Interior Least Tern Productivity in Relation to Flow in the Central Platte River Valley

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Abstract

Implementation of the Platte River Recovery Implementation Program's (Program) adaptive management plan (AMP) has proceeded with the understanding that management uncertainties, expressed as hypotheses, encompass complex physical and ecological responses. Adaptive management in the Platte River ecosystem relies on a combination of monitoring of physical and biological responses to management treatments, predictive modeling, and retrospective analyses. Given the abundance and diversity of fish occurring in streams decreases with groundwater extractions and flow alterations, we used existing interior least tern productivity data and flow data collected on the central Platte River in retrospective analyses to assess the influence of forage fish availability during the brood rearing season on interior least tern productivity. We found low flows during the least tern brood rearing season do not negatively affect interior least tern productivity. As such, we used this indirect line of evidence to build empirical support to assess the forage fish-related hypotheses in the Program's AMP and concluded forage fish abundance does not limit interior least tern productivity on the central Platte River.

Key Words: central Platte River, forage fish, interior least tern, Platte River Recovery Implementation Program, productivity.

Introduction

The Platte River Recovery Implementation Program (Program) is responsible for implementing certain aspects of the endangered interior least tern (*Sterna antillarum athalassos*; hereafter, least tern) recovery plan in the Associated Habitat Reach (AHR) of the Platte River in central Nebraska. One of the Program's management objectives is to increase least tern productivity within the AHR. Uncertainty related to the relationship between least tern productivity, prey (forage fish) availability, and river flow is captured in several priority hypotheses in the Program's Adaptive Management Plan (AMP; Program 2006). To date, these hypotheses have served as guidance for the Program to investigate the implications of low flow in the central Platte River during summer on the abundance of small fish for least terns and any resulting impact on least tern productivity. However, no studies have been conducted to date and thus no data exists that would suggest the fish community within the AHR limits least tern productivity (USFWSa, USFWSb).

Within the Great Plains, abundance and diversity of fish occurring in streams has been shown to decrease with groundwater extractions and flow alterations, especially when desiccation events occur and water temperature rises due to prolonged periods of low flow adversely affect the fish community (Marchetti and Moyle 2001, Falk et al. 2010, Kiernan et al. 2012, Perkin et al. 2014). It is hypothesized that low flows during the nesting season limit prey fish populations, which in turn limits least tern productivity (Figure 1; Wilson et al. 1993, National Research Council 2004, Department of the Interior et al. 2006, Jenniges and Plettner 2008). The Program's Biological Opinion indicates the Program will investigate whether or not the fish community within the AHR provides an adequate forage base for least terns (USFWS 2006).

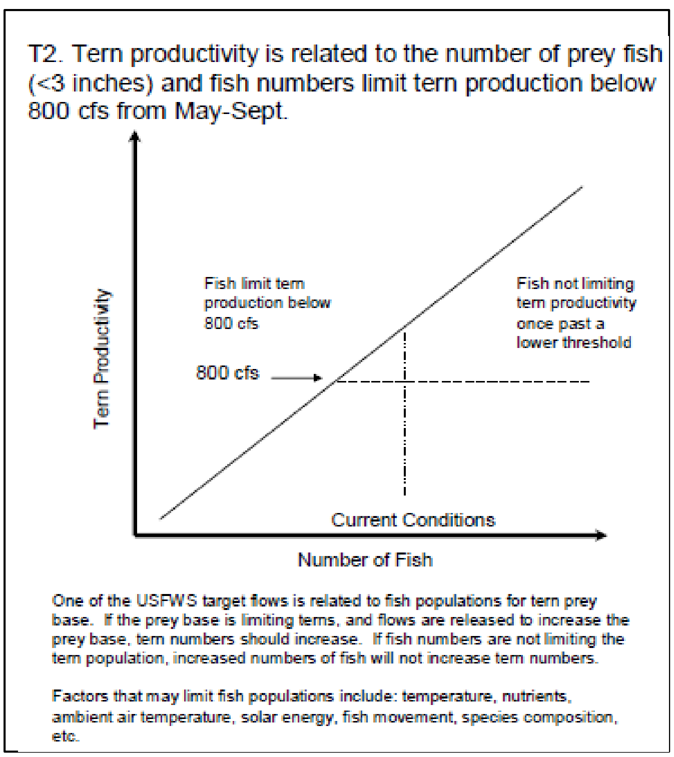

Figure 1. Hypothesized relationships between forage fish abundance and least tern productivity (Priority Hypothesis T2).

Ideally the preferred condition would have been for the Program to develop and implement a targeted research project or conservation monitoring protocol designed to specifically address management objectives and forage-based *a priori* hypotheses (Nichols and Williams 2006) to test if forage availability limits least tern productivity more below 800 cfs than above. Such a study would require extensive fish sampling and handling and weighing least tern chicks on a regular basis. To date, the monetary cost and potential for negative impacts to both least terns and the fish community have not been justified given the paucity of information indicating abundance of appropriate sized forage fish in the Platte River or any riverine system limit least tern productivity (Chadwick 1997). Furthermore, the Program has a limited ability to manage flows in the river and would have great difficulty showing a causative relationship between a decrease in the abundance and diversity of the fish community associated with reductions in flow and least tern productivity. Therefore, in the spirit of Platt's "strong inference" (Platt 1964), which has been used by the Program with other questions related to the application of management actions and species response, a more systematic approach was used.

The Program strives to use all available data in a credible manner to inform Program decision making. Analyses of available forage fish data, discharge records, and data on least tern productivity and behavior on the central Platte River proved to be uninformative and suggested a retrospective analysis might provide insight on certain Program hypotheses. Retrospective analyses can be useful as a "compromise" between expedience and rigor when attempting to develop useful information for decision making (Smith 1998). The objective of this study was to utilize existing data to investigate if the fish community during the nesting and brood rearing season was adequate to support least tern productivity within the AHR. Program priority hypothesis T2 is a syllogism between flow, forage fish availability and least tern productivity. As such, it was hypothesized that decreases in flow, a proxy for forage fish availability, would influence productivity of least terns within the AHR. We used this deductive reasoning to build empirical support to assess the forage fish related hypothesis T2 in the Program's AMP.

Methods

Study Area

The Program surveys an 1,815 km^2 area between Lexington and Chapman, Nebraska USA (hereafter, AHR) for least tern nesting and foraging activity on an annual basis. Least tern nesting and foraging habitat surveyed within the AHR includes a 145 km reach of the central Platte River and off-channel habitat (sand and gravel mines) within approximately 4.8 km of the river (Figure 2).

Flow measurements

We obtained mean daily flow (m^{3}s^{-1}; henceforth, cms) records from United States Geological Survey (USGS) gaging stations on the Platte River near the cities of Overton (06768000), Kearney (06770200) and Grand Island, Nebraska (06770500), 2001–2014. The gage closest to the geographic location of each brood was identified. The flow records were used to calculate minimum and average mean flow for the 7, 14, and 21 days prior to the day when each brood's fate was determined.

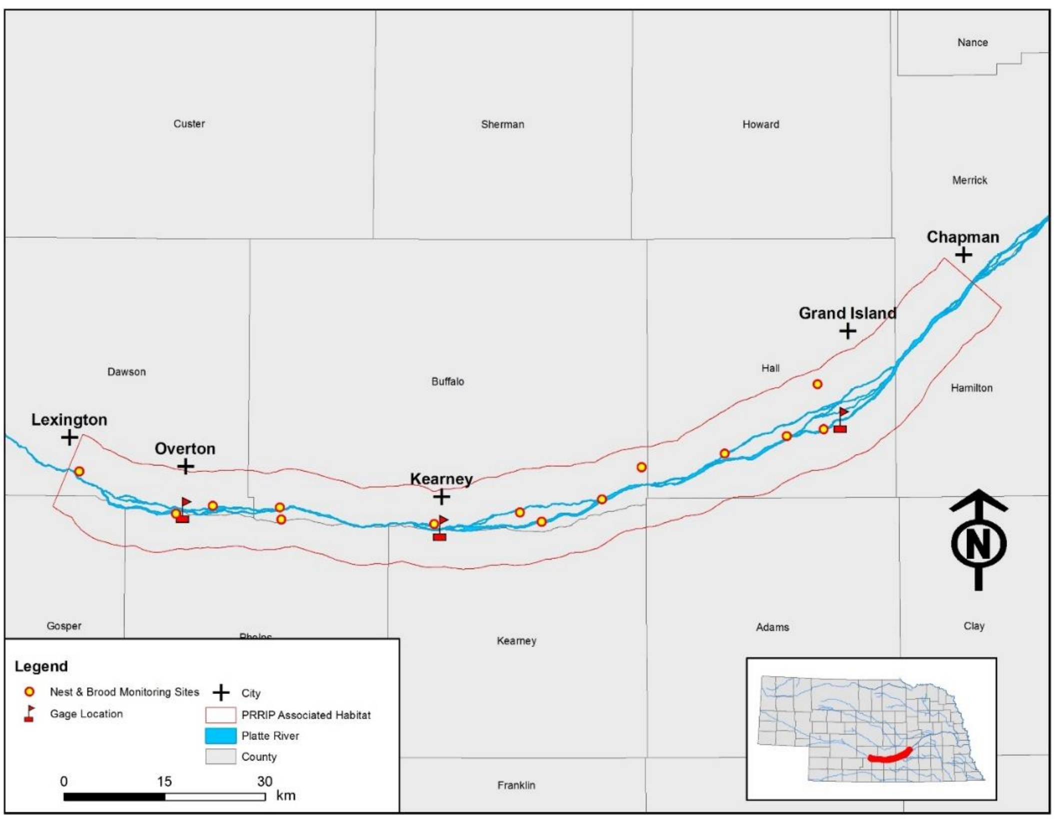

Figure 2. Study area (AHR) showing least tