FORAGE FISH ABUNDANCE AND THE INFLUCENCE OF RIVER FLOW – MANAGEMENT IMPLICATIONS FOR THE ENDANGERED LEAST TERN

Chadwin B. Smith[a], David M. Baasch[a], and Trevor J. Hefley[b]
[a] *Headwaters Corporation and Platte River Recovery Implementation Program*
[b] *University of Nebraska-Lincoln; IGERT Program*

ABSTRACT
Forage fish abundance was sampled at five sites on the central Platte River, Nebraska periodically from 1999-2011 by implementing the Nebraska Public Power District and Central Nebraska Public Power and Irrigation District's forage fish monitoring protocol. To the extent possible, using these data fish abundance was measured by the Program to relate river discharge to interior least tern (*Sterna antillarum*) productivity. Fish were caught in open channel habitats using seines or trawls and were identified to species and counted. The abundance of the predominant six forage species and young of the year, adjusted for size of area sampled, and the number of the six species and young of the year present in each sample was modeled against several metrics of river discharge. A generalized linear mixed model with orthogonal polynomials was used to explore the complexity of the relationship between fish abundance and number of species and six flow covariates. Model results show that four flow covariates of discharge have an effect on number of species in each sample, but models for abundance were unable to detect an effect of any of the flow covariates.

INTRODUCTION
The Platte River Recovery Implementation Program (Program)initiated on January 1, 2007 to address issues related to the loss of habitat in the Platte River in central Nebraska by managing certain land and water resources following the principles of adaptive management to provide benefits for four "target species": the endangered whooping crane (*Grus americana*), interior least tern (*Sterna antillarum*), and pallid sturgeon (*Scaphirhynchus albus)*; and the threatened piping plover (*Charadrius melodus*). Central to the Program is its Adaptive Management Plan, which provides a systematic process to test priority hypotheses and apply the information learned to improve management on the ground (AMP, 2006).

Figure 1. Interior least tern

Figure 2. Sand shiner (*Credit: Cornell University*)

Interior least terns utilize open river sandbars and gravel pit spoil piles ("sandpits") for nesting on the central Platte River annually from May through August (Held, 2007). During the nesting season on the Platte, least terns forage for small fish generally less than 3 inches in length in sand pits and open river channel (Wilson et al., 1993; NRC, 2005). The decline in productivity of least terns on the central Platte is often attributed to several factors including the loss of river sandbar habitat, flow alteration, and sandbar encroachment (NRC, 2005). As such, several priority hypotheses in the AMP focus on the productivity of interior least terns on the central Platte and its relationship to habitat availability, river flow, and other factors (AMP, 2006).

Priority hypothesis T2 states: "Tern productivity is related to the number of prey fish (<3 inches) and fish numbers limit tern production below 800 cfs from May-September." This hypothesis relates to concerns over the relationship between declining tern productivity on the central Platte and the availability of forage fish in the river due to low summer flows. A sub-hypothesis of T2 postulates a non-linear relationship between the number of fish (fish abundance and diversity) and river discharge (Figure 3).

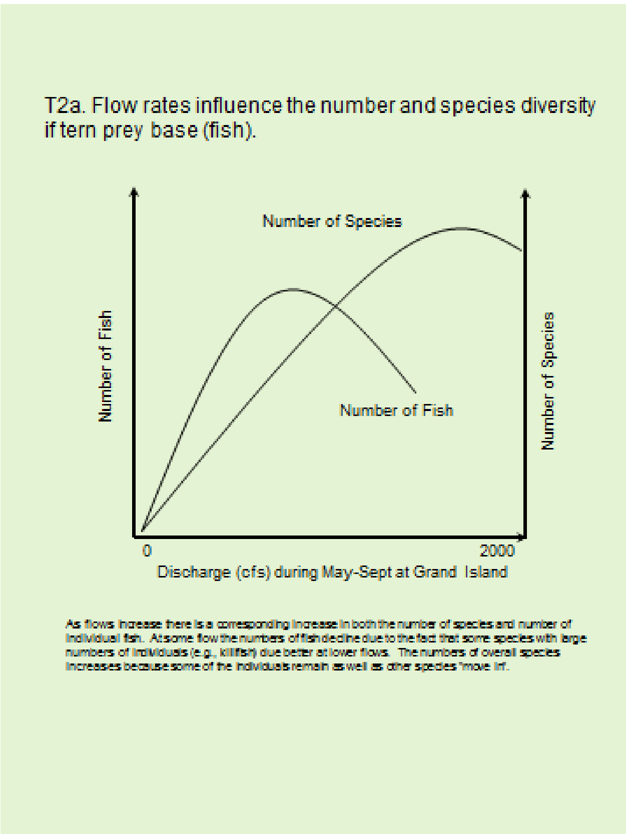

Figure 3: X-Y graph for forage fish abundance/river discharge hypothesis (AMP, 2006).

