North American Journal of Fisheries Management
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/ujfm20

Estimating Regional Fishing Mortality for Freshwater Systems: a Florida Largemouth Bass Example

Janice A. Kerns[a], Micheal S. Allen[a], Jason R. Dotson[b] & Joseph E. Hightower[c]

[a] Fisheries and Aquatic Sciences Program, University of Florida, 7922 Northwest 71st Street, Gainesville, Florida 32653, USA

[b] Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, Gainesville Freshwater Fisheries Office, 7386 Northwest 71st Street, Gainesville, Florida 32653, USA

[c] North Carolina Cooperative Fish and Wildlife Research Unit, Department of Applied Ecology, North Carolina State University, Campus Box 7617, Raleigh, North Carolina 27695, USA

Published online: 09 Jul 2015.

To cite this article: Janice A. Kerns, Micheal S. Allen, Jason R. Dotson & Joseph E. Hightower (2015) Estimating Regional Fishing Mortality for Freshwater Systems: a Florida Largemouth Bass Example, North American Journal of Fisheries Management, 35:4, 681-689, DOI: 10.1080/02755947.2015.1040561

To link to this article: http://dx.doi.org/10.1080/02755947.2015.1040561

North American Journal of Fisheries Management 35:681–689, 2015

ISSN: 0275-5947 print / 1548-8675 online
DOI: 10.1080/02755947.2015.1040561

ARTICLE

Estimating Regional Fishing Mortality for Freshwater Systems: a Florida Largemouth Bass Example

Janice A. Kerns* and Micheal S. Allen
Fisheries and Aquatic Sciences Program, University of Florida, 7922 Northwest 71st Street, Gainesville, Florida 32653, USA

Jason R. Dotson
Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, Gainesville Freshwater Fisheries Office, 7386 Northwest 71st Street, Gainesville, Florida 32653, USA

Joseph E. Hightower
North Carolina Cooperative Fish and Wildlife Research Unit, Department of Applied Ecology, North Carolina State University, Campus Box 7617, Raleigh, North Carolina 27695, USA

Abstract
Species-specific harvest regulations in recreational fisheries are commonly applied regionally to protect stocks from overharvest and satisfy a diverse set of anglers. While setting regulations is a complex task and may incorporate the best available social and biological information, fisheries managers commonly obtain directed fishing mortality estimates within a single lake and then assume similar rates among other systems when setting regional harvest regulations. Thus, there is a need to assess regional levels of fishing mortality for informed use of regionally applied regulations. We implemented a practical method for assessing catch and harvest for a recreational fishery across a broad spatial region. We used a passive tag-reward study design and a regional management regulation area for Florida Largemouth Bass *Micropterus salmoides floridanus* in central Florida as our case study. The estimated fishing mortality rate included both harvest and deaths due to catch and release. We found overall regional fishing mortality for Florida Largemouth Bass in central Florida was relatively low. From the 247 dart tags returned, the mean annual instantaneous total fishing mortality rate was 0.11 (95% credible interval = 0.08–0.15). We also found fishing mortality rates did not vary with lake size or fish total length. Our study design did not provide mortality estimates for any specific lake due to a low number of tagged fish per lake, but the method could be used to elucidate the effectiveness of regulations that are applied at a regional scale.

Species-specific management plans for individual freshwater fisheries are uncommon because most state agencies lack the funding to conduct stock assessments for specific waterbodies within a region. Further, relatively few recreational fisheries are of such singular importance that they provide strong sociopolitical or economic motives for active management (Radomski et al. 2001; Pereira and Hansen 2003). Consequently, fisheries management plans are often applied across broad spatial regions (Radomski et al. 2001; Pereira and Hansen 2003). As a result, many water bodies are sampled infrequently, or not at all, and it is usually unknown whether regionally applied regulations like size and bag limits are appropriate for desired fishery outcomes (e.g., trophy fish production, high catch rates) on individual fisheries. Thus, there is a critical need to evaluate the efficacy of management strategies across broad spatial scales.

*Corresponding author: jkerns@uwsp.edu
Received November 20, 2014; accepted March 31, 2015

Florida's freshwater fisheries are worth about US$1.7 billion annually to the state's economy (Smithwick Associates 2012); the majority of which is derived from 16 million angler days spent targeting black bass, which compose the genus *Micropterus* (USFWS 2011). A voluntary catch and release ethic has increased since the 1990s for many fisheries (Quinn 1996), including those targeting Largemouth Bass *M. salmoides* (Myers et al. 2008; Gaeta et al. 2013), and this change from a harvest-orientated fishery has reduced fishing mortality rates (Allen et al. 2008). However, Henry (2003) found that even when overall fishing mortality was low, exploitation of the largest Largemouth Bass still exceeded 30%. Even when average exploitation rates are low enough that traditional recruitment overfishing is of little concern, fishing mortality could still alter the population size structure and substantially reduce the number of trophy fish (Dotson et al. 2013). In recent years, anglers have expressed a greater interest in catching trophy-size fish (Chen et al. 2003; Margenau and Petchenik 2004). Thus, there is a need to assess fishing mortality rates and test whether those rates vary with fish size.

Because freshwater fisheries occur in a landscape with hundreds to thousands of potential fishing sites, many monitoring programs concentrate efforts on large, important fisheries, and smaller water bodies are often sampled less frequently or not at all (Pereira and Hansen 2003). For example, the Florida Fish and Wildlife Conservation Commission (FWC) long-term monitoring program generally focuses on lakes over 400 ha in area, but the majority of Florida lakes are smaller and sampled on an infrequent basis (Bonvechio 2009). Similarly, the frequency and sampling methods also vary with lake size in Minnesota, where large lakes are sampled more frequently and more intensively than small lakes (Schlagenhaft 1993; Wingate and Schupp 1985). Minnesota protocols suggest that high-priority lakes are ideally sampled every 3 years, whereas the lowest priority lakes may be sampled every 20 years (Schlagenhaft 1993) For lake-rich landscapes like Florida and Minnesota, smaller water bodies may receive a substantial amount of the total recreational fishing effort. Minnesota's small lakes account for approximately 60% of the entire statewide angling harvest of Walleyes *Sander vitreus* (MDNR 1997), but sampling these individual water bodies regularly may be logistically unattainable. Thus, there is a need to test whether fishing mortality rates obtained for larger water bodies are similar to smaller, less frequently sampled systems.

Few studies in freshwater systems have evaluated fishing mortality rates at a regional scale—the typical scale at which management decisions are made and regulations applied. Meyer and Schill (2014) estimated annual exploitation across systems and species in Idaho, and they found that exploitation rates varied substantially among species. They found some evidence that vulnerability to harvest increased with fish size in trout, crappies, and bass, but they did not evaluate whether fishing mortality varied with lake size. Other estimates of regional fishing mortality rates across systems are lacking in the literature. The objectives of this study were to (1) assess fishing mortality of Florida Largemouth Bass *M. salmoides floridanus* (hereafter Florida Bass) at a regional scale in central Florida, and (2) evaluate whether fishing mortality rates varied with fish length groups and lake size. We used a passive tag-reward system to estimate regional harvest mortality. We also tested whether fishing mortality varied between lake size and fish length groups. Our methods could provide critical information needed to identify management strategies (e.g., harvest or effort restrictions) to improve recreational fisheries that are managed across broad spatial scales.

METHODS

Sampling.—We used a passive tag-reward method across a large number of central Florida lakes (Figure 1) to estimate Florida Bass fishing mortality. The study design did not provide fishing mortality estimates on any specific lake but was intended to provide an estimate of the average level of fishing mortality for the overall management region. Florida Bass were captured using boat electrofishing and tagged in the fall (September–December) of 2009 and 2010 on 30 lakes as part of the FWC long-term monitoring (LTM) program (see Bonvechio et al. 2009 for specific sampling methods). Lakes within the LTM program were generally large (4,314 ha on average) high-priority fishing lakes deemed significant fisheries at the statewide level. To test whether regional fishing mortality varied with lake size, Florida Bass were also tagged in the fall of 2010 at 29 additional small lakes (<405 ha) that were not part of the FWC LTM program. Florida Bass were tagged with plastic tipped dart tags (Hallprint, Hindmarsh Valley, Australia) and released in the same area where they were captured. The tags were 124 mm in length, with a barb length of 18.5 mm and an outside diameter of 4.0 mm.

To evaluate whether fishing mortality varied with fish size, we attempted to tag a minimum of 200 fish in each of two size groups (350–500 mm TL and >500 mm TL) each year. To ensure that not all fish were tagged in the same location within each lake, a maximum of two total fish were tagged per electrofishing transect on large lakes. Because the entire perimeter of the lake was generally sampled on small lakes, all fish were tagged immediately after capture during sampling on small lakes.

The passive tagging approach required several assumptions that are common to tagging models: (1) the tagged sample is representative of the target population, (2) the fate of each fish is independent, and (3) all tagged fish within a cohort have the same annual survival (adapted from Pollock et al. 2001). To ensure the tagged fish on large lakes were a representative sample of the target population, shorelines were indiscriminantly selected for sampling (Bonvechio et al. 2009). To ensure a representative sample on small lakes where the entire shoreline was sampled, sampling effort was uniformly distributed across the shoreline.

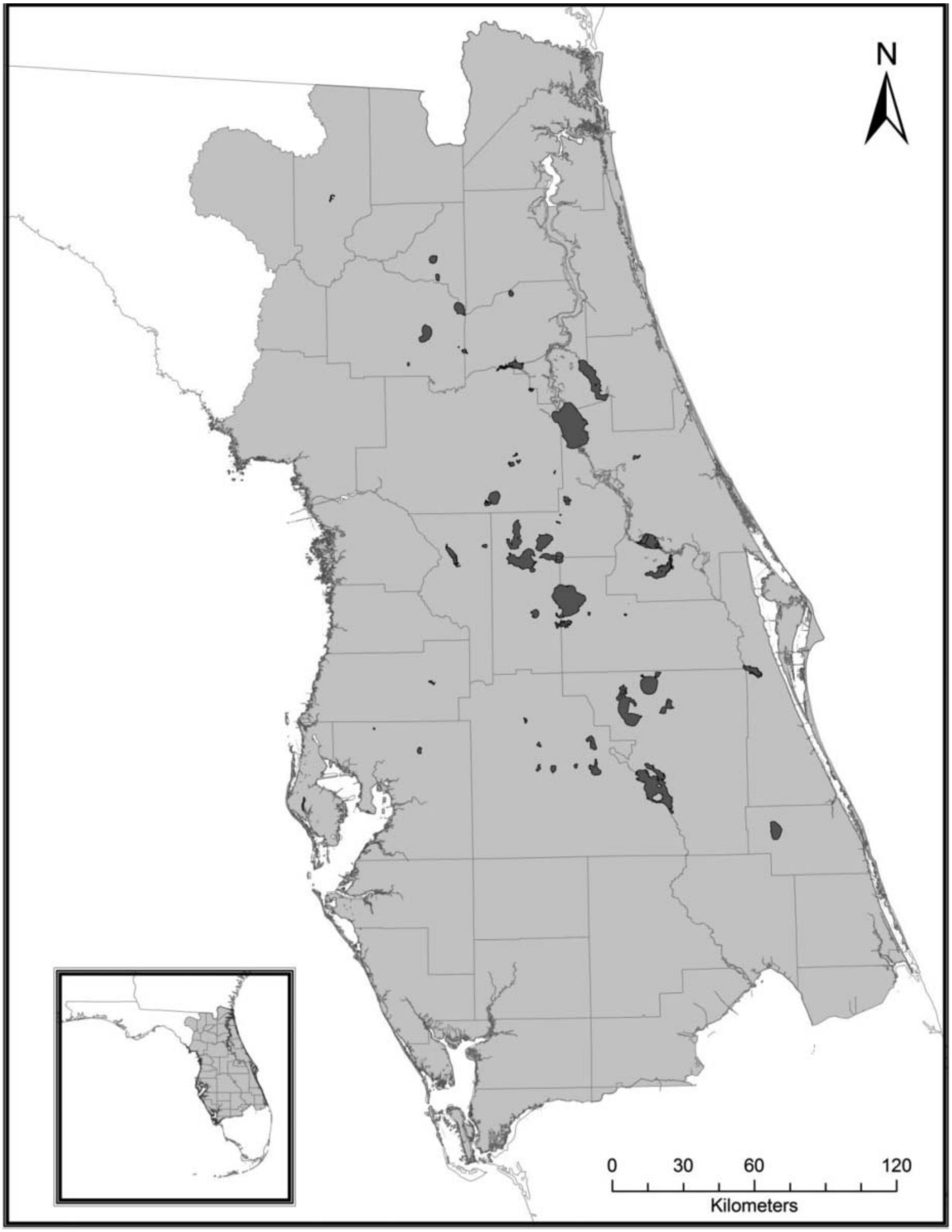

FIGURE 1. Map of study area in central Florida with study lakes highlighted in dark gray. The light gray area indicates the 356-mm minimum length limit Florida Largemouth Bass management regulation zone.

TABLE 1. Target Florida Largemouth Bass tagging numbers for a regional fishing mortality study conducted in central Florida from 2009 to 2010, based on lake size for large lakes. The lowest lake-size category (<1,000 ha) was used for target tagging numbers in small lakes sampled in 2010.

Lake		Fish		
		350–500 mm		>500 mm
Size (ha)	Number	\$200 tag	\$5 tag	\$200 tag
<1,000	34	2	4	All
1,000–5,000	17	4	8	All
5,001–10,000	6	8	16	All
10,001–20,000	3	16	32	All

Additionally, because large lakes have larger bass population abundance than small lakes, tags were distributed across lakes proportional to lake size, larger lakes being assigned more tagged fish (Table 1). Allocating tags based on lake size ensured that lakes with larger bass populations would receive more tags, and thus, each lake's influence on the overall exploitation rate was weighted generally to the expected bass population size (Table 1) in both years of the study for large lakes. In year 2, target tagging numbers for the additional 29 small lakes was constant and aligned with the lowest category of lakes size (Table 1). All lakes used in the study had the same harvest regulation (five-fish daily bag limit and a 356-mm TL minimum size limit with only one >559 mm TL), and thus, there were no regulation differences that would have influenced the observed fishing mortality rates among systems.

The passive tagging approach also assumed that all fish with high-reward tags caught by anglers were reported and that tag loss and tagging mortality were minimal. All fish were tagged with either a US\$5 or \$200 reward amount. The relative return rates were used to estimate the reporting rate for \$5, based on the assumption that all \$200 tags were reported by anglers (Nichols et al. 1991; Taylor et al. 2006; Meyer et al. 2012). Each tag had printed instructions indicating the reward amount and how to report catches of tagged fish. Tagging mortality was negligible for Florida Bass tagged with dart tags in the fall (0%; Henry 2003). We estimated short-term tagging mortality in four private lakes by placing tagged fish in mesh cages for 72 h. Tag loss was determined by releasing fish in four private lakes that were double-tagged with dart tags and implanted with internal passive integrated transponders that have been shown to have a 100% retention rate (Harvey and Campbell 1989; Hangsleben et al. 2012). Recapture trips occurred in conjunction with another study (Hangsleben et al. 2012), where sampling occurred two times in fall (early December) of 2009, spring (February–March), and summer (June) of 2010 and three times in fall (October–December) of 2010 and spring (January–February) of 2011. An instantaneous tag loss rate was estimated within the mortality model using a binomial distribution assuming a constant rate over all sampling events. Any uncertainty around the tag loss estimate was therefore incorporated into all mortality estimates.

Press releases and tag reward signs were distributed to inform the public about the study (Pollock et al. 2001). Signs were posted at fishing access points around each lake and at local bait and tackle shops; reward amounts were not specified on signage. Anglers were asked to provide catch information through FWC's Angler Tag Return Hotline. Anglers were also asked to retain tags from harvested fish and to cut tags close to the base of released fish so that they could be mailed in for the monetary reward listed on tags. Information collected from anglers included date, location of catch, and whether the fish was harvested or released.

