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Using standardized fishery data to inform rehabilitation efforts

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Abstract

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Lakes and reservoirs progress through an aging process often accelerated by human activities, resulting in degradation or loss of ecosystem services. Resource managers thus attempt to slow or reverse the negative effects of aging using a myriad of rehabilitation strategies. Sustained monitoring programs to assess the efficacy of rehabilitation strategies are often limited; however, long-term standardized fishery surveys may be a valuable data source from which to begin evaluation. We present 3 case studies using standardized fishery survey data to assess rehabilitation efforts stemming from the Nebraska Aquatic Habitat Plan, a large-scale program with the mission to rehabilitate waterbodies within the state. The case studies highlight that biotic responses to rehabilitation efforts can be assessed, to an extent, using standardized fishery data; however, there were specific areas where minor increases in effort would clarify the effectiveness of rehabilitation techniques. Management of lakes and reservoirs can be streamlined by maximizing the utility of such datasets to work smarter, not harder. To facilitate such efforts, we stress collecting both biotic (e.g., fish lengths and weight) and abiotic (e.g., dissolved oxygen, pH, and turbidity) data during standardized fishery surveys and designing rehabilitation actions with an appropriate experimental design.

Key words: aquatic habitat, assessment, monitoring, rehabilitation, reservoirs

Lakes and reservoirs change states through time; however, human activities often accelerate changes, resulting in a structure and function indicative of a system older than its chronological age (Cairns and Palmer 1993, Miranda et al. 2010, Miranda and Krogman 2015). Land-use change can increase nutrient and sediment loading, subsequently reducing ecosystem services provided by lakes and reservoirs (Costanza et al. 1997). In particular, degraded water quality and habitat loss can decrease recruitment and growth of fish, reducing recreational opportunities (Allan and Castillo 2007). Habitat rehabilitation is therefore an important management tool to slow or reverse the effects of aging, and an abundance of resources are expended annually to maintain or revert waterbodies to a desired state and enhance fishing opportunities (Cooke 1999, Pegg and Chick 2010).

Goals of rehabilitation projects often include inducing a combination of physiochemical (e.g., increase Secchi depth transparency) and biological (e.g., increase fish abundance) responses following a habitat manipulation (Minns et al. 1996, Baldigo and Warren 2008). A commonly evoked sampling design to detect such changes has been the before-after control-impact (BACI) design; if initiated correctly, a BACI design can separate year-to-year fluctuations in a system from responses related to a habitat intervention (Underwood 1991, Baldigo and Warren 2008). These designs and their extensions are complex, and replication in both time and space is needed to isolate system responses (Underwood 1992). Coupling monitoring and assessment with habitat

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manipulation projects has been limited (Bash and Ryan 2002, Pegg and Chick 2010), however, and data used to assess the extent of system response to a particular habitat improvement project and inform future rehabilitation actions are often nonexistent. As a result, alternative approaches, and possibly alternative data sources, are needed to determine the efficacy of rehabilitation actions with respect to abiotic and biotic responses.

In the case of aquatic systems, an often available data source is standardized fish surveys (Bonar et al. 2009). Fishery survey data may have potential for use in assessing rehabilitation projects because these data are ideally collected at regular intervals and are thus likely to be available both before and after rehabilitation occurs. Standardized sampling regimes preferably maintain consistency in gear types to reduce bias and include water quality parameters (i.e., dissolved oxygen and water temperature) in addition to biological data (Bonar et al. 2009). These data, however, are not necessarily collected in a manner specifically designed to evaluate the biotic and abiotic responses to a rehabilitation action (Lindenmayer and Likens 2010); thus, the utility of standardized fish survey data to serve as a surrogate monitoring source is unknown.

The Nebraska Aquatic Habitat Plan (AQHP) is an example of a nationally recognized, large-scale, state-run aquatic habitat program. The program is designed to enhance fishing and recreation by rehabilitating Nebraska's aquatic habitats, improving angler access, and increasing angler success in these areas. Rehabilitation techniques implemented through AQHP are targeted to address a specific waterbody's habitat impairment and often include sediment removal (i.e., dredging), aeration, vegetation management, shoreline stabilization, and wetland and sediment basin construction among other commonly used practices employed by management agencies. Similar to other rehabilitation programs, monitoring coinciding with rehabilitation actions is often limited, but standardized fish surveys (e.g., composition and catch) have been implemented in Nebraska since 1984 on all of the state's managed lakes and reservoirs. Our objective was to assess abiotic and biotic responses to rehabilitation actions implemented through the AQHP using standardized fishery survey data. We present 3 case studies that include rehabilitation efforts at Two Rivers Lake #1, Smith Lake, and Yankee Hill Reservoir from the AQHP to represent a range of projects funded by the AQHP in terms of both scale of technique implemented and cost.