The objective of this analysis was to utilize existing central Platte forage fish monitoring data to estimate the impacts on forage fish abundance due to river discharge and other factors and begin to build empirical evidence to test the forage fish-related tern hypotheses in the AMP. The results of the analysis could be useful in further estimating the relationship between prey abundance and tern productivity and how those two parameters can factor into Program management actions.

METHODS

Sampling Area

The sampling area encompassed the roughly 90 miles of the central Platte River where Program activities are focused, consisting of an area 3.5 miles on either side of the Platte River centerline beginning at the junction of U.S. Highway 283 and Interstate 80 near Lexington, Nebraska and extending eastward to Chapman, Nebraska. Forage fish sampling generally occurred during the latter portion of the least tern nesting season (June 1 to August 31) in 1999, 2003, 2005, and 2007–2011. Four forage fish sampling sites were established in 1999 based on their relationship to areas managed as least tern nesting habitat. A fifth sampling location near Alda, Nebraska was added in 2003 (Jenniges and Peyton, 2007). Sampling locations included: Lexington (1.6 km downstream of the US Highway 283 river bridge); Overton (2.3 km upstream of the Overton river bridge); Cottonwood Ranch (8 km upstream of the US Highway 183 river bridge); Elm Creek (1 km downstream of the US Highway 183 river bridge); and Alda (2.4 km downstream of the Alda river bridge). Sampling was conducted by staff from the Nebraska Public Power District, Central Nebraska Public Power and Irrigation District, Central Platte Natural Resources District, the Program Executive Director's Office, and the Program's tern and plover monitoring crew which was comprised of United States Geological Survey staff and technicians.

Sampling Design and Techniques

Forage fish data were collected in 1999-2010 through implementation of the monitoring protocol *Monitoring Riverine Prey Base for Least Terns: Fish Species Composition, Spatial Distribution, and Habitat Utilization in the Central Platte River* (AMP, 2006). Each study area included a 200 m reach of river with habitat classifications of open channel, open channel and side channel bank, open channel snag, backwater, isolated backwater, slough, pond, and side channel (AMP, 2006). For the purposes of this analysis, only data collected from the open channel habitat classification at each sampling location was considered. In all years, roughly 80% of all fish collected were in the open channel. Previous investigations of tern foraging behavior, as well as observation of tern foraging on the central Platte, generally indicate a preference for open water foraging on rivers (Wilson et al., 1993; Tibbs and Galat, 1998).

Only open channel data collected for six species of potential forage fish (Table 1) and all unidentifiable young-of-the-year (YOY) fish species were included in the analysis since these groups comprised >75% of all fish sampled every year. In addition, least terns are generally considered to be opportunistic feeders that focus on a certain size range of fish as opposed to species-specific forage selection (USFWS, 2006).

Common Name	Scientific Name
Red shiner	*Cyprinella lutrensis*
Sand shiner	*Notropis stramineus*
Bigmouth shiner	*Notropis dorsalis*
Brassy minnow	*Hybognathus hankinsoni*
Mosquitofish	*Gambusia affinis*
Plains killifish	*Fundulus zebrinus*

Table 1. *Predominant identifiable potential forage fish species sampled on the central Platte River, 1999-2011.*

The forage fish monitoring protocol defines open channel as the flowing portion of the active channel area greater than 23 m (AMP, 2006). When flows allowed during 1999-2010, open channel areas at 5 sites were sampled using 1/8-inch mesh seines to enclose an area 7.5 m by 15 m and capture available forage fish of the appropriate size (AMP, 2006). In 2011, a 3 meter wide trawl was pulled downstream a distance of 50 m to sample forage fish availability. In 1999, a total of ten randomly placed seining replicates were completed in open channel areas at the Cottonwood Ranch, Elm Creek, Lexington and Overton sites. During 2003 and 2005, ten randomly placed seines were completed at Cottonwood Ranch, Elm Creek, and Alda; only 5 seines were completed at Lexington and Overton because of insufficient channel area. Seine hauls were completed along six transects, which included 2 samples in the north, center, and south third of the channel, at all 5 sites in 2007-2009 and all sites except Lexington during 2010. Five trawl samples were completed at Cottonwood Ranch, Elm Creek, and Overton and 6 were completed at Lexington during 2011. All captured fish were counted and identified to species or were classified as YOY if they were too small to identify.