Model structure and analysis.—Jiang et al.'s (2007) tag return model was used to estimate regional fishing mortality within a Bayesian framework. This model was developed from instantaneous rates formulation of the Brownie tag return model (Brownie et al. 1985; Hoenig et al. 1998) and improved upon past tag return studies by allowing for catch and release of fish as well as harvest. This model enhancement was accomplished by separating deaths due to harvest and the "deaths" of tags removed from fish released alive. Within the model, the expected number of low-reward tags (\$5) returned, $E(R_{Hij})$, from fish tagged and released in year i and harvested (H) in year j across the entire region was:

$$E\left(R_{Hij}\right) = N_i P_{Hij}, \tag{1}$$

Where

$$P_{Hij} = \begin{cases} \left(\prod_{v=i}^{j-1} S_v\right)\left(1 - S_j\right)\dfrac{F_{Hj}}{F_{Hj} + F'_{CRj} + M}\lambda & \text{when } j > i \\ \left(1 - S_j\right)\dfrac{F_{Hj}}{F_{Hj} + F'_{CRj} + M}\lambda & \text{when } j = i \end{cases}$$

$$S_j = \exp - \left(F_{Hj} + F'_{CRj} + M\right), \tag{2}$$

where N_i is the number of fish tagged in year i, the subscript v refers to the tags that survived (S), j refers to the year a tag was returned, R_{Hij} is the number of tags reported from harvested fish, P_H is the probability of a tagged fish being harvested and reported by an angler, λ is the estimated reporting rate for low reward tags, S_j is the survival rate in year j, F_H is the instantaneous rate of fishing mortality for tags of fish harvested, F_{CR} represents the instantaneous fishing mortality for tags of fish caught and released, and M is the instantaneous natural mortality rate. The expected number of standard tag returns R_{CR} from fish tagged and released in year i and caught and released without a tag in year j across the entire region was

$$E\left(R'_{CRij}\right) = N_i P'_{CRij}, \tag{3}$$

Where

$$P'_{CRij} = \begin{cases} \left(\prod_{v=i}^{j-1} S_v\right)(1-S_j)\dfrac{F'_{CRj}}{F_{Hj}+F'_{CRj}+M}\lambda & \text{when } j>i \\ (1-S_j)\dfrac{F'_{CRj}}{F_{Hj}+F'_{CRj}+M}\lambda & \text{when } j=i \end{cases}, \tag{4}$$

where P_{CR} is the probability of a tagged fish being caught, released, and reported by an angler. The same expressions were used for high-reward tags except that λ was removed because of an assumed 100% reporting rate. Regional, lake size, and fish size, as well as fish capture and fishing mortality rates were estimated from their respective data sets with the same model structure.

The multinomial likelihood function (L_{tag}) of fish tagged in year i and subsequently harvested or caught (R_{Hij}) and released and (R'_{CRij}) across the region follows Hoenig et al. (1998):

$$L_{\text{tag}} = \prod_{i=1}^{I} \left[\begin{matrix} N_i \\ R_{Hii}, R_{Hii+1,\ldots}, R_{Hij}, R'_{CRii}, R'_{CRii+1,\ldots}, R'_{CRij}, \\ N_i - \sum_{j=i}^{J}\left(R_{Hij}+R'_{CRij}\right) \end{matrix} \right] \times \left(\prod_{j=i}^{J} P_H{}^{R_H} P'_{CR}{}^{R'_{CR}}\right) \left[1-\sum_{v=i}^{J}\left(P_{Hiv}+P'_{CRiv}\right)\right]^{N_i - \sum_{v=i}^{J}(R_{Hiv}+R'_{CR})}. \tag{5}$$

Equation (5) can be simply described as the number of ways the observed events can occur, multiplied by the probabilities of the events. The probabilities within this likelihood were determined by the parameter values within the model, specifically, F_H and F'_{CR}. Unless stated specifically, all prior distributions used in the model were uninformative uniform distributions (McCarthy 2007). Posterior distributions of the model parameters were sampled using OpenBUGS (http://www.openbugs.info/w/). The Bayesian approach was chosen because it has been shown to be a statistically robust way of integrating multiple data sources, and it can consider prior information about a problem, thus improving statistical inference (Walters and Martell 2004; Kurota et al. 2009).

Additionally derived parameters were also calculated from estimated parameters. The instantaneous catch-and-release fishing mortality rate F_{CR} was then estimated as:

$$F_{CR} = \delta_{CR} F'_{CR}, \tag{6}$$

where δ_{CR} is the catch-and-release mortality rate of caught and released fish, and F'_{CR} is the instantaneous capture rate of fish that were caught and released. To account for catch-and-release mortality, total F was adjusted upward using the following equation (Jiang et al. 2007):

$$\hat{F}_{adj} = F_H + F_{CR}. \tag{7}$$

Catch-and-release mortality was estimated (using an uninformative binomial distribution and telemetry data from Kerns 2013) as the total number of deaths due to catch and release ($n = 5$) divided by the total number released ($n = 67$) in that study. The total capture rate (F_o) within the regional fishery was calculated as $F_H + F'_{CR}$. Credible intervals (CIs) for all estimates were the 2.5th and 97.5th percentiles of the posterior distributions.

Model assumptions followed the Jiang et al. (2007) age-independent tag-return model structure. The model assumed that (1) λ was constant over years and between release types (i.e., released versus harvested), (2) all tagged fish were fully recruited to the fishery, (3) M was constant over years, and (4) fates of tagged fish are independent. For a full discussion of model assumptions and potential biases inherent in high-reward multiple-year tagging studies (Pollock et al. 2001).

Within our 2-year study, information about M was primarily derived from the second year of tag returns (i.e., relative tag returns between the first-year and second-year tagged cohorts). Estimates of λ and natural mortality can be unreliable even over long-term (e.g., 20 years) tagging studies (Pollock et al. 2004). We therefore chose to estimate M using an informative prior from a concurrent study occurring in the region that utilized a combined telemetry-tag return approach ($M \sim$ normal distribution, $\mu = 0.37$, SD $= 0.053$; Kerns 2013).

RESULTS

A total of 497 Florida Bass were tagged in the fall (October–December) of 2009 on 30 large lakes currently sampled by FWC in their LTM program, all within the same regulation zone. During the fall of 2010, 561 Florida Bass were collected and tagged from 30 LTM lakes, and 247 were tagged from the 29 small lakes within the same regulation zone. The 30 LTM lakes sampled in each year were the same with the exception of one lake that was switched in the second year due to low number of fish sampled. A total of 247 tags (18%) with a total reward cost of \$31,850 were reported for fish caught and released or harvested by anglers across all lakes sampled over the 2 years of the study (Table 2). After the completion of the study, an additional 66 tags valued at \$10,470 were reported as caught or harvested as of April 2013.

