d) mortality (using each trial as the sampling unit) of tagged wild fish was about 1% higher than that of untagged wild fish. For hatchery trout, Tag_m averaged 0% after 1 d and 0.8% after 22–33 d. Based on these findings, Tag_m was assumed to be very low but not zero; therefore, 1% was used as an estimate.

Taking into account the angler tag reporting rate for nonreward tags, Tag_l, and Tag_m, estimates of u' for individual tagging events averaged 19.4% but varied widely from a low of 2.0% to a high of 44.3% (Table 4). Based on ANOVA (using each tagging event as a sampling unit, or point estimate, of u'; n = 45), exploitation differed among species ($F = 2.80$, df = 6, P = 0.02) but not between years ($F = 2.10$, df = 3, $P = 0.12$). Exploitation was generally highest for crappies (mean u' ± SE = 28.7 ± 2.7%) and Smallmouth Bass (mean $u' = 22.0$ ± 2.3%) and lowest for wild trout (mean u' = 9.5 ± 9.5%; Figure 1). The 90% CIs around the u' estimates were (on average) 34% of the point estimate, and nearly one-half of the u' estimates had 90% CIs that were less than or equal to 25% of the point estimate (Table 4).

The rate of catch-and-release angling in these fisheries averaged 14.8% but also varied widely among species and among tagging events (Table 4). Rates of catch-and-release angling were lowest for the three most harvest-oriented species, including Yellow Perch (3.2%), Walleyes (mean = 7.1%), and crappies (mean = 9.6%). Catch-and-release rates were highest for Largemouth Bass (mean = 30.6%) and Smallmouth Bass (mean = 29.1%).

Based on tag returns from one full year and two full years after release, A averaged 81.7% and varied from 28.3% to 100% (Table 4; Figure 1). However, this mean value was influenced by the extremely high estimates for Smallmouth Bass (11 estimates; mean = 95.2%) and hatchery trout (12 estimates;

TABLE 2. Estimates of tag loss within 1 and 2 years of tagging for various fish species in Idaho.

Species	Number of double-tagged fish released	Year-1 tag reporting: Double-tagged fish reported as: Single-tagged	Double-tagged	Year-1 tag loss (%) (±90% CI)	Year-2 tag reporting: Double-tagged fish reported as: Single-tagged	Double-tagged	Year-2 tag loss (%) (±90% CI)
Crappies	2,530	39	650	2.9 ± 1.1	15	147	4.8 ± 3.1
Hatchery trout	3,080	108	553	8.8 ± 2.0	34	41	27.8 ± 13.0
Wild trout	1,079	31	143	9.7 ± 3.7	19	54	14.7 ± 7.0
Largemouth Bass	458	32	90	14.8 ± 5.1	20	21	30.3 ± 11.9
Smallmouth Bass	3,103	198	838	10.5 ± 1.5	24	14	41.6 ± 14.3
Walleye	633	20	77	11.4 ± 5.2	30	16	43.2 ± 12.8
Yellow Perch	309	1	43	1.1 ± 1.9	3	32	4.5 ± 3.7
Total	11,192	429	2,394	8.2 ± 0.7	145	325	17.8 ± 2.3

TABLE 3. Estimates of short-term mortality for tagged and untagged wild fish that were held in cages and tagged hatchery fish that were held in raceway net pens (no untagged hatchery fish were held). For each holding experiment, all tagged and untagged fish were held in one cage.

Water body	Species	Origin	Tagged fish: Fish TL (mm): *n*	Mean	Range	Percent mortality: 1 d	7 d	Untagged fish: Fish TL (mm): *n*	Mean	Range	Percent mortality: 1 d	7 d
Brownlee Reservoir	Crappies	Wild	20	193	185–225	0	5	20	193	180–215	0	0
Brownlee Reservoir	Crappies	Wild	20	217	200–228	0	0[a]	20	213	200–228	0	0[a]
C.J. Strike Reservoir	Crappies	Wild	40	200	190–239		7.5[a]	40	199	195–215		5[a]
Brownlee Reservoir	Smallmouth Bass	Wild	14	395	205–465	0	0	14	381	310–470	0	0
Brownlee Reservoir	Smallmouth Bass	Wild	20	418	308–518	0	0[a]	20	390	306–475	0	0[a]
C.J. Strike Reservoir	Smallmouth Bass	Wild	15	318	305–347	6.7	6.7	15	329	306–395	0	6.7
Lake Lowell	Largemouth Bass	Wild	16	344	308–388	0	0	15	353	305–419	0	0
South Fork Snake River	Rainbow Trout	Wild	20	477	380–605		0	20	459	368–520		0
South Fork Boise River	Rainbow Trout	Wild	20	425	320–570	0	0	20	449	285–583	0	0
Ririe Reservoir	Cutthroat Trout	Hatchery	500	285		0						
Hatchery	Rainbow Trout	Hatchery	500	280		0	1.0[b]					
Hatchery	Rainbow Trout	Hatchery	500	250		0	0.4[b]					
Hatchery	Rainbow Trout	Hatchery	500	260		0	1.8[b]					
Hatchery	Rainbow Trout	Hatchery	100	240		0	0[b]					

[a]Sampling occurred 8 d after release.
[b]Fish were held in the hatchery for 22–33 d.

TABLE 4. Annual rates of exploitation by anglers (adjusted), catch-and-release angling, and total mortality (±90% CI) for each of 45 fish tagging events in Idaho.

Year	Water body	Species	Origin	Exploitation (%)	Catch-and-release angling (%)	Total mortality (%)
2006	Brownlee Reservoir	Crappies	Wild	24.1 ± 4.7	6.2 ± 5.1	62.8 ± 8.9
2007	Brownlee Reservoir	Crappies	Wild	29.3 ± 5.4	13.1 ± 5.4	90.1 ± 4.9
2008	Brownlee Reservoir	Crappies	Wild	22.1 ± 4.9	6.9 ± 4.9	85.2 ± 7.2
2009	Brownlee Reservoir	Crappies	Wild	30.3 ± 5.5	4.4 ± 5.5	93.5 ± 4.5
2006	C.J. Strike Reservoir	Crappies	Wild	21.6 ± 6.5	13.3 ± 6.5	82.4 ± 9.5
2007	C.J. Strike Reservoir	Crappies	Wild	21.9 ± 5.0	11.9 ± 5.0	50.1 ± 9.6
2008	C.J. Strike Reservoir	Crappies	Wild	26.0 ± 5.2	10 ± 5.2	66.9 ± 8.6
2009	C.J. Strike Reservoir	Crappies	Wild	38.6 ± 6.1	6.4 ± 6.1	86.3 ± 5.6
2006	Mann Lake	Crappies	Wild	44.3 ± 7.9	13.8 ± 7.9	85.2 ± 6.3
2006	Ben Ross Reservoir	Largemouth Bass	Wild	14.4 ± 10.4	11.5 ± 10.4	75.5 ± 21.8
2007	Ben Ross Reservoir	Largemouth Bass	Wild	8.2 ± 5.5	41.1 ± 6.1	75.3 ± 10.9
2006	Pend Oreille River	Largemouth Bass	Wild	30.9 ± 8.7	39.3 ± 8.8	82.1 ± 6.7
2006	Brownlee Reservoir	Smallmouth Bass	Wild	18.7 ± 5.0	28.8 ± 5.0	98.5 ± 2.0
2007	Brownlee Reservoir	Smallmouth Bass	Wild	19.4 ± 5.0	22.0 ± 5.0	98.3 ± 2.2
2008	Brownlee Reservoir	Smallmouth Bass	Wild	31.2 ± 6.3	27.4 ± 6.3	97.6 ± 2.3
2009	Brownlee Reservoir	Smallmouth Bass	Wild	15.3 ± 4.9	15.3 ± 4.9	97.5 ± 3.5
2006	Cascade Reservoir	Smallmouth Bass	Wild	11.8 ± 7.7	7.9 ± 7.7	74.3 ± 21.5
2006	C.J. Strike Reservoir	Smallmouth Bass	Wild	20.8 ± 6.0	41.6 ± 6.1	98.5 ± 2.0
2007	C.J. Strike Reservoir	Smallmouth Bass	Wild	33.7 ± 6.5	44.7 ± 6.6	99.1 ± 1.3
2008	C.J. Strike Reservoir	Smallmouth Bass	Wild	22.5 ± 5.5	27.5 ± 5.5	98.6 ± 1.9
2009	C.J. Strike Reservoir	Smallmouth Bass	Wild	33.5 ± 6.5	23.6 ± 6.5	98.8 ± 1.7
2007	Dworshak Reservoir	Smallmouth Bass	Wild	21.9 ± 5.4	25.7 ± 5.4	88.0 ± 5.4
2006	Milner Reservoir	Smallmouth Bass	Wild	13.6 ± 4.2	55.3 ± 4.4	98.0 ± 1.9
2009	Oakley Reservoir	Walleye	Wild	18.1 ± 5.9	6.0 ± 5.8	71.7 ± 12.4
2007	Salmon Falls Creek Reservoir	Walleye	Wild	13.6 ± 3.3	8.2 ± 3.2	26.4 ± 8.1
2009	Cascade Reservoir	Yellow Perch	Wild	17.0 ± 4.4	3.2 ± 4.4	57.3 ± 12.2
2006	Coeur d'Alene River	Rainbow Trout, Cutthroat Trout, and hybrids	Wild	11.0 ± 8.8	16.4 ± 8.8	89.4 ± 15.3
2007	Henry's Lake	Cutthroat Trout and hybrids	Wild	1.9 ± 1.3	1.9 ± 1.3	56.9 ± 22.4
2006	Moyie River	Rainbow Trout and Brook Trout	Wild	4.0 ± 2.5	4.0 ± 2.5	85.1 ± 14.9
2006	South Fork Snake River	Rainbow Trout	Wild	8.8 ± 4.5	22.0 ± 4.6	75.9 ± 11.3
2007	South Fork Snake River	Rainbow Trout and hybrids	Wild	11.9 ± 3.6	10.7 ± 3.6	82.9 ± 7.9
2006	Williams Lake	Rainbow Trout	Wild	19.8 ± 6.8	5.7 ± 6.8	61.4 ± 14.7
2007	Williams Lake	Rainbow Trout	Wild	9.4 ± 4.8	4.7 ± 4.8	86.2 ± 13.9
2008	Anderson Ranch Reservoir	Rainbow Trout	Hatchery	7.5 ± 2.7	1.1 ± 2.7	84.8 ± 11.8
2007	Boise River	Rainbow Trout	Hatchery	26.9 ± 6.2	26.3 ± 6.2	100
2006	Cascade Reservoir	Rainbow Trout	Hatchery	5.4 ± 2.1	2.1 ± 2.1	90.7 ± 9.2
2006	Chesterfield Reservoir	Rainbow Trout	Hatchery	10.2 ± 4.0	7.2 ± 4.0	63.5 ± 14.1
2007	Glendale Reservoir	Rainbow Trout × Cutthroat Trout hybrids	Hatchery	38.4 ± 7.3	13.2 ± 7.2	98.6 ± 2.0
2006	Lake Walcott	Rainbow Trout	Hatchery	14.3 ± 3.5	2.9 ± 3.4	49.3 ± 10.8

TABLE 4. Continued.

Year	Water body	Species	Origin	Exploitation (%)	Catch-and-release angling (%)	Total mortality (%)
2007	Little Wood Reservoir	Rainbow Trout × Cutthroat Trout hybrids	Hatchery	3.0 ± 2.2	0	100
2006	Lucky Peak Reservoir	Rainbow Trout	Hatchery	17.9 ± 5.2	5.4 ± 5.2	93.9 ± 6.0
2007	Mann Creek Reservoir	Rainbow Trout	Hatchery	39.4 ± 7.3	2.4 ± 7.3	91.6 ± 5.2
2006	Mann Lake	Rainbow Trout	Hatchery	23.8 ± 6.2	13.2 ± 6.2	100
2007	North Fork Payette River	Rainbow Trout	Hatchery	10.5 ± 3.0	7.5 ± 3.0	100
2008	Ririe Reservoir	Cutthroat Trout	Hatchery	6.0 ± 3.1	4.8 ± 3.1	34.9 ± 17.7

mean = 84.3%). Mean A for wild fish populations not including Smallmouth Bass was 73.6%.

Several species showed graphical evidence of size-selective vulnerability to anglers (Figure 2). Vulnerability to anglers generally increased at the smallest sizes, reached an apex at about 250–350 mm (depending on the species), and declined beyond the apex. Based on ANOVA results, this pattern of higher vulnerability for intermediate-sized fish and lower vulnerability for smaller and/or larger fish was statistically significant for wild trout (F = 8.61, df = 6, P < 0.0001), crappies (F = 2.73, df = 2, P = 0.07), and Largemouth Bass (F = 2.16, df = 4, P = 0.07). The pattern was similar but not statistically significant for Smallmouth Bass (F = 1.17, df = 4, P = 0.15), and there was no apparent relationship for Yellow Perch (F = 0.40, df = 1, P = 0.75) or Walleyes (F = 0.90, df = 4, P = 0.48). No such analyses could be conducted for hatchery trout because all fish were stocked at relatively the same size (i.e., 250 mm).

DISCUSSION

The statewide angler tag reporting system allowed us to produce a multitude of estimates of u' with reasonably tight confidence bounds, which Idaho fisheries managers have subsequently found to be useful in understanding and managing these sport fish populations. Using this system, IDFG biologists now tag 30,000–40,000 fish/year to evaluate angler exploitation in a variety of Idaho's resident fisheries, especially those targeting the roughly 2 million catchable-sized (i.e., TL = 250 mm) hatchery Rainbow Trout that are stocked annually in put-and-take fisheries across the state (Cassinelli and Koenig 2013); stocking rates and locations have been adjusted accordingly. The study design and statistical analyses presented herein were relatively simple yet practical and provided a straightforward method of producing accurate and precise confidence bounds around estimates of u', relative to more complicated methods, such as those using simulation or resampling procedures (e.g., Miranda et al. 2002; Isermann et al. 2005).

A costly aspect of the program was paying anglers a total of about \$90,000 for high-reward tag returns. However, when considering the cost per estimate of u' produced (\$2,000), the expenditure was not prohibitive. Moreover, a large percentage of the reward payments were needed to determine the value that would elicit a λ of 100% (see Meyer et al. 2012a). With this information now at hand, future studies will not need to release so many reward tags, and \$200 tags will not be necessary. We believe that in most instances, a nonreward : high-reward tagging ratio of about 10:1 will provide adequate estimates of λ at individual water bodies. If a statewide or provincial program is established, reward tags will only be required in some of the water bodies, and the release of fewer than 100 high-reward tags per year would probably provide an adequate estimate of λ across the area of inference. It should be noted that values of λ are likely to be higher for species that anglers are more likely to harvest and lower for species that anglers are more likely to catch and release (Meyer et al. 2012a), so we recommend estimating exploitation with λ values that are species specific or group specific (e.g., wild trout). Following these suggestions would yield a substantial reduction in reward payments compared with those employed in the current study and would likely involve little sacrifice in confidence for actual estimates of λ or exploitation. Certainly, the total costs associated with conducting statewide evaluations of angler exploitation using tag returns would be less than the costs of using creel surveys and population estimates at the same waters to obtain exploitation estimates (see Miranda and Bettoli 2007).

Our results indicate that rates of exploitation by anglers in Idaho were highest for harvest-oriented coolwater and warmwater fisheries and were similar to rates of exploitation typical of other North American fisheries. For example, Allen et al. (1998) reviewed 18 estimates of crappie exploitation, finding an average of 48% and a range of 0–84%, slightly higher than the average (29%) and range (22–44%) in this study. Baccante and Colby (1996) similarly reviewed 46 estimates of Walleye exploitation in North America, and their average (21%) was similar to that identified for Walleyes in the present study (16%). In reviewing 32 studies of Largemouth Bass exploitation in North America, Allen et al. (2008) found that harvest from 1953 to 2003 was parabolic shaped due to voluntary catch-and-release behavior since 1990; mean exploitation from 1990 to 2003 was 18%, identical to the rate we found for Largemouth Bass. Finally,

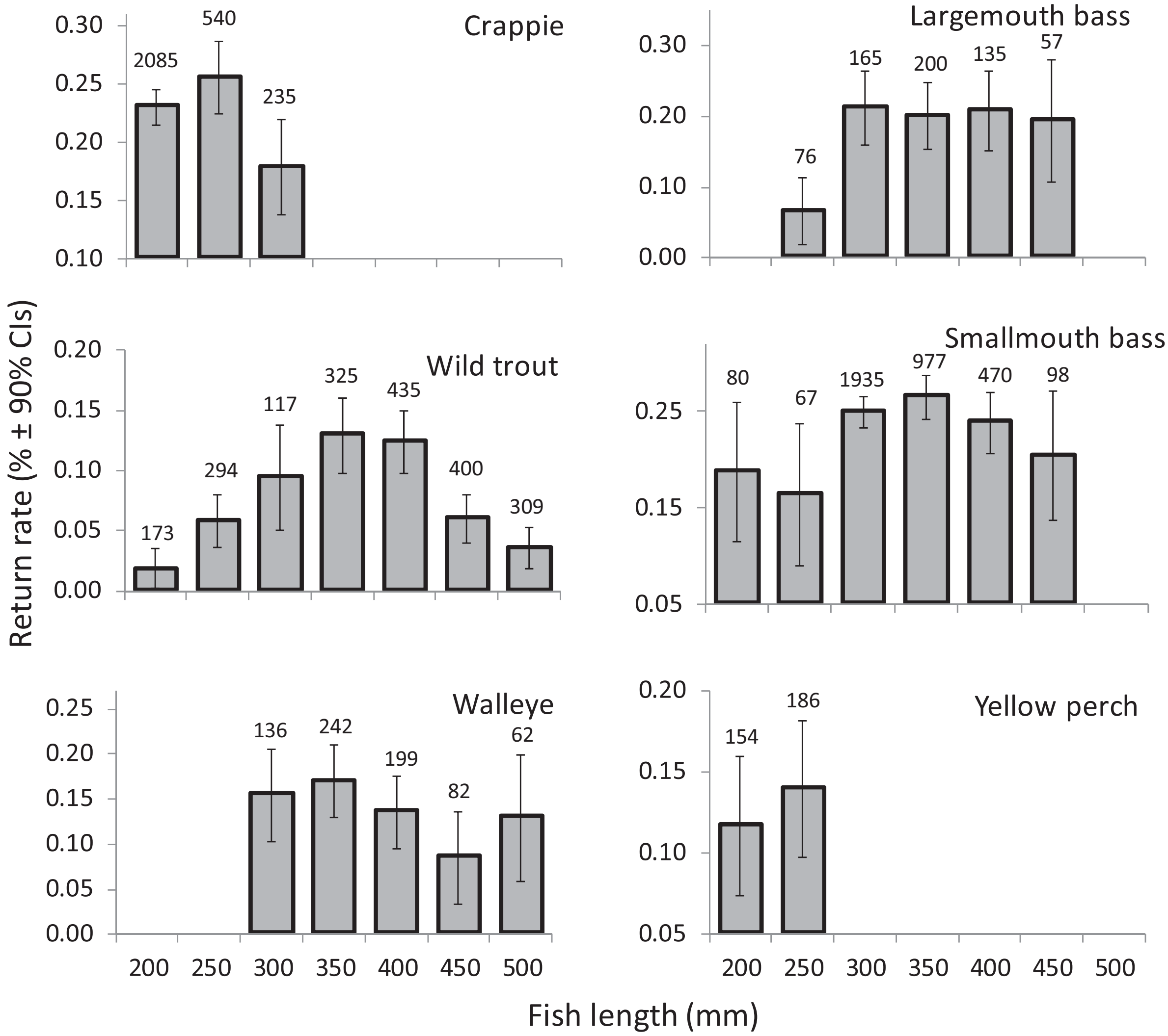

FIGURE 2. Percentage of tag returns (±90% CI) in various size-at-tagging bins (50-mm TL-groups) for fish species in Idaho. Numbers above bars indicate sample sizes within each size bin.

Marinac-Sanders and Coble (1981) estimated exploitation for Smallmouth Bass and summarized estimates for seven other studies around North America, finding an average of 41%; although our average for Smallmouth Bass (22%) was much lower, it was nevertheless within the range of estimates compiled by Marinac-Sanders and Coble (1981). This difference for Smallmouth Bass can be partly explained by the fact that the previous estimates were all made prior to the recent adoption of the voluntary catch-and-release ethic by many bass anglers (Slipke et al. 1998; Myers et al. 2008).

In contrast to the plausibility of estimates of u' in the present study, estimates of A were dubiously high for some species, especially Smallmouth Bass and wild trout. For example, the mean A for Smallmouth Bass populations in this study was 95%—much higher than the average of 54% across eight North American studies (Marinac-Sanders and Coble 1981). Similarly, the mean A of 76% for wild trout in this study (mostly Rainbow Trout and Cutthroat Trout) was much higher than the average of 47% reported by Meyer et al. (2012b) for 24 Rainbow Trout populations in Idaho. Estimates of A for the remaining species in our study appeared to be more realistic. For example, the mean for crappies (78%) was similar to the mean (75%) of 33 North American estimates summarized by Allen et al. (1998); estimates for Yellow Perch and Walleyes in this study were similarly in accordance with other estimates in the literature (e.g., Quist et al. 2004; Schoenebeck and Brown 2011). Total annual mortality for stocked catchable-sized trout in Idaho often approaches 100% in both lotic (High and Meyer 2009) and lentic (Koenig and Meyer 2011) environments, and estimates from the present study concur with those prior findings. Finally, the mean for Largemouth Bass (77%) in our study was similar to but slightly higher than the mean (64%) from 34 North American studies reviewed by Allen et al. (1998), although our estimate was based on only three tagging events.

The implausibility of estimates of *A* for some species could have stemmed from violations of a number of important assumptions. At least one of the potentially violated assumptions was that all sizes of fish have equal vulnerability to anglers (Figure 2). For crappies, basses, and wild trout, the smallest fish became more vulnerable as they grew; this could have resulted in higher-than-expected tag returns by anglers in year 2, which would have led to underestimation of total mortality. However, the vast majority of fish tagged in our study were at or beyond the apex of the relationship between fish size and vulnerability to angling, especially for Smallmouth Bass (96%), Largemouth Bass (88%), and wild trout (72%). In contrast, for crappies, a greater percentage of tagged fish (73%) were at or before the apex. Thus, for most of the tagged bass and wild trout in our study, vulnerability to anglers was lower in year 2 than in year 1, which likely resulted in reduced tag returns in year 2 for these species and consequently led to an overestimation of their total mortality. Statistical significance in this relationship was not evident for Smallmouth Bass, but graphically the assumption of equal vulnerability across all sizes of fish nevertheless appeared tenuous (Figure 2). Size-selective angler catch is not uncommon in freshwater sport fisheries (e.g., Serns and Kempinger 1981; Miranda and Dorr 2000), but accounts are often anecdotal and poorly documented (e.g., Miranda and Dorr 2000), and the direction of change is not necessarily consistent across species. For example, larger White Bass *Morone chrysops* were more vulnerable to anglers in Kansas reservoirs (Schultz 2004), whereas vulnerability of crappies declined for larger fish in southeastern North America (Miranda and Dorr 2000).

A number of possible mechanisms are likely responsible for what we are terming "unequal vulnerability in angler catch," including selective angling gear, fish morphology, fish behavior, habitat preferences, and seasonality of angler effort (e.g., Miranda and Dorr 2000; Cooke et al. 2005; Heermann et al. 2013). Perhaps the most likely explanation is a probable shift in behavior or habitat preference, with larger fish moving to deeper water, making them less vulnerable to anglers. Such a behavioral shift of larger fish to deeper water has been observed for many of the species in our study, including crappies (Markham et al. 1991), black basses (Probst et al. 1984; Cole and Moring 1997), and wild trout (Baltz et al. 1991; Jakober et al. 2000).

Estimates of Tag_m in our study were based on only 14 holding trials that were of short duration. Nevertheless, our results concur with literature findings that suggest minimal tagging mortality when anchor tags are used. For example, mortality was 3% over 2–4 d for Yellow Perch in South Dakota (Scholten et al. 2002), 11% over 2 d for crappies in southeastern North America (Miranda et al. 2002), 0% over 191 d for Largemouth Bass in an Illinois pond (Tranquilli and Childers 1982), 0% over 300 d for Brook Trout in a Wisconsin pond (Carline and Brynildson 1972), and 0% over 160 d for Arctic Char *Salvelinus alpinus* in a Canadian hatchery (Rikardsen et al. 2002). Tagging mortality associated with anchor tags is generally thought to be so low that biologists often assume zero mortality without any evaluation (e.g., Knapp et al. 1991; Muoneke 1994; Schultz and Robinson 2002). If tagging and handling in our study resulted in more severe mortality that was delayed for several months, this could have reduced year-2 tag returns and perhaps partly explained our implausibly high estimates of *A*. However, because tagging with anchor tags is generally believed to cause little initial mortality and even less delayed mortality (Nielsen 1992; Pollock et al. 2001), delayed tagging mortality was unlikely to have had an appreciable impact on our estimates of *A*.

Another possible explanation for the dearth of tag returns in year 2 is violation of the assumption that catch-and-release mortality was negligible. Violation of this assumption would have had the largest impacts on estimates of *A* for Smallmouth Bass and Largemouth Bass, as they had the highest rates of catch-and-release angling. However, although catch-and-release mortality can be high for black bass in some situations (reviewed by Cooke et al. 2002), it is generally considered to be relatively low (Siepker et al. 2007); thus, high rates of catch-and-release mortality seem unlikely to be the primary cause of the inflated estimates of *A*. Our estimates of *A* also involved the assumption that if an angler caught a tagged fish but chose to not report the tag, the angler released the fish with the tags intact. However, it is possible that some anglers were disgruntled because the fish they caught had tags attached to them, and uncooperative anglers may have chosen to pull all of the tags off before releasing the fish and to avoid reporting the tags. This would have inflated the actual Tag_l, and the inflation would not be detectable since our estimates of Tag_l were derived from double-tagged fish that had lost only one of the two tags.