Data Analysis

Since total area sampled for each site and method was different, we standardized forage fish counts to density estimates (fish/acre) in our analyses. For example, if the sample area was 0.025 acres and 10 fish were captured, this would equate to a density of 400 fish/acre (i.e., 10 fish/0.025 acres). Forage fish abundance per acre was reported as the number of total individuals of the six primary fish species and YOY by site, date, and seine haul (n=255). Number of species present in each seine hall was calculated by adding the total number of unique species from the six primary fish species and YOY by site, date, and seine haul.

Discharge, in cubic feet per second (cfs), was included as the mean daily flow on the day of sampling, minimum mean daily flow during June, minimum daily flow during July, minimum daily flow during June and July, mean daily flow during June, and mean daily flow during July. Discharge for the Lexington sample site was measured at the Nebraska Department of Natural Resources gaging station near Cozad, Nebraska (6766500). Discharge for the Overton sample site were measured as return flows from Central Platte Public Power and Irrigation Districts' Johnson-2 (J-2) hydro canal which encompasses all flows that pass through this channel area. Discharge at the Cottonwood Ranch and Elm Creek sites were measured at the upstream U.S. Geological Survey (USGS) gaging station near Overton, Nebraska (06768000; USGS, 2012). Discharge at the Alda site was measured at the downstream U.S. Geological Survey (USGS) gaging station near Grand Island, Nebraska (06770500). Attempts to include water temperature and channel width data in the analysis were abandoned because of incomplete data collection or reports for these covariates.

Both fish abundance and number of species were non-normally distributed. In addition there was a potential correlation between samples from the same date, site, and seine hauls. Generalized linear mixed models (GLMMs) are statistical methods capable of dealing with non-normally distributed data with correlation structure and were used in this analysis (Bolker *et al.* 2009). Given the hypothesized non-linear relationship between discharge and forage fish abundance in priority hypothesis T2a, orthogonal polynomials with linear, quadratic, and cubic effects were used in our GLMM based analyses. The model for fish abundance was assumed to have a Poisson distribution and the model for number of species captured was assumed to have a binomial distribution. Both models included a unit-of-observation level random effect to account for overdispersion. Alternative unit-of-observation level random effects distributions for the GLMM describing fish abundance may be more appropriate. For example, our model assumes that the unit-of-observation level random effect is normally distributed on the log scale. An alternative approach would assume that the unit-of-observation level random effects is gamma distributed; this assumption would lead to the Negative Binomial distribution and may be more appropriate in this situation, however, negative binomial models developed in Program R (package HGLMMM and glmmADMB, which use the program AD model builder) failed to converge or resulted in nonsensical estimates; we feel it is unlikely that using negative binomial models would change the interpretation of the results. Correlation due to year, site, seine and the interaction of site by seine were incorporated as independent normally distributed random effects. The correlation due to site by seine appeared to be negligible and therefore was removed from all models. All statistical analyses were conducted using the software package R, Version 2.15.0 (R Core Development Team, 2012) and all GLMM analyses were conducted using the lme4 R package.

All six flow covariates were highly correlated (r=0.82–0.96). Highly correlated covariates can produce parameter estimates that are biologically nonsensical, highly biased, have large variance, or, in the case when two predictor variables are perfectly linearly correlated ($r^2 = 1$), have an infinite number of estimates for the two coefficients (Neter et al. 1996, Guthery and Bingham 2007). Because of the high correlation between all flow covariates, we included only one covariate in each model set. This resulted in six sets of models for fish abundance and number of species. Each model set included four models that described the effects of the single flow covariate: null (i.e. no effect of flow covariate), linear, quadratic, and cubic. Akaike information criterion for small sample size (AIC_c) was used for model selection (Burnham and Anderson 2002). Inference was made conditional of the AIC_c best model. The AIC_c best model was defined as the model with the lowest AIC_c in each model set. In the case were the AIC_c best model and other models differed by less the two, the model with the lower order polynomial was chosen. Ninety five percent confidence bands were constructed using parametric bootstrapping.