Study sites

Two Rivers Lake #1 is a 1.8 ha sandpit lake located within the Two Rivers State Recreation Area in eastern Nebraska (Fig. 1). Dissolved oxygen (DO) in Lake #1 typically fell below 5 ppm during summer months, resulting in fish kills; therefore, an aeration system designed to maintain DO concentration >5 ppm was installed May 1999 at a cost of $6,284.

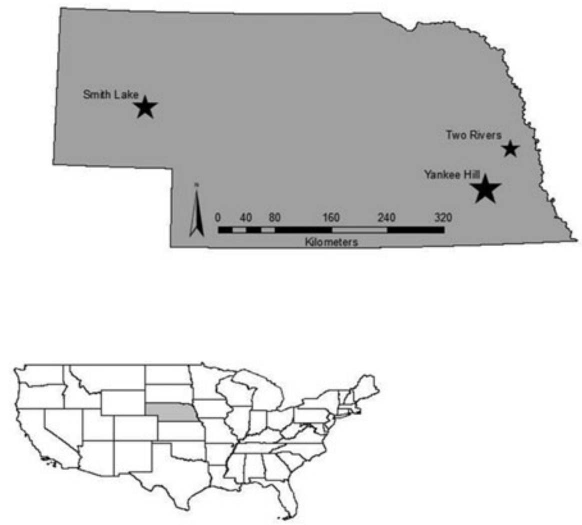

Figure 1. Location of Smith Lake, Two Rivers Lake #1, and Yankee Hill in Nebraska. The star size reflects the relative size of the lakes to one another.

Smith Lake is an 89 ha shallow natural lake (maximum depth 2.4 m) located in the Sandhill ecoregion of Nebraska (Fig. 1) and has a history of winter and summer fish kills due to low (<5.0 ppm) DO concentrations. Managers have attempted aeration in the past but have been unable to abate the problem; therefore, dredging was conducted during 1999 and 2000, resulting in the removal of 27,721 m^3 of sediment at a cost of $411,610 to provide deeper water to reduce the surface coverage of aquatic vegetation and as a refuge for fish.

Yankee Hill is an 84 ha flood-control reservoir located in southeastern Nebraska (Fig. 1). Since construction, erosion originating from both the watershed (e.g., agriculture fields) and wind-driven wave action within the reservoir have resulted in substantial sediment deposition and a loss of reservoir volume. Sedimentation and nutrient loading resulted in reduced water quality, and introductions of nonnative fish species such as common carp (*Cyprinus carpio*) further decreased water clarity through substrate perturbation. Rehabilitation actions included construction of 3 sediment dikes to trap incoming sediment and nutrients from the watershed and dredging to remove 267,441 m^3 of substrate to increase reservoir volume. Jetties, offshore breakwaters, scallops (depth diversity features near shorelines), and islands were also constructed to protect the shoreline from erosion due to wave action. The lake was then treated with a piscicide (rotenone) to remove undesirable fish species and restocked with bluegill (*Lepomis macrochirus*), largemouth bass (*Micropterus salmoides*), and walleye (*Sander vitreus*). The project spanned from 2002 to 2004 and cost $1,873,148.

Methods

We limited our analysis to responses of largemouth bass and bluegill because they are popular sportfish, they were present in all waterbodies, pre- and post-rehabilitation data existed, and they were likely to reflect a cumulative biological response to rehabilitation techniques employed. No physiochemical information was available in the standardized fishery survey database. Staff from the Nebraska Game and Parks Commission performed standard fish surveys during spring when fish counts, total length (TL), and weight were collected. Sample techniques used to estimate population indices included pulsed-DC electrofishing for largemouth bass and frame netting for bluegill; nets consisted of 16 mm bar mesh, 1.5 × 0.9 m frames, and 1.2 × 15 m leads (Hurley and Jackson 2002). Sampling did not occur every year, but data were available for both pre- and post-rehabilitation periods for each waterbody. In Two Rivers Lake #1, pre-rehabilitation data consisted of all data prior to 1999 and post-rehabilitation data consisted of all data after 1999. For largemouth bass in Two Rivers Lake #1, pre-rehabilitation data consisted of data collected in 1997 and 1998, and post-rehabilitation data consisted of data collected in 2000, 2001, 2003, 2007, and 2009. For bluegill in Two Rivers Lake #1, pre-rehabilitation data consisted of data collected in 1997 and 1998, and post-rehabilitation data consisted of data collected in 2000, 2001, and 2003. In Smith Lake, pre-rehabilitation data consisted of all data prior to 1999, and post-rehabilitation data consisted of data collected after 2000. For largemouth bass in Smith Lake, pre-rehabilitation data consisted of data collected in 1994, 1995, 1996, and 1997, and post-rehabilitation data consisted of data collected in 2002, 2003, 2005, 2007, and 2011. For bluegill in Smith Lake, pre-rehabilitation data consisted of data collected in 1994, 1996, 1997, and 1998, and post-rehabilitation data consisted of data collected in 2001, 2002, 2003, 2004, 2005, 2006, 2007, 2008, 2010, and 2011. In Yankee Hill Reservoir, pre-rehabilitation data consisted of all data prior to 2002, and post-rehabilitation data consisted of data collected after 2004. For largemouth bass in Yankee Hill Reservoir, pre-rehabilitation data consisted of data collected in 1998, 1999, and 2000, and post-rehabilitation data consisted of data collected in 2008, 2009, and 2010. For bluegill in Yankee Hill Reservoir, pre-rehabilitation data consisted of data collected in 1998, and post-rehabilitation data consisted of data collected in 2010.

We assessed changes in both largemouth bass and bluegill populations with indices of relative abundance and length–distribution analysis. We compared relative abundance pre- and post-rehabilitation using catch per unit effort (CPUE) data, measured as fish per hour for largemouth bass and fish per net-night for bluegill. In addition to an estimate of overall CPUE, we compared mean CPUEs within length categories defined by Gabelhouse (1984) for each species. We used Welch's one-tailed *t*-tests with $\alpha = 0.05$ to compare pre- and post-rehabilitation overall CPUE estimates and CPUE estimates among size categories (Zar 1999). We assessed assumptions of normality for CPUE data for each species and waterbody using the Shapiro-Wilk normality test (Zar 1999). Equality of variances among samples and independences were also assumed; however, statistical tests such as the *t*-test we employed are relatively resilient to aberrations from their common assumptions, including the assumption of normality (Zar 1999, Zuur et al. 2007). We chose one-tailed tests because management actions were aimed at improving physiochemical characteristics of each waterbody. Because indirect results of the implemented rehabilitation actions are thought to contribute to increased recruitment and growth for both largemouth bass and bluegill (Pegg and Chick 2010), we wanted to explicitly know whether or not an increase in catch occurred. We compared length distributions pre- and post-rehabilitation using Kolmogorov–Smirnov tests with $\alpha = 0.05$ to test our alternative hypothesis that the distribution of lengths from the pre-rehabilitation period would be smaller than the distribution of lengths from post-rehabilitation period. We pooled length distributions across pre- and post-rehabilitation periods, but because only counts of 10 mm TL length-groups were available for Yankee Hill Reservoir post-rehabilitation, we compared length distributions for Yankee Hill Reservoir pre- and post-rehabilitation using Person's chi-square test of independence with $\alpha = 0.05$. As is common in rehabilitation efforts, control lakes were not available to provide a robust statistical approach to rehabilitation efforts; however, statewide mean relative abundance estimates for each ecosystem type (i.e., sandpit lakes, Sandhill lakes, flood control reservoirs) between 1994 and 2009 (same temporal coverage of our indices) were available as a baseline to compare the response of waterbodies used in the current study to that of an ecosystem average (Hurley 2011). We compared both pre- and post-rehabilitation catch statistics (CPUE) to the ecosystem average (averaged between 1994 and 2009) using a *t*-test and examined the 95% confidence intervals (CI) around the differences between the means. We analyzed all data using Program R v3.0.1 (R Development Core Team 2014).

Table 1. Comparison of catch per unit effort in 3 Nebraska waterbodies pre- and post- rehabilitation for largemouth bass (fish/h electrofishing) and bluegill (fish/net-night). Comparisons were made within size groups derived from Gabelhouse (1984). The length groups assessed were stock-length (S) fish, stock- to quality-length (S-Q) fish, quality- to preferred-length (Q-P) fish, preferred- to memorable-length (P-M) fish, and memorable- to trophy-length (M-T) fish. Welch's one-tailed *t*-tests were used in all comparisons. ND denotes inadequate data to carry out the test and * denotes significant result.

Waterbody	Species	Group	df	*t*	*P*
Two Rivers Lake #1	Largemouth Bass	Overall	4	−2.309	0.038*
		S	4	−1.264	0.133
		S-Q	3	−1.071	0.182
		Q-P	4	−0.442	0.339
		P-M	4	0.320	0.614
		M-T	1	0.130	0.544
	Bluegill	Overall	2	−1.887	0.095
		S	1	−1.755	0.114
		S-Q	2	−3.239	0.036*
		Q-P	1	0.370	0.616
		P-M	2	−2.000	0.092
		M-T	ND	ND	ND
Smith Lake	Largemouth Bass	Overall	7	−5.754	< 0.001*
		S	7	−6.405	< 0.001*
		S-Q	5	−1.905	0.061
		Q-P	6	−3.177	0.009*
		P-M	6	−7.252	< 0.001*
		M-T	5	−4.310	0.006*
	Bluegill	Overall	3	0.855	0.775
		S	3	0.892	0.783
		S-Q	3	1.181	0.842
		Q-P	3	1.141	0.832
		P-M	ND	ND	ND
		M-T	ND	ND	ND
Yankee Hill Reservoir	Largemouth Bass	Overall	2	−3.846	0.028*
		S	2	−2.521	0.062
		S-Q	2	−3.761	0.041*
		Q-P	2	−1.215	0.173
		P-M	2	1.571	0.890
		M-T	ND	ND	ND

Results

Two Rivers #1

The Shapiro–Wilk test of normality failed to reject the null hypothesis that CPUE data were normally distributed for largemouth bass ($w = 0.970$, $P = 0.876$) and bluegill ($w = 0.978$, $P = 0.943$) in Two Rivers #1. Largemouth bass CPUE increased ($t = -2.309$, df $= 4$, $P = 0.038$) in Two Rivers Lake #1 following rehabilitation; however, CPUE did not differ for any of the individual length groups (Table 1). The length distribution of largemouth bass following aeration did not increase (Table 2; Fig. 2; $D = 0.0399$, $P = 0.8697$). Conversely, bluegill CPUE did not differ ($t = -1.887$, df $= 2$, $P = 0.095$) between pre- and post-rehabilitation, but there was an increase in the number of stock-length to quality-length (S-Q) fish (Table 1). The bluegill length distribution did not change between pre- and post-rehabilitation periods (Table 2, Fig. 2; $D = 0.0147$, $P = 0.9574$). Prior to rehabilitation, bluegill CPUE was less than the average CPUE for sandpit lakes within the state of Nebraska (Table 3), and bluegill and largemouth bass CPUE post-rehabilitation were greater than the average CPUE for sandpit lakes within the state of Nebraska (Table 3).

Smith Lake

The Shapiro–Wilk test of normality failed to reject the null hypothesis that CPUE data were normally distributed for largemouth bass ($w = 0.916$, $P = 0.327$) but did so for bluegill ($w = 0.767$, $P = 0.001$) in Smith Lake. Largemouth bass CPUE increased ($t = -5.754$, df $= 7$, $P < 0.001$) in Smith Lake (Table 1). The increases in CPUE were accompanied by a shift in size structure of largemouth bass (Table 2; $D = 0.2269$, $P < 0.0001$), where more large

Table 2. Statistical results of comparison (Kolmogorov–Smirnov test) of length distributions in three Nebraska waterbodies pre- and post-rehabilitation. Length distribution data were grouped across years for each period (i.e., pre- and post- rehabilitation). The alternative hypothesis for each test was that the pre-rehabilitation length distribution was less than the post-rehabilitation length data. ND denotes inadequate data to carry out the test.

Waterbody	Species	*D*	*P*
Two Rivers Lake #1	Largemouth Bass	0.0399	0.8697
	Bluegill	0.0147	0.9574
Smith Lake	Largemouth Bass	0.2269	<0.0001
	Bluegill	0.2846	<0.0001
Yankee Hill Reservoir	Largemouth Bass	ND	ND
	Bluegill	0.5731	<0.0001

fish were sampled following rehabilitation (Fig. 3). Bluegill CPUE did not differ ($t = 0.855$, df $= 3$, $P = 0.775$) between pre- and post-rehabilitation or for any of the length groups (Table 1). The assumption of normality was not met for bluegill CPUE, and therefore the estimated *P*-value may need to be interpreted with some caution, although the statistical test used is robust to some deviation in normality. Prior to the rehabilitation, neither memorable-length nor trophy-length bluegill were captured, but following rehabilitation, both were sampled. Bluegill length distribution shifted following rehabilitation to more large fish present (Table 2, Fig. 3; $D = 0.2846$, $P < 0.0001$). Bluegill and largemouth bass CPUEs did not differ compared to the average CPUEs for lakes in the Sandhill ecosystem of Nebraska following

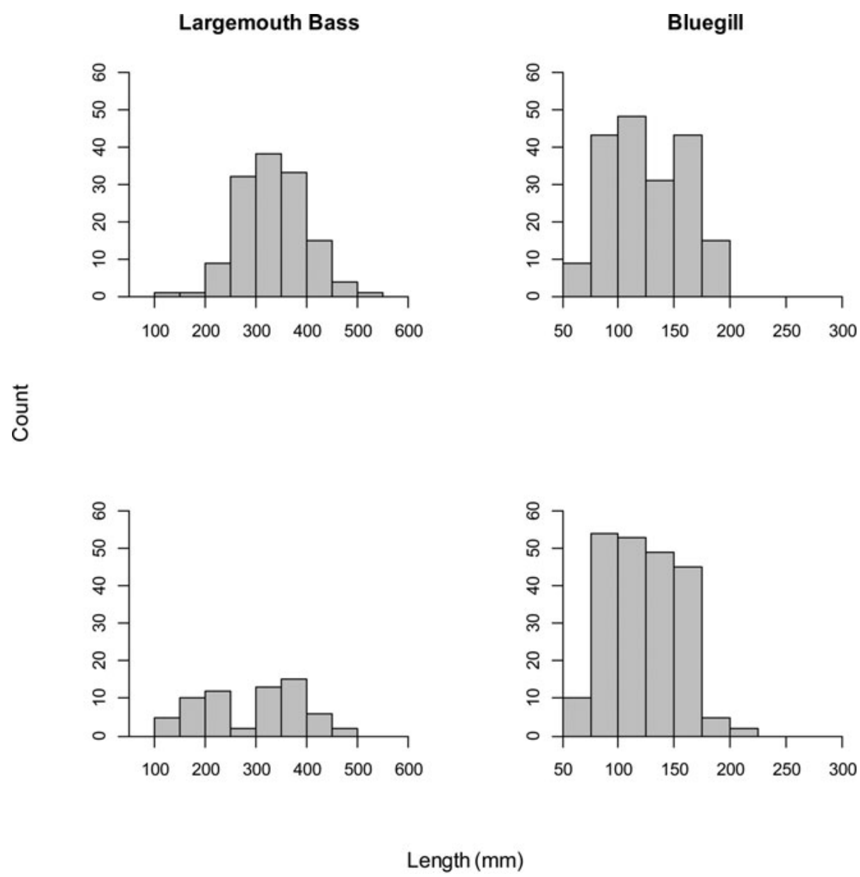

Figure 2. Largemouth bass and bluegill size structure pre- (top) and post-rehabilitation (bottom) in Two Rivers Lake #1, Nebraska. Nighttime electrofishing occurred 1997–2001, 2003, 2007, and 2009 (largemouth bass data), and frame netting occurred 1997–2001 and 2003 (bluegill data).

Table 3. Comparison of pre- and post-rehabilitation catch per unit effort (CPUE ± 95% CI) and the CPUE estimates for lakes and reservoirs of similar type across Nebraska (ecosystem CPUE ± 95% CI). A single ecosystem CPUE value (i.e., control) was used that incorporated the long-term variability in each ecosystem type including sandpit or dugout lakes, Sandhill ecoregion lakes, and flood control reservoirs. The *t*-value is calculated by comparing 2 means with degrees of freedom (df) and the *P*-value associated with each test. A *t*-value greater than the critical *t*-value of 1.96 indicates a statistically significant difference between the means. * indicates a change in CPUE occurred between pre- and post-rehabilitation compared to the long-term ecosystem average; ND denotes inadequate data to carry out the test.

Period	Waterbody	System	Species	CPUE	System CPUE	*t*-value	df	*P*-value
	Two Rivers Lake #1	Sandpit	Bluegill	40 ± 23	47 ± 9.1	−0.55	15	0.7051
			Largemouth Bass	144 ± 17	0.7 ± 0.2	11.91	15	< 0.0001
Pre	Smith	Sandhill	Bluegill	25 ± 24	26 ± 14.0	−0.07	12	0.5274
			Largemouth Bass	23 ± 13	65 ± 17.0	−3.83	18	0.9993
	Yankee Hill	Flood Control	Bluegill	23 ± NC	69 ± 26.0	NC	NC	NC
			Largemouth Bass	39 ± 14	105 ± 22.0	−5.01	16	0.9999
	Two Rivers Lake #1	Sandpit	Bluegill*	69 ± 18	47 ± 9.1	2.10	16	0.026
			Largemouth Bass	232 ± 73	0.7 ± 0.2	6.10	18	< 0.0001
Post	Smith	Sandhill	Bluegill	15 ± 5.0	26 ± 14.0	−1.48	17	0.9214
			Largemouth Bass*	77 ± 13.0	65 ± 17.0	1.12	17	0.1391
	Yankee Hill	Flood Control	Bluegill	42 ± NC	69 ± 26.0	NC	NC	NC
			Largemouth Bass*	209 ± 86	105 ± 22.0	2.31	16	0.0173

rehabilitation (Table 3), although pre-rehabilitation largemouth bass CPUE was below the average for lakes in the Sandhill ecosystem (Table 3).

Yankee Hill

The Shapiro–Wilk test of normality failed to reject the null hypothesis that CPUE data were normally distributed for largemouth bass ($w = 0.867$, $P = 0.216$) in Yankee Hill Reservoir. The CPUE of largemouth bass differed pre- and post-rehabilitation, with more largemouth bass being captured following rehabilitation efforts ($t = -3.846$, df $= 2$, $P = 0.028$). The CPUE of largemouth bass in the S-Q length group was greater post-rehabilitation compared to pre-rehabilitation ($t = -3.761$, df $= 2$, $P = 0.041$); however, CPUE did not differ between any other length groups in Yankee Hill Reservoir (Table 1). The largemouth bass length distribution was shifted to the left (i.e., smaller) post-rehabilitation compared to pre-rehabilitation (Fig. 4; $\chi^2 = 96.82$, df $= 39$, $P < 0.0001$). Bluegill CPUE could not be compared statistically because only one sample was taken pre- and post-rehabilitation. Nevertheless, CPUE of stock-length bluegill was 22 fish/net-night in 1998 and 42 fish/net-night in 2010. Bluegill length distribution significantly changed, with more large fish present in the samples following the rehabilitation (Table 2, Fig. 4; $D = 0.5731$, $P < 0.0001$). Largemouth bass CPUE was less than the average CPUE for flood-control reservoirs prior to rehabilitation and was greater than the average following rehabilitation (Table 3).

Discussion

Standardized fishery survey data can be used to assess rehabilitation efforts, as we observed in all 3 case studies from the AQHP. For instance, increased largemouth bass CPUE, either overall CPUE or length–group-specific CPUE, followed all 3 rehabilitation projects. In Smith Lake, memorable-length and trophy-length bluegill were absent pre-rehabilitation (from 1994 to 1998), but both size classes were evident following implementation of dredging and an increase in lake volume. Largemouth bass CPUE in Smith Lake was below the average CPUE for Sandhill lakes in the state of Nebraska prior to rehabilitation; however, rehabilitation efforts seemingly aided an increase in largemouth bass relative abundance because largemouth bass CPUE post-rehabilitation met the state average for other Sandhill lakes. In Yankee Hill Reservoir, bluegill achieved larger lengths

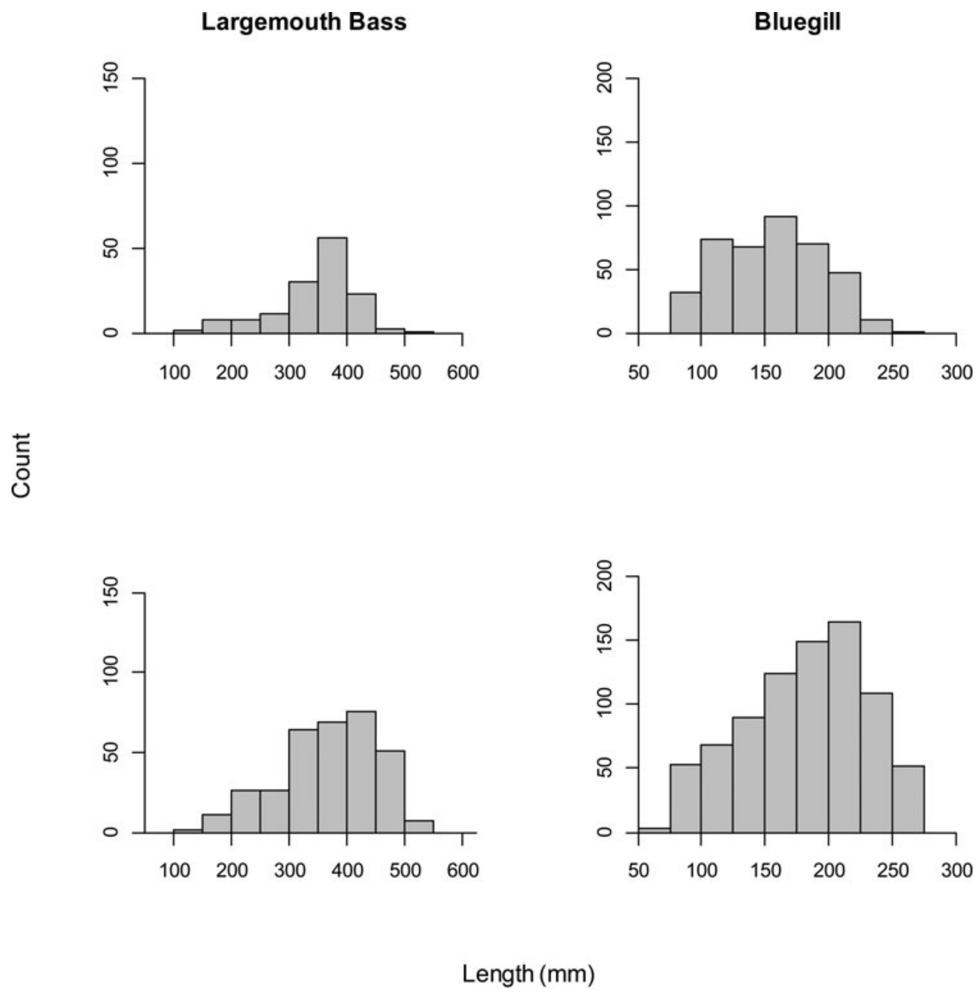

Figure 3. Largemouth bass and bluegill size structure during pre- (top) and post-rehabilitation (bottom) in Smith Lake, Nebraska. Nighttime electrofishing occurred 1994–1997, 2000, 2002, 2003, 2005, 2007, and 2011 (largemouth bass data), and frame netting occurred 1994, 1996–2008, 2010, and 2011 (bluegill data).

post-rehabilitation, likely resulting from the synergistic influence of habitat and fish community management. In other instances, no change was detected in CPUE or length distribution for largemouth bass or bluegill, such as in post-rehabilitation using aeration at Two Rivers #1; however, other responses may have occurred but were not measured (e.g., summer DO concentrations). Our results indicate aeration alone may be insufficient to produce the desired response in largemouth bass or bluegill populations in the case of Two Rivers #1. As such, detecting the presence or absence of biological responses from fish populations following rehabilitation and an initial assessment of rehabilitation techniques (e.g., aeration) is feasible with standardized fishery data.

Calls to establish monitoring programs in concert with rehabilitation projects are common (Palmer et al. 2005), and long-term datasets to assess changes (i.e., alternative states) in lakes and reservoirs are needed (Pegg and Chick 2010, Pope et al. 2014) because biotic and abiotic responses are generally not immediate. For instance, fish populations may take years to respond to rehabilitation techniques as a result of timing of fish reproductive cycle, growth, and the time it takes fish to recruit to sampling gears (Pegg and McClelland 2004, McClelland et al. 2012). However, increased monitoring efforts and complex sampling designs (i.e., BACI), with both spatial and temporal replication (Underwood 1992), impart significant responsibility on already financially stressed management agencies. Fortunately, standardized fishery surveys that are persistent through time and consistent with established data collection protocols can serve, at a minimum, as an initial assessment of rehabilitation projects in the absence of project-specific monitoring and complex sampling designs that may not always be feasible to implement (Pegg and Chick 2010).

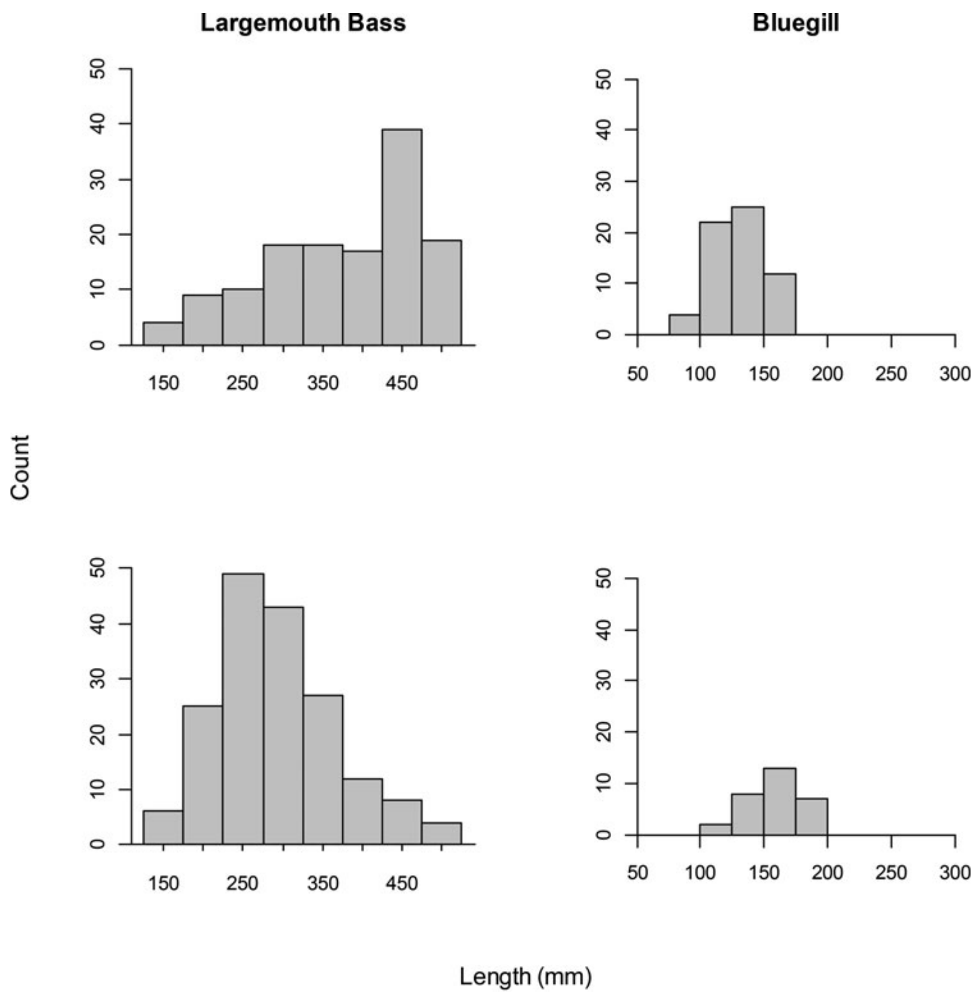

Figure 4. Largemouth bass and bluegill bass size structure during pre- (top) and post-rehabilitation (bottom) in Yankee Hill Reservoir, Nebraska. Note different scales on figure axes. Nighttime electrofishing occurred 1998–2000, 2008, 2009, and 2010 (largemouth bass data), and frame netting occurred 1998–2010 (bluegill data).

Despite the potential benefits of standardized data collection (Bonar et al. 2009), several issues were evident that may reduce the effectiveness of standardized fish surveys to assess specific rehabilitation actions that would allow managers to solely rely on this approach in all instances. In our case studies, the lack of control lakes and reservoirs and the simultaneous implementation of multiple rehabilitation actions limited our ability to pinpoint the most effective rehabilitation techniques and control for multiple other factors that may have contributed to the observed system responses (Underwood 1992). Largemouth bass CPUE increased in Yankee Hill Reservoir (pre $n = 38$, standard deviation [SD] $= 12$; post $n = 209$, SD $= 75$) and was higher than average CPUE for all flood control reservoirs in the state of Nebraska following rehabilitation ($n = 105$, SD $= 64.60$; Hurley 2011). Largemouth bass CPUE and length distribution in Smith Lake were greater following aeration and dredging efforts; however, the relative abundance of largemouth bass was below average for other Sandhill lakes, suggesting additional management efforts may be needed. The combination of rehabilitation techniques employed at Yankee Hill Reservoir improved aquatic habitat and increased fishing opportunities, but no one technique can be singled out as most important. Thus, if the goal of a monitoring program is to determine the optimal suite of rehabilitation techniques, then standardized fishery data alone, as we have used it, is not likely to provide an answer. Instead, managers and researchers would have to rely on more traditional sampling designs with both spatial and temporal replication for the multiple rehabilitation actions taken (Underwood 1992, Baldigo and Warren 2008). Bonar et al. (2009) stated that physiochemical data should be an integral part of a standardized fishery survey. Our case studies also highlight the importance of ancillary data collection; water quality measurements were not taken in concert with fish data in our case studies. Adequate water quality measures may have aided in clearly understanding changes in the current rehabilitation assessments by providing an alternative data source in addition to fish population responses.

Standardized fishery surveys can provide a key data source for researchers and managers to assess multiple objectives. Standardization of fishery surveys is certainly not a new concept, and such data are vital to a management agency's ability to fulfill mission requirements. Because these data can also be used to assess rehabilitation actions, they become a rich source of data for managers to assess measureable objectives of rehabilitation programs (Palmer et al. 2005). Our study highlights areas where sampling methodology can be improved to ensure meaningful data are collected (Eberhardt and Thomas 1991). Maximizing the utility of such datasets to work smarter, not harder can be achieved by including both biotic (e.g., fish lengths and weight) and abiotic (e.g., DO, pH, and turbidity) data in standardized surveys each time sampling occurs. Conducting rehabilitation actions with control lakes in place or in a step-wise fashion to evaluate the efficacy of the individual rehabilitation action should also be considered (Eberhardt and Thomas 1991, Underwood 1992).

Lake and reservoir managers can use standardized fish survey data to assess the general success and failures of rehabilitation techniques. As shown by our study, however, testing specific rehabilitation techniques may be limited if multiple techniques are employed at one time and without regard to more rigorous statistical design (e.g., BACI designs). Although gaps are likely when using standardized fishery survey data to assess rehabilitation efforts, as we have done here, we have shown that information within these data can reflect fish community responses while further enhancing our knowledge of aquatic habitat projects.

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