TABLE 2. Number of Florida Largemouth Bass tagged and reported caught (i.e., harvested or released) from 2009 to 2011 in central Florida lakes.

	Tagged		Returns (2009–2010)		Returns (2010–2011)	
Tag reward	Year	Number	Harvested	Released	Harvested	Released
\$5	2009	248	8	11	2	12
	2010	410			17	40
\$200	2009	249	17	34	4	11
	2010	398			13	78

TABLE 3. Recaptures and tag loss of Florida Largemouth Bass initially double tagged with passive integrated transponders (PIT) and dart tags in four private lakes in north-central Florida from December of 2009 through March 2011.

Months from initial tagging	PIT tags recaptured	Dart tags lost
1	21	0
2	13	0
3	17	1
4	15	0
5	10	1
6	5	1
7	25	1
8	2	1
9	0	0
10	0	0
11	3	2
12	2	0

Tagging mortality and tag loss were estimated from an independent concurrent study on four private lakes in central Florida. Within 1 year of release, 91 of 195 double-tagged fish were recaptured at least once (Table 3) and a total of 7 fish lost their tag. Of the 113 total recaptures, 94% occurred with 7 months of release. Annual instantaneous tag loss was estimated as 0.26 (95% confidence interval [CI] = 013–0.43), based on number of months at large up to 1 year. No deaths were observed among 127 double-tagged fish placed within cages during the 72-h holding period, and thus, tagging mortality was assumed to be zero.

Annual mean capture rate F_o across all lakes and across both years was 0.33 (CI = 0.27–0.40), and estimated total fishing mortality rate ($\hat{F}_{adj}$) was 0.11 (CI = 0.08–0.15), which includes the estimated mortality of fish harvested and fish caught and released. Directed fishing mortality F_H from harvest for the region was 0.09 (CI = 0.07–0.12) and was similar between years (Table 4). Thus, fishing mortality was low but had relatively good precision. Natural mortality was estimated as 0.40 (CI = 0.30–0.50). The average instantaneous catch-and-release fishing mortality (F_{CR}) was 0.02, and voluntary release rates ranged as high as 64% (year 1) to 79% (year 2). This means that F_{CR} ranged from 18% to 20% of the total adjusted fishing mortality estimate. All mortality and capture rates were estimated with a reporting rate of 0.55 (CI = 0.44–0.70) for low-reward tags and a δ_{CR} of 0.09 (CI = 0.03–0.16).

Fishing mortality rates were similar in both years and across fish size and lake size groups. Although the mean capture rate estimate was slightly higher for small rather than large lakes, there was substantial overlap of the credible intervals of both fishing mortality and capture rates among different lake and fish size groups (Figure 2).

DISCUSSION

Our annual fishing mortality rates from harvest were below average for Largemouth Bass in the USA but similar to previous lake-specific estimates in Florida. Two reviews of Largemouth Bass mortality rates showed annual exploitation rates

TABLE 4. Mean annual instantaneous capture (F_o) and mortality rates (total fishing [$\hat{F}_{adj}$], harvest [F_H], and catch and release [F_{CR}]) of Florida Largemouth Bass tagged in central Florida between October 2009 through September 2011. Tags were dispersed among 30 large (>405 ha) lakes in 2009 and a total of 59 lakes (30 large and 29 small) in 2010. The standard deviation and 95% credible intervals (CI) are shown. Parameter estimates accounted for nonreporting of caught fish, tag mortality, and tag loss.

	2009–2010		2010–2011		Overall	
Parameter	Mean (SD)	CI	Mean (SD)	CI	Mean (SD)	CI
F_o	0.29 (0.039)	0.22–0.38	0.37 (0.043)	0.30–0.46	0.33 (0.034)	0.27–0.40
$\hat{F}_{adj}$	0.12 (0.023)	0.08–0.17	0.10 (0.018)	0.07–0.14	0.11 (0.017)	0.08–0.15
F_H	0.10 (0.022)	0.07–0.15	0.08 (0.014)	0.05–0.11	0.09 (0.014)	0.07–0.12
F_{CR}	0.02 (0.008)	0.01–0.04	0.03 (0.010)	0.01–0.05	0.02 (0.008)	0.01–0.04

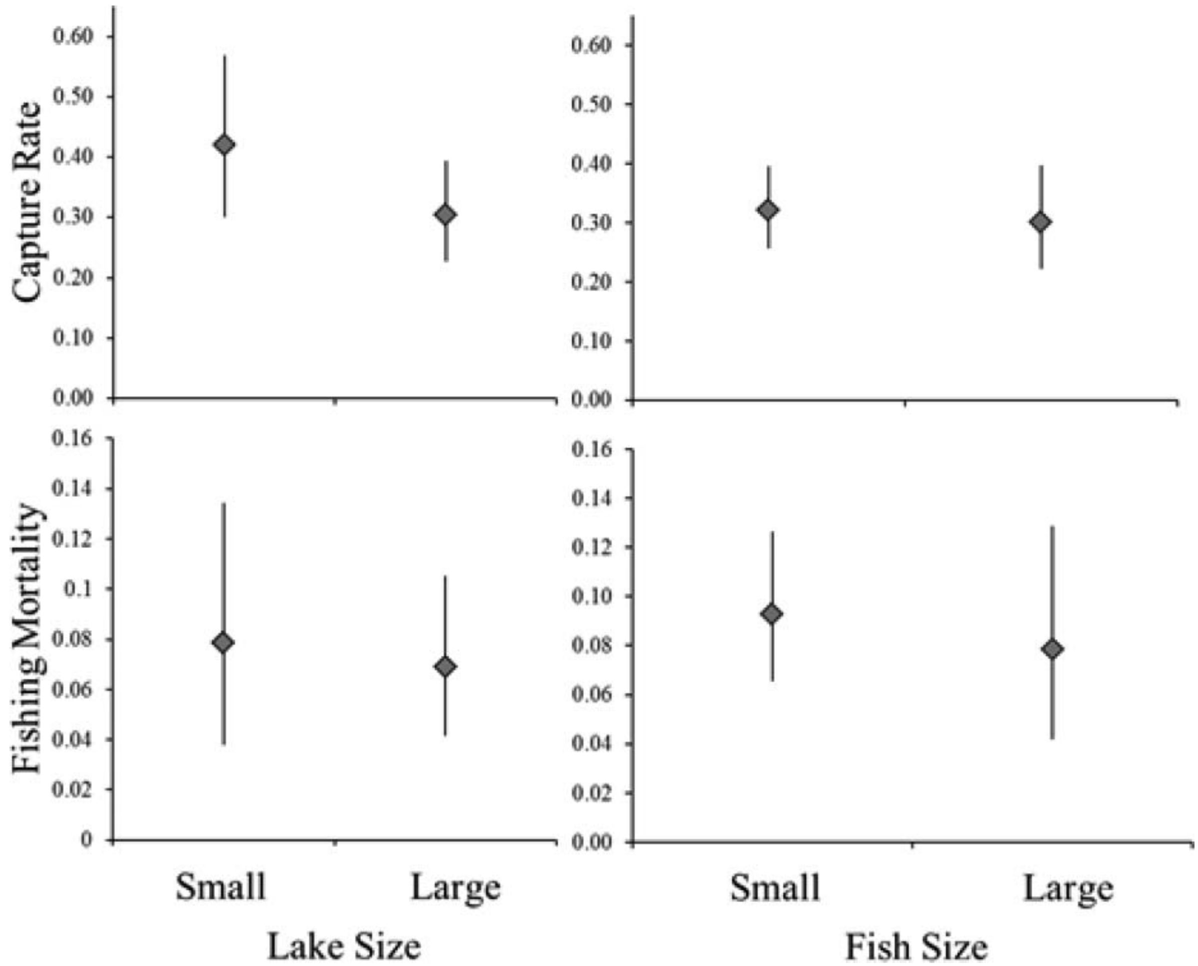

FIGURE 2. Comparison of annual capture F_o and fishing mortality rates F_H of Florida Largemouth Bass by lake size (left panels) and fish size (right panels), where small fish are 350–500 mm TL and large are ≥500 mm TL. Rates estimated from tag return data for 30 large lakes (>405 ha) and 29 small lakes (<405 ha) throughout central Florida from October 2010 through September 2011. Bars represent 95% credible intervals.

(u) to range from 7% to 72% in North America (Allen et al. 1998, 2008), with estimates from central Florida ranging from 11% to 17% (Renfro et al. 1999; Henry 2003). Meyer and Schill (2014) found that regional exploitation rates averaged about 18% for Largemouth Bass in Idaho. However, the value of 0.09 for F_H is equivalent to an exploitation rate of 0.07 ($u = F\frac{1-S}{Z}$; Ricker 1975), which is not unexpected given the downward trend in Largemouth Bass exploitation as voluntary release rates increase and harvest regulations become more strict (Allen et al. 2008; Myers et al. 2008; Gaeta et al. 2013).

The mean instantaneous capture rate of 0.33 or equivalent finite rate of 23% was identical to an estimate of 0.33 for Rodman Reservoir, Florida (Henry 2003). In contrast, Driscoll et al. (2007) estimated that 62% of the tagged Largemouth Bass were caught annually at Sam Rayburn Reservoir, Texas. Sam Rayburn reservoir is a popular fishery with relatively few alternative fishing sites, and thus, it is not unexpected that the capture rate would be higher there than the regional average in central Florida, where thousands of potential fishing sites exist. Capture rates and fishing mortality rates can vary widely across regions depending on human population size and the number of overall potential fishing sites (e.g., Sullivan 2003).

Although overall regional fishing mortality values were low and there were no observed differences between the sizes of fish, managers may still want to consider that fishing mortality could still reduce the number of trophy fish. Past studies on Largemouth Bass fisheries have shown angling to influence the size structure of a population, even when there is preference for catch-and-release fishing (Hayes et al. 1995; Carlson and Isermann 2010). The current management strategy within Florida places a high value on trophy-sized bass. The FWC recently developed an incentive-based angler recognition program called "Trophy Catch" to encourage anglers to release trophy-sized Florida Bass and reduce fishing mortality of trophy fish (see Dutterer et al. 2014). Additionally, the FWC staff have proposed a statewide regulation change for a 406-mm maximum size limit (with one fish >406 mm TL/angler per day) to increase numbers of available trophy bass. Similar to Driscoll et al. (2007), we found no evidence that fishing mortality varied with fish size for fish over 356 mm TL. However, the cumulative impacts of relatively low fishing mortality rates would influence the number of bass reaching trophy sizes (Dotson et al. 2013), and thus, regulations would still have utility for increasing trophy fish abundance.

We also found no difference in fishing mortality with lake size. Thus, a tagging study such as this could provide reasonable estimates of exploitation across broad spatial regions that include both small and large lakes. This approach provides a logistically attainable sampling design to evaluate the efficacy of regional and statewide harvest regulations. There are no previous studies that compare capture or exploitation rates as a function of lake size. Further studies should evaluate whether this relationship is maintained through time and other geographic locations for smaller lakes, but our results suggest that regionally applied regulations would be equally applicable on small and large lakes because fishing mortality rates were similar across lake size groups.

Tagging fish in a large number of lakes had benefits in terms of analysis and management implications. From an analysis perspective, the wider dispersal range ensures a greater likelihood of tag return independence. With only a few tags placed in any individual lake, anglers were less likely to catch and hold on to multiple low-reward tags before reporting them once a high reward tag is caught and thereby inflating the reporting rate. We believe this assumption was met because no more than two tags were reported by any individual angler. There were only two occasions when anglers reported multiple tag returns on the same day and both times the tag values were identical (one angler reported two \$5 tags and the other reported two \$200 tags). From a management perspective, there is also a reduced chance of artificially increasing angler effort via anglers fishing for profitable tags (Pollock et al. 2001). If management objectives are to monitor fishing mortality, dispersing high-reward tags across a large geographic range and multiple lakes is unlikely to attract fishing effort on any individual system. Thus, the regional estimates of fishing mortality were robust to issues of independence among fish and problems related to attracting fishing effort with high rewards.

The drawback of a regional mortality estimate is that the estimate may not represent conditions that are present at any one lake. The lakes within this region potentially represented a wide range of exploitation rates, trophic levels, fish abundance, and recruitment levels (Allen et al. 2008; Florida LAKEWATCH. 2009). This concern means that setting harvest regulations based on the regional values may not be optimal for any particular water body. Ideally, it would be wise to combine regional estimates at periodic intervals (e.g., every 5–10 years) with site-specific estimates at lakes where fishing mortality is suspected to deviate from the regional estimate. Obtaining some information at both spatial scales would also be important for establishing the variability of fishing mortality and may capture some dynamics of angling effort.

There is evidence that regional estimation of fishing mortality rates may be becoming more common among state management agencies. Meyer and Schill (2014) estimated regional exploitation for a wide range of warmwater and coldwater fish in Idaho, and found that the estimate was cost-effective and had adequate precision for setting regulations. Similarly, following this study, FWC began a statewide tagging program for trophy Florida Bass in attempt to measure exploitation of large fish at the statewide level (Dutterer et al. 2014). Our results also showed that fishing mortality estimates were relatively precise and could be used to inform regional harvest regulations, and use of this method may increase in the future for state management agencies.

Setting fisheries regulations can be a complex task. Many states set a statewide or regionwide regulation for lakes based on the best available social and biological information (best-case scenario), or perhaps on what a subset of agency biologists and administrators think is acceptable based on anecdotal information (Radomski et al. 2001). These decisions may be driven by a few vocal and influential stakeholders, and in some cases regulations are set without much scientific backing (Radomski et al. 2001). Carlson and Isermann (2010) noted that lake-rich states like Minnesota often lack fishery data due to logistics and budgetary constraints that only allow individual studies to be conducted on large high-priority lakes. Subsequently, we believe the ideal scenario generally relies on data from monitoring programs that operate at scales utilized by management and include feedback and interactions with the public. The approach we used is novel because it provides a framework for measuring fishing mortality across water bodies that is much more cost-effective than measuring fishing mortality at many individual lakes and can inform management decisions with better biological data about fishing mortality rates.

ACKNOWLEDGMENTS

We thank Wes Porak and Jim Estes for help in the initial conception of this study. We also thank members of the Allen Lab, FWC Tag Return Hotline, and the numerous FWC biologists for help with data collection and processing. This study was funded by the Florida Fish and Wildlife Conservation Commission using U.S. Fish and Wildlife Service Sport Fish Restoration Program funds. The Cooperative Fish and Wildlife Research Unit is jointly supported by North Carolina State University, North Carolina Wildlife Resources Commission, U.S. Geological Survey, U.S. Fish and Wildlife Service, and Wildlife Management Institute. Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

REFERENCES

Allen, M. S., L. E. Miranda, and R. E. Brock. 1998. Implications of compensatory and additive mortality to the management of selected sportfish 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.

Bonvechio, K. 2009. Standardized sampling manual for lentic systems, version 5. Florida Fish and Wildlife Conservation Commission, Fish and Wildlife Research Institute, St. Petersburg.

Bonvechio, K. I., M. J. Catalano, R. E. Sawyers, and S. Crawford. 2009. Determining electric fishing sample size for monitoring fish communities in three Florida lakes. Fisheries Management and Ecology 16:409–412.

Brownie, C., D. R. Anderson, K. P. Burnham, and D. S. Robson. 1985. Statistical inference from band-recovery data—a handbook, 2nd edition. U.S. Fish and Wildlife Service Resource Publication 156.

Carlson, A. J., and D. A. Isermann. 2010. Mandatory catch and release and maximum length limits for Largemouth Bass in Minnesota: is exploitation still a relevant concern? North American Journal of Fisheries Management 30:209–220.

Chen, R. J., K. M. Hunt, and R. B. Ditton. 2003. Estimating the economic impacts of a trophy Largemouth Bass fishery: issues and applications. North American Journal of Fisheries Management 23:835–844.

Dotson, J. R., M. S. Allen, J. A. Kerns, and W. F. Pouder. 2013. Utility of restrictive harvest regulations for trophy Largemouth Bass management. North American Journal of Fisheries Management 33:499–507.

Driscoll, M. T., J. L. Smith, and R. A. Myers. 2007. Impact of tournaments on the Largemouth Bass population at Sam Rayburn Reservoir, Texas. North American Journal of Fisheries Management 27:425–433.

Dutterer, A. C., C. Wiley, B. Wattendorf, J. R. Dotson, and W. E. Pouder. 2014. TrophyCatch: a conservation program for trophy bass in Florida. Florida Scientist 77:167–183.

Florida LAKEWATCH. 2009. Long-term fish, plants, and water quality monitoring program: 2009. Florida LAKEWATCH and the Program for Fisheries and Aquatic Science in Cooperation with Florida Fish and Wildlife Conservation Commission, Gainesville.

Gaeta, J. W., B. Beardmore, A. W. Latzka, B. Provencher, and S. R. Carpenter. 2013. Catch-and-release rates of sport fishes in northern Wisconsin from an angler diary survey. North American Journal of Fisheries Management 33:606–614.

Hangsleben, M. A., M. S. Allen, and D. C. Gwinn. 2012. Evaluation of electrofishing catch per unit effort for indexing fish abundance in Florida lakes. Transactions of the American Fisheries Society 142:247–256.

Harvey, W. D., and D. L. Campbell. 1989. Technical notes: retention of passive integrated transponder tags in Largemouth Bass brood fish. Progressive Fish-Culturist 51:164–166.

Hayes, D. B., W. W. Taylor, and H. L. Schramm. 1995. Predicting the biological impact of competitive fishing. North American Journal of Fisheries Management 15:457–472.

Henry, K. R. 2003. Evaluation of Largemouth Bass exploitation and potential harvest restrictions at Rodman Reservoir, Florida. Master's thesis. University of Florida, Gainesville.

Hoenig, J. M., N. J. Barrowman, W. S. Hearn, and K. H. Pollock. 1998. Multiyear tagging studies incorporating fishing effort data. Canadian Journal of Fisheries Aquatic Sciences. 55:1466–1476.

Jiang, H., K. H. Pollock, C. Brownie, J. M. Hoenig, R. J. Latour, B. K. Wells, and J. E. Hightower. 2007. Tag return models allowing for harvest and catch and release: Evidence of environmental and management impacts on Striped Bass fishing and natural mortality rates. North American Journal of Fisheries Management 27:387–396.

Kerns, J. A. 2013. Dissecting mortality components for recreational fisheries with high rates of released fish. Doctoral dissertation. University of Florida, Gainesville.

Kurota, H., M. K. McAllister, G. L. Lawson, J. I. Nogueira, S. L. H. Teo, and B. A. Block. 2009. A sequential Bayesian methodology to estimate movement and exploitation rates using electronic and conventional tag data: application to Atlantic Bluefin tuna (*thunnus thynnus*). Canadian Journal of Fisheries and Aquatic Sciences 66:321–342.

Margenau, T. L., and J. B. Petchenik. 2004. Social aspects of Muskellunge management in Wisconsin. North American Journal of Fisheries Management 24:82–93.

McCarthy, M. A. 2007. Bayesian methods for ecology. Cambridge University Press, Cambridge, UK.

Meyer, K. A., F. S. Elle, J. A. Lamansky, E. R. J. M. Mamer, and A. E. Butts. 2012. A reward-recovery study to estimate tagged-fish reporting rates by Idaho anglers. North American Journal of Fisheries Management 32:696–703.

Meyer, K. A., and D. J. Schill. 2014. Use of statewide angler tag reporting system to estimate rates of exploitation and total mortality for Idaho sport fisheries. North American Journal of Fisheries Management 34:1145–1158.

MDNR (Minnesota Department of Natural Resources). 1997. Potential, target, and current yields for Minnesota's large Walleye lakes. Minnesota Department of Natural Resources, Section of Fisheries, Special Publication 151, St. Paul.

Myers, R., J. Taylor, M. Allen, and T. F. 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.

Pereira, D. L., and M. J. Hansen. 2003. A perspective on challenges to recreational fisheries management: summary of the symposium on active management of recreational fisheries. North American Journal of Fisheries Management 23:1276–1282.

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.

Pollock, K. H., H. Jiang, and J. E. Hightower. 2004. Combining telemetry and fisheries tagging models to estimate fishing and natural mortality rates. Transactions of the American Fisheries Society 133:639–648.

Quinn, S. 1996. Trends in regulatory and voluntary catch-and-release fishing. Pages 152–162 *in* L. E. Miranda and D. R. DeVries, editors. Multidimensional approaches to reservoir fisheries management. American Fisheries Society, Symposium 16, Bethesda, Maryland.

Radomski, P. J., G. C. Grant, P. C. Jacobson, and M. F. Cook. 2001. Visions for recreational fishing regulations. Fisheries 26(5):7–18.

Renfro, D. J., W. F. Porak, and S. Crawford. 1999. Angler exploitation of Largemouth Bass determined using variable reward tags in two central Florida lakes. Proceedings of the Annual Conference Southeastern Association of Fish and Wildlife Agencies 51(1997):175–183.

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

Schlagenhaft, T. 1993. Manual of instructions for lake survey. Minnesota Department of Natural Resources, Section of Fisheries, Special Publication 147, St. Paul.

Smithwick Associates. 2012. Sport fishing in America: an economic force of conservation. American Sportfishing Association, Federal Aid in Sport Fish Restoration, Project VA M-26-R, Alexandria, Virginia.

Sullivan, M. G. 2003. Active management of Walleye fisheries in Alberta: dilemmas of managing recovering fisheries. North American Journal of Fisheries Management 23:1343–1358.

Taylor, R. G., J. A. Whittington, W. E. Pine, and K. H. Pollock. 2006. Effect of different reward levels on tag reporting rates and behavior of Common Snook anglers in southeast Florida. North American Journal of Fisheries Management 26:645–651.

USFWS (U.S. Fish and Wildlife and Service). 2011. National survey of fishing, hunting, and wildlife-associated recreation. USFWS and U.S. Census Bureau, Washington, D.C.

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

Wingate, P. J., and D. H. Schupp. 1985. Large lake sampling guide. Minnesota Department of Natural Resources, Section of Fisheries, Special Publication 140, St. Paul.