RESULTS

A basic evaluation of the data shows a narrow range of average fish abundance by site with high abundances observed within a few samples (Figure 5). Plots of observed discharge by site (Figure 6) show a limited amount of data was collected at flows >1,000cfs which may have limited our ability to detect significant relationships. We were unable to detect a relationship between abundance of forage fish within individual samples and any flow metric tested as the null model had the lowest AIC_c value for each of the 6 covariate model sets tested (Figure 7).

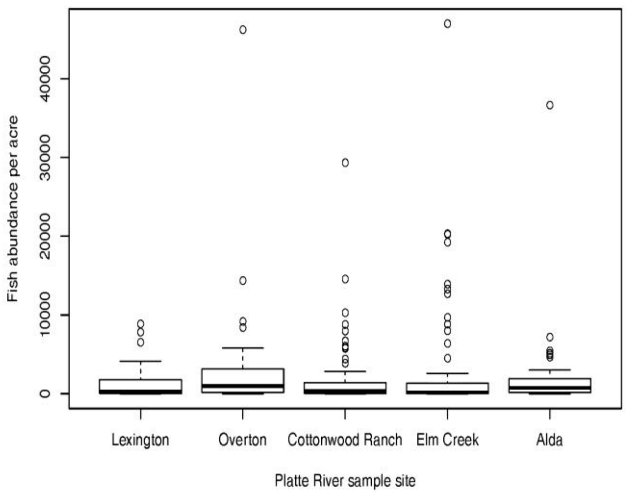

Figure 5. Potential forage fish abundance by site.

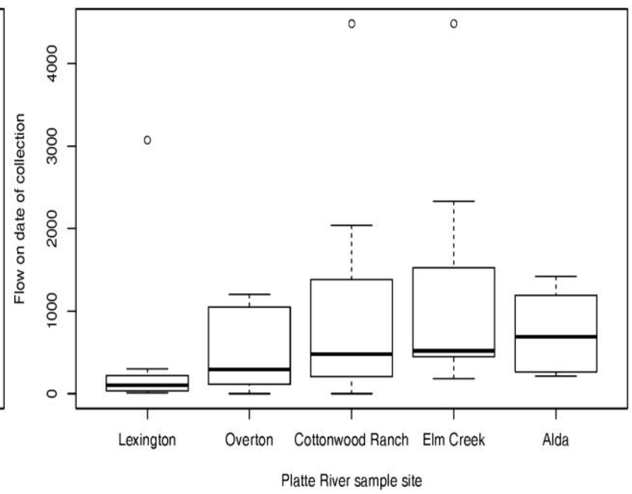

Figure 6. Discharge during sampling periods by site.

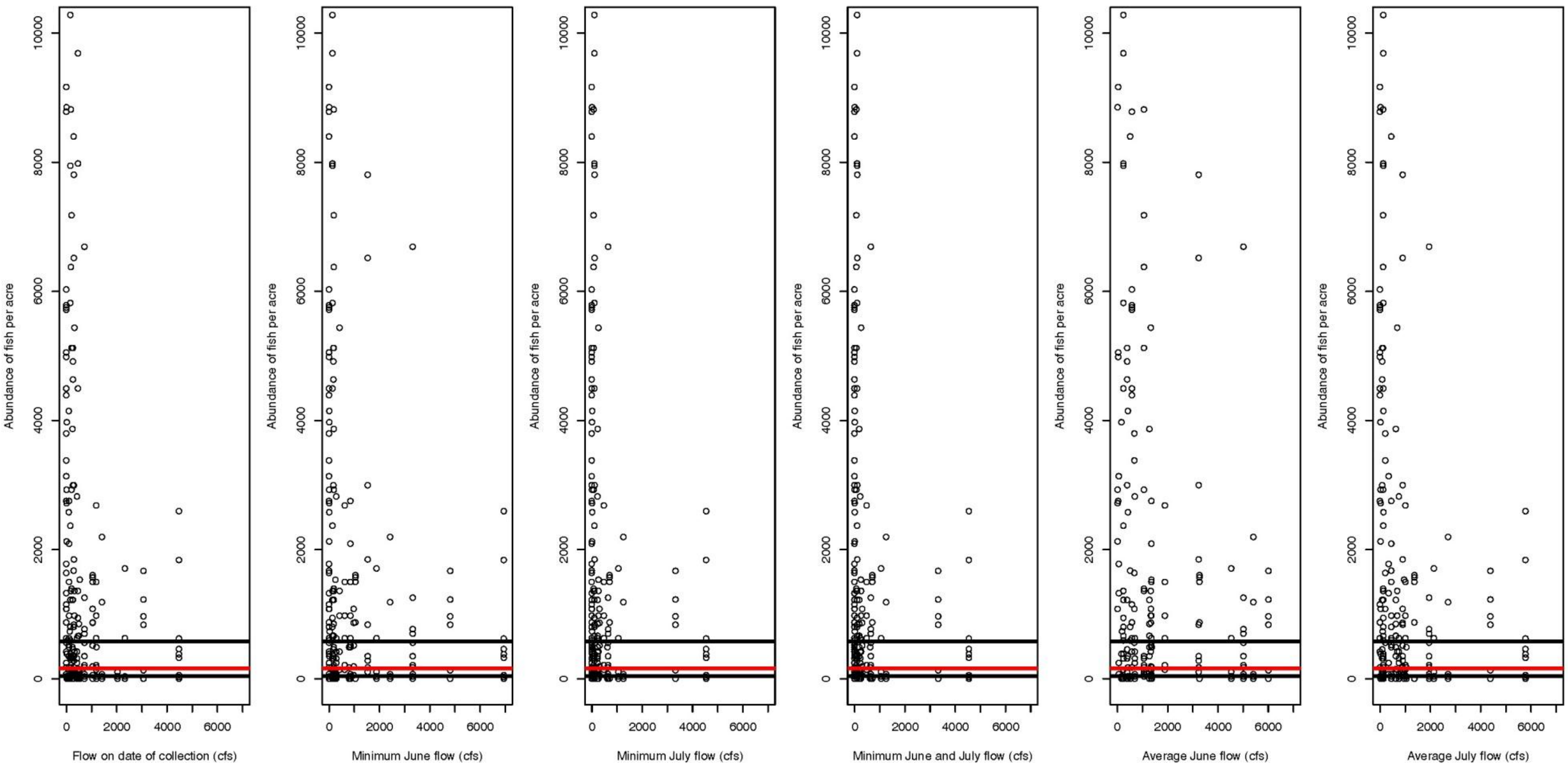

Figure 7. Predicted relationships between forage fish abundance and 6 flow covariates (red lines) as well as 95% confidence intervals (black lines). Black circles are densities of forage fish observed in each sample. Note: observed forage fish densities of 12,686; 13,276; 13,902; 14,355; 14,564; 19,233; 20,244; 20,314; 29,338; 36,655; 46,237; and 47,003 fish/acre were included in the dataset used to develop predicted relationships and confidence intervals, but are not displayed in the figure.

Average forage fish density across all samples, sites and years was found to be 2,438 fish/acre (Table 1; 95% CI: 1715–3161 fish/acre). We observed the lowest average forage fish densities across all sites following the natural high flow event in 2010, when 287 fish/acre were captured within the sample areas at average observed daily flows of 1748cfs (range 1,202-2,330cfs).

Table 2. Forage fish densities (fish/acre), numbers of forage species captured, and flow metrics recorded at nearby USGS, DNR, and CNPPID gaging stations during sampling sessions. Note: forge fish densities and numbers of species captured are summarized by site; however, individual sample counts were included in all analyses.

			Sample Area	Forage Fish[1]/Acre	Forage Fish	Observed	Minimum Monthly Flow (cfs)		Average Monthly Flow (cfs)	
Site	Date	Samples	(acres)	(site average)	Species Captured	Flow (cfs)	June	July	June	July
Lexington	8/5/2011	6	0.23	804	3	3,070	4,820	3,330	6,014	4,392
Overton	8/5/2011	5	0.19	551	2	1,049	983	309	1,343	905
CWR[2]	8/5/2011	5	0.19	535	4	4,480	6,950	4,550	7,675	5,788
Elm Creek	8/5/2011	5	0.19	741	3	4,480	6,950	4,550	7,675	5,788
Alda	NA[3]	NA	NA	NA	NA	NA	NA	NA	NA	NA
Lexington	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Overton	8/10/2010	6	0.17	122	4	1,202	799	627	1,378	1,056
CWR	8/11/2010	6	0.17	41	3	2,040	1,890	1,060	4,536	2,147
Elm Creek	8/10/2010	6	0.17	401	4	2,330	1,890	1,060	4,536	2,147
Alda	8/5/2010	6	0.17	587	4	1,420	2,430	1,260	5,414	2,711
Lexington	8/3/2009	6	0.17	1,214	3	101	12	20	426	141
Overton	7/31/2009	6	0.17	4,135	3	0	0	0	683	214
CWR	8/3/2009	6	0.17	1,005	4	248	191	238	1,282	635
Elm Creek	7/31/2009	6	0.16	4,604	5	502	191	238	1,282	635
Alda	8/4/2009	6	0.17	1,411	5	326	420	267	1,337	688
Lexington	8/13/2008	6	0.17	139	4	141	25	13	196	111
Overton	8/13/2008	6	0.17	1,614	4	0	0	0	65	348
CWR	8/14/2008	6	0.17	5,557	6	426	288	229	701	755
Elm Creek	8/14/2008	6	0.17	3,293	7	426	288	229	701	755
Alda	8/15/2008	6	0.17	923	3	1,050	1,050	709	3,271	1,370
Lexington	8/14/2007	6	0.17	99	4	48	12	12	523	453
Overton	8/13/2007	6	0.17	1,823	5	294	0	0	517	452
CWR	8/13/2007	6	0.17	290	4	538	257	268	1,362	965
Elm Creek	8/13/2007	6	0.17	3,397	6	538	257	268	1,362	965
Alda	8/14/2007	6	0.17	1,022	2	1,190	626	484	1,896	1,013
Lexington	7/7/2005	5	0.14	878	3	22	12	12	170	25
Overton	7/7/2005	5	0.14	3,463	5	0	0	0	586	0
CWR	7/7/2005	10	0.29	2,697	5	185	191	75	1,064	127
Elm Creek	7/6/2005	10	0.29	3,139	6	211	191	75	1,064	127
Alda	7/6/2005	10	0.29	5,404	7	233	259	8	1,057	111
Lexington	6/23/2003	5	0.14	3,540	4	10	9	11	17	28
Overton	6/23/2003	5	0.14	13,638	4	0	0	0	42	0
CWR	6/23/2003	10	0.29	4,429	6	162	139	106	247	135
Elm Creek	6/24/2003	10	0.29	9,251	5	466	139	106	247	135
Alda	6/24/2003	10	0.29	1,986	6	266	176	0	397	93
Lexington	7/12/1999	10	0.29	2,101	5	303	1,540	114	3,241	906
Overton	7/12/1999	10	0.29	906	4	112	852	0	1,360	453
CWR	7/13/1999	10	0.29	1,042	4	724	3,330	652	5,020	1,956
Elm Creek	7/13/1999	10	0.29	66	2	724	3,330	652	5,020	1,956
Alda	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

[1] Forage fish included 6 species (red shiner, sand shiner, bigmouth shiner, brassy minnow, mosquito fish, and plains killifish) and young-of-the-year fish deemed suitable interior least tern forage
[2] Cottonwood Ranch site
[3] Indicates fish samples were not collected

Four of the six sets of models describing the relationship between numbers of species captured and flow covariates indicate a quadratic relationship exists in the data, but not as hypothesized. These model sets included: mean daily flow on the sampling date, minimum daily flow during July, minimum daily flow during June and July, and average daily flow during July (Figure 8). The other two model sets describing number of species captured showed no relationship between the two remaining flow covariates; minimum daily flow during June and average daily flow during June.

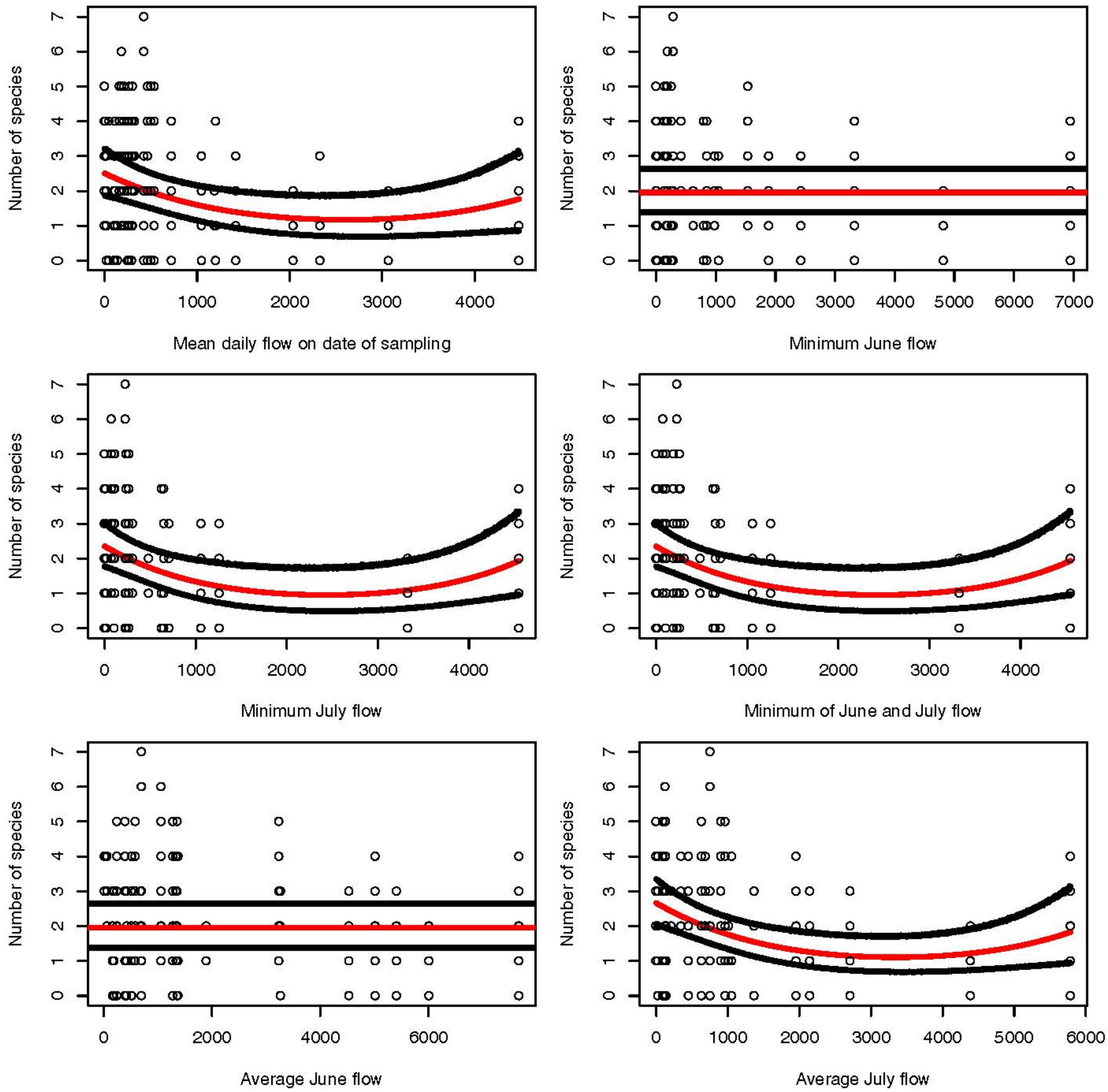

Figure 8. Predicted relationships between numbers of species expected to be included in a sample and flow covariates (red lines) as well as 95% confidence intervals (black lines). Black circles are the number of unique species observed in each sample.

DISCUSSION AND MANAGEMENT IMPLICATIONS

As designed, the current forage fish monitoring protocol is directed at measuring fish abundance and potentially available forage fish species. Despite several years of data collection and the availability of a rather large sample size (n=255), statistical analyses performed indicate there was no relationship between discharge and forage fish abundance; however, several potentially important covariates (i.e., channel width, depth, speed, temperature, etc.) were not collected or evaluated. Although our analyses did not indicate any relationship between discharge and potential forage fish abundance, given a basic understanding of the ecology of forage fish in the Platte River, a non-linear relationship likely exists in nature as reflected by priority hypothesis T2a (Figure 3) – at zero discharge there are no fish and increasing discharge supports an increasing number of fish up to a certain point before the river becomes too fast and deep to support fish in their expected habitats and making them unavailable as forage.

We found the average forage fish density across all samples, sites, and years was 2,438 fish/acre which was approximately 300 fish/acre less than Sherfy et al. (2012) observed at in-channel sample sites within the central Platte River, 2009–2010. We used interior least tern and piping plover habitat classification results for 2009 and 2011 (lowest and highest observed flow when aerial imagery was captured by the Program, respectively) to calculate total wetted channel area within the Program Associated Habitat Area. We found there were approximately 6,066 acres and 11,353 acres within the active channel that were covered by water during mid-June 2009 and 2011, respectively. We extrapolated average forage fish densities across the wetted channel areas and estimate there were 14.8 million (CI_{95} = 10.8–19.5 million) and 27.7 million (CI_{95} = 20.2–36.5 million) potential forage fish available within the active channel area during 2009 and 2011. These estimates assume potential forage fish were distributed equally throughout the study area which is supported by Chadwick and Associates (1992) findings, however, only 5 sites were sampled and the variability between samples, sites, and years was generally high. Our estimate for 2009 is similar to the 13 million potential forage fish Chadwick and Associates (1992) reported under similar summer flow conditions and our estimate for 2011 is slightly higher; however, they included samples collected during June and July when fish abundance was reported to be lower.