Taking all of these assumptions into consideration, the inflated estimates of *A* we observed for some species, particularly wild trout and Smallmouth Bass, were perhaps caused by the cumulative effects of slight violations of several assumptions. Often, little or no effort is made to evaluate many of the assumptions associated with estimating *A* from two consecutive years of angler tag returns (e.g., Rawstron and Hashagen 1972; Rieman 1987; Muoneke 1994; Schultz and Robinson 2002). Based on the present results, caution should be used by biologists who are considering an angler tagging study to estimate *A* for fish populations unless it can be shown that the assumptions necessary to estimate *A* are not being violated.

Tag loss rates for the species in this study were generally lower than those reported in most other studies using T-bar anchor tags. For example, year-1 tag loss for crappies was lower in this study (mean = 2.9%) than in studies by Larson et al. (1991; mean = 18%) and Miranda et al. (2002; 47%). Tag loss was similarly low for Largemouth Bass in our study (mean = 14.8% in year 1) compared with studies by Tranquilli and Childers (1982; 56% after 6 months) and Hartman and Janney (2006; 57% after 13 months). The estimate of 8.8% annual tag loss for hatchery trout was similar to estimates reported by Carline and Brynildson (1972; 4% after 8 months), Mourning et al. (1994; 11% after 4 months), and Walsh and Winkelman (2004; 9% after 6 months). Often, the cumulative tag loss after 2 years in this study (e.g., 5% for crappies) was still lower than published rates of tag loss within 1 year.

CONCLUSIONS

Despite the well-reasoned concerns of Miranda et al. (2002) regarding cost and imprecision, we believe our results demonstrate that using the high-reward tagging method to estimate u' can be an effective tool for inland fisheries management. As noted above, nearly half of the estimates of u' herein had 90% CIs that were within 25% of the point estimate (Table 4), and many more estimates were low enough that a fairly strong sense of angler harvest impact was discernible despite imprecision in the estimates. From a management perspective, perhaps only 3 of the 45 estimates of u' in Table 4 had error bounds that were too wide to be informative. The straightforward concept of angler exploitation estimates makes them easily understood and thus perhaps more readily accepted by biologists, anglers, and policymakers alike. Fish managers routinely use such information in public meetings to (1) inform the angling public of the harvest rates for specific fish populations or (2) defend or modify harvest regulations as needed (Allen and Hightower 2010). As long as the assumptions of the high-reward tagging method can be met and as long as correction parameters can be estimated if necessary, this method is likely to be cost effective for biologists attempting to evaluate the effects of angler harvest on the fisheries they manage.

Conversely, our study demonstrates the potential incompatibility of the tag return method in estimating A. When vulnerability to anglers is not equal across all size-classes of fish, estimates of A may prove spurious. Simultaneous monitoring of growth in the fish population by using other field sampling methods may allow biologists to model and correct size-selectivity issues before estimating A; future research along these lines would be useful. Alternatively, other more commonly employed approaches for estimating A, such as building catch curves, may be needed in conjunction with tag return estimates of u' if a detailed investigation of population mortality sources is desired.

ACKNOWLEDGMENTS

We thank the IDFG staff members who assisted with tagging efforts, especially Art Butts, Patrick Kennedy, Tony Lamansky, and Liz Mamer for tagging assistance and data management. We are grateful to Rick Alsager and the Nampa Fish Hatchery crew and to Joe Chapman and the Hagerman State Fish Hatchery crew for their assistance with the hatchery trout used in this study. Special thanks are extended to the U.S. Bureau of Reclamation for providing a grant to cover tag reward costs. Mike Quist, Robert Arlinghaus, Mike Allen, and Jacob Hughes provided helpful critiques on earlier versions of the paper.

REFERENCES

Allen, M. S., and J. E. Hightower. 2010. Fish population dynamics: mortality, growth, and recruitment. Pages 43–80 *in* W. A. Hubert and M. C. Quist, editors. Inland fisheries management in North America, 3rd edition. American Fisheries Society, Bethesda, Maryland.

Allen, M. S., L. E. Miranda, and R. E. Brock. 1998. Implications of compensatory and additive mortality to the management of selected sport fish populations. Lakes and Reservoirs: Research and Management 3:67–79.

Allen, M. S., C. J. Walters, and R. Myers. 2008. Temporal trends in Largemouth Bass mortality, with fishery implications. North American Journal of Fisheries Management 28:418–427.

Baccante, D. A., and P. J. Colby. 1996. Harvest, density and reproductive characteristics of North American Walleye populations. Annales Zoologici Fennici 33:601–615.

Baltz, D. M., B. Vondracek, L. R. Brown, and P. B. Moyle. 1991. Seasonal changes in microhabitat selection by Rainbow Trout in a small stream. Transactions of the American Fisheries Society 120:166–176.

Carline, R. F., and O. M. Brynildson. 1972. Effects of the Floy anchor tag on the growth and survival of Brook Trout (*Salvelinus fontinalis*). Journal of the Fisheries Research Board of Canada 29:458–460.

Cassinelli, J., and M. Koenig. 2013. Hatchery trout evaluations. Idaho Department of Fish and Game, Annual Performance Report 13–04, Boise.

Cohen, J. 1990. Things I have learned (so far). American Psychologist 45:1304–1312.

Cole, M. B., and J. R Moring. 1997. Relation of adult size to movements and distribution of Smallmouth Bass in a central Maine Lake. Transactions of the American Fisheries Society 126:815–821.

Cooke, S. J., B. L. Barthel, C. D. Suski, M. J. Siepker, and D. P. Philipp. 2005. Influence of circle hook size on hooking efficiency, injury, and size selectivity of Bluegill with comments on circle hook conservation benefits in recreational fisheries. North American Journal of Fisheries Management 25: 211–219.

Cooke, S. J., J. F. Schreer, D. H. Wahl, and D. P. Philipp. 2002. Physiological impacts of catch-and-release angling practices on Largemouth Bass and Smallmouth Bass. Pages 489–512 *in* D. P. Philipp and M. S. Ridgway, editors. Black bass: ecology, conservation, and management. American Fisheries Society, Symposium 31, Bethesda, Maryland.

Danner, G. R., K. W. Muto, A. M. Zieba, C. M. Stillman, J. A. Seggio, and S. T. Ahmad. 2011. Spearmint (l-carvone) oil and wintergreen (methyl salicylate) oil emulsion is an effective immersion anesthetic of fishes. Journal of Fish and Wildlife Management 2:146–155.

Fleiss, J. L. 1981. Statistical methods for rates and proportions, 2nd edition. Wiley, New York.

Guy, C. S., H. L. Blankenship, and L. A. Nielsen. 1996. Tagging and marking. Pages 353–383 *in* B. R. Murphy and D. W. Willis, editors. Fisheries techniques, 2nd edition. American Fisheries Society, Bethesda, Maryland.

Hartman, K. J., and E. C. Janney. 2006. Visual implant elastomer and anchor tag retention in Largemouth Bass. North American Journal of Fisheries Management 26:665–669.

Heermann, L., M. Emmrich, M. Heynen, M. Dorow, U. König, J. Borcherding, and R. Arlinghaus. 2013. Explaining recreational angling catch rates of Eurasian Perch, *Perca fluviatilis*: the role of natural and fishing-related environmental factors. Fisheries Management and Ecology 20: 187–200.

Henny, C. J., and K. P. Burnham. 1976. A reward band study of mallards to estimate reporting rates. Journal of Wildlife Management 40:1–14.

High, B., and K. A. Meyer. 2009. Survival and dispersal of hatchery triploid Rainbow Trout in an Idaho river. North American Journal of Fisheries Management 29:1797–1805.

Isermann, D. A., D. W. Willis, D. O. Lucchesi, and B. G. Blackwell. 2005. Seasonal harvest, exploitation, size selectivity, and catch preferences associated with winter Yellow Perch anglers on South Dakota lakes. North American Journal of Fisheries Management 25:827–840.

Jakober, M. J., T. E. McMahon, and R. F. Thurow. 2000. Diel habitat partitioning by Bull Charr and Cutthroat Trout during fall and winter in Rocky Mountain streams. Environmental Biology of Fishes 59:79–89.

Knapp, M., L. Talent, and E. Maughan. 1991. A comparison of two exploitation rate estimators for crappie in an Oklahoma reservoir. U.S. Forest Service General Technical Report RM 207:283–286.

Koenig, M. K., and K. A. Meyer. 2011. Relative performance of diploid and triploid catchable Rainbow Trout stocked in Idaho lakes and reservoirs. North American Journal of Fisheries Management 31:605–613.

Larson, S. C., B. Saul, and S. Schleiger. 1991. Exploitation and survival of Black Crappies in three Georgia reservoirs. North American Journal of Fisheries Management 11:604–613.

Marinac-Sanders, P., and D. W. Coble. 1981. The Smallmouth Bass population and fishery in a northern Wisconsin lake, with implications for other waters. North American Journal of Fisheries Management 1:15–20.

Markham, J. L., D. L. Johnson, and R. W. Petering. 1991. White Crappie summer movements and habitat use in Delaware Reservoir, Ohio. North American Journal of Fisheries Management 11:504–512.

McCammon, G. W., and D. A. LaFaunce. 1961. Mortality rates and movement in the Channel Catfish population of the Sacramento Valley. California Fish and Game 47:5–26.

McFadden, J. T. 1961. A study of the Brook Trout (*Salvelinus fontinalis*). Wildlife Monographs 7:1–73.

Meyer, K. A., F. S. Elle, J. A. Lamansky, E. R. J. M. Mamer, and A. E. Butts. 2012a. A reward fish tagging study to estimate angler tag reporting rates in Idaho. North American Journal of Fisheries Management 32:696–703.

Meyer, K. A., B. High, and F. S. Elle. 2012b. Effects of stocking catchable-size hatchery Rainbow Trout on wild Rainbow Trout abundance, survival, growth, and recruitment. Transactions of the American Fisheries Society 141:224–237.

Miranda, L. E., and P. W. Bettoli. 2007. Mortality. Pages 229–277 *in* C. S. Guy and M. L. Brown, editors. Analysis and interpretation of freshwater fisheries data. American Fisheries Society, Bethesda, Maryland.

Miranda, L. E., R. E. Brock, and B. S. Dorr. 2002. Uncertainty of exploitation estimates made from tag returns. North American Journal of Fisheries Management 22:1358–1363.

Miranda, L. E., and B. S. Dorr. 2000. Size selectivity of crappie angling. North American Journal of Fisheries Management 20:706–710.

Mourning, T. E., K. D. Fausch, and C. Gowan. 1994. Comparison of visible implant tags and floy anchor tags on hatchery Rainbow Trout. North American Journal of Fisheries Management 14:636–642.

Muoneke, M. I. 1994. Dynamics of a heavily exploited Texas White Bass population. North American Journal of Fisheries Management 14:415–422.

Myers, R. A., J. Taylor, M. Allen, and T. Bonvechio. 2008. Temporal trends in voluntary release of Largemouth Bass. North American Journal of Fisheries Management 28:428–433.

Nichols, J. D., R. J. Blohm, R. E. Reynolds, R. E. Trost, J. E. Hines, and J. P. Bladen. 1991. Band reporting rates for mallards with reward bands of different dollar values. Journal of Wildlife Management 55:119–126.

Nielsen, L. A. 1992. Methods of marking fish and shellfish. American Fisheries Society, Special Publication 23, Bethesda, Maryland.

Pollock, K. H, J. M. Hoenig, W. S. Hearn, and B. Calingaert. 2001. Tag reporting rate estimation 1: an evaluation of the high-reward tagging method. North American Journal of Fisheries Management 21:521–532.

Probst, W. E., C. F. Rabeni, W. G. Covington, and R. F. Marteney. 1984. Resource use by stream-dwelling Rock Bass and Smallmouth Bass. Transactions of the American Fisheries Society 113:283–294.

Quist, M. C., J. L. Stephen, C. S. Guy, and R. D. Schultz. 2004. Age structure and mortality of Walleyes in Kansas reservoirs: use of mortality caps to establish realistic management objectives. North American Journal of Fisheries Management 24:990–1002.

Rawstron, R. R., and K. A. Hashagen. 1972. Mortality and survival rates of tagged Largemouth Bass *Micropterus salmoides* at Merle Collins Reservoir. California Fish and Game 58:221–230.

Rikardsen, A. H., M. Woodgate, and D. A. Thompson. 2002. A comparison of Floy and soft VI alpha tags on hatchery Arctic Charr, with emphasis on tag retention, growth and survival. Environmental Biology of Fishes 64: 269–273.

Ricker, W. E. 1975. Computation and interpretation of biological statistics of fish populations. Fisheries Research Board of Canada Bulletin 191.

Rieman, B. E. 1987. Fishing and population dynamics of Largemouth Bass (Micropterus salmoides) in select northern Idaho lakes. Doctoral dissertation. University of Idaho, Moscow.

Schoenebeck, C. W., and M. L. Brown. 2011. Gender- and year-specific mortality of Yellow Perch with evidence of compensatory mortality. North American Journal of Fisheries Management 31:474–482.

Scholten, G. W., D. A. Isermann, and D. W. Willis. 2002. Retention and survival rates associated with the use of t-bar anchor tags in marking Yellow Perch. Proceedings of the South Dakota Academy of Science 81:35–38.

Schultz, R. D. 2004. Size-specific angling return rates of White Bass in Kansas reservoirs. North American Journal of Fisheries Management 24:719–723.

Schultz, R. D., and D. A. Robinson Jr. 2002. Exploitation and mortality rates of White Bass in Kansas reservoirs. North American Journal of Fisheries Management 22:652–658.

Serns, S. L., and J. J. Kempinger. 1981. Relationship of angler exploitation to the size, age, and sex of Walleyes in Escanaba Lake, Wisconsin. Transactions of the American Fisheries Society 110:216–220.

Siepker, M. J., K. G. Ostrand, S. J. Cooke, D. P. Philipp, and D. H. Wahl. 2007. A review of the effects of catch-and-release angling on black bass, *Micropterus* spp.: implications for conservation and management of populations. Fisheries Management and Ecology 14:91–101.

Slipke, J. W., M. J. Maceina, V. H. Travnichek, and K. C. Weathers. 1998. Effects of a 356-mm minimum length limit on the population characteristics and sport fishery of Smallmouth Bass in the Shoals Reach of the Tennessee River, Alabama. North American Journal of Fisheries Management 18:76–84.

Stephens, P. A., S. W. Buskirk, G. D. Hayward, and C. Martinez Del Rio. 2005. Information theory and hypothesis testing: a call for pluralism. Journal of Applied Ecology 42:4–12.

Tranquilli, J. A., and W. F. Childers. 1982. Growth and survival of Largemouth Bass tagged with floy anchor tags. North American Journal of Fisheries Management 2:184–187.

Walsh, M. G., and D. L. Winkelman. 2004. Anchor and visible implant elastomer tag retention by hatchery Rainbow Trout stocked into an Ozark stream. North American Journal of Fisheries Management 24:1435–1439.

Walters, C. J., and S. J. D. Martell. 2004. Fisheries ecology and management. Princeton University Press, Princeton, New Jersey.

Yates, F. 1980. Sampling methods for censuses and surveys, 4th edition. Charles Griffin, London.