Sherfy et al. (2012) found forage fish abundance at least tern foraging sites and random locations were similar which would also indicate forage fish abundance was high throughout the river channel. Sherfy et al. (2012) also found least terns frequently traveled distances of 6 miles to forage which would make a wide range of habitats and water conditions and hundreds of thousands of forage fish available to least terns while foraging. Our findings do not easily translate into data useful for assessing priority hypotheses such as T2a and ultimately the relationship between forage fish abundance and least tern productivity. However, there is no evidence that abundance of forage fish within the central Platte River currently limit least tern productivity.

In order to test our assumptions and fully evaluate least tern response to forage fish abundance throughout the Program Associated Habitat Area, additional protocols and a systematic approach, such as sampling at Program anchor points, would be needed. Sampling efforts would also need to be expanded to include the wide range of discharges observed during the May-September time period to provide a larger data set of fish abundance at different river discharges and to capture a broader fish response to discharge related to both fish recruitment and availability as tern forage. Evaluating least tern response to forage fish abundance would also require capturing and weighing least tern chicks on multiple occasions to establish the relationship between growth rates and forage fish abundance, as we currently have no means of linking forage fish abundance to least tern productivity. At this time, however, we don't feel these additional expenses, efforts, and risk of injury to least tern chicks are warranted as it appears forage fish abundance is adequately high to support the central Platte River population of least terns.

REFERENCES

Adaptive Management Plan. 2006. Final Platte River Recovery Implementation Program. U.S. Department of the Interior, State of Wyoming, State of Nebraska, State of Colorado.

Bolker B.M., M.E. Brooks, C.J. Clark, S.W. Geange, J.R. Poulsen , M.H. Stevens, and J.S. White. 2009. Generalized linear mixed models: a practical guide for ecology and evolution. Trends in 622 Ecology and Evolution 24:127–135.

Burnham K. P. and D.R Anderson. 2002. Model selection and multi-model inference. Springer Verlag, New York, New York, USA.

Chadwick and Associates. 1992. Forage Fish Monitoring Study Central Platte River, Nebraska 1990-1991. Report prepared for Nebraska Public Power District and Central Nebraska Public Power and Irrigation District.

Guthery F.S. and R.L. Bingham. 2007. A primer on interpreting regression models. Journal of Wildlife Management 71:684–692.

Held, R.J. 2007. Comprehensive report of habitat requirements of least terns and piping plovers on the lower Platte River in Nebraska. Final Report for Nebraska Game and Parks Commission.

Jenniges, J.J. and M. Peyton. 2007. Annual report – fish population studies 2007. Platte River Recovery Implementation Program.

National Research Council. 2005. Endangered and threatened species of the Platte River. The National Academies Press, Washington, DC, USA.

Neter J, Kutner MH, Nachtsheim CJ, and Wasserman W. 1996. Applied Linear Statistical Models. Third edition. McGraw-Hill, New York City, New York, USA.

Tibbs, J.E. and D.L. Galat. 1998. The influence of river state on endangered least terns and their fish prey in the Mississippi River (USA). Regulated Rivers: Research & Management 14: 257-266.

R Development Core Team (2012). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. ISBN 3-900051-07-0, URL http://www.R-project.org.

Sherfy, M.H., M.J. Anteau, T.L. Shaffer, M.A. Sovada, and J.H. Stucker. 2012. Foraging Ecology of Least Terns and Piping Plovers Nesting on Central Platte River Sandpits and Sandbars. Open-File Report 2012–1059.

U. S. Fish and Wildlife Service (USFWS). 2006. Biological opinion on the Platte River Recovery Implementation Program. U.S. Fish and Wildlife Service, Denver, CO, USA.

U.S. Geological Survey (USGS). 2012. Real-time water data for Nebraska. U.S. Geological Survey, http://waterdata.usgs.gov/ne/nwis/current/?type=flow&group_key=NONE&search_site_no_station_nm=platte%20river

Wilson, E.C., W.A. Hubert, and S.H. Anderson. 1993. Nesting and foraging of least terns on sand pits in central Nebraska. The Southwestern Naturalist 38:9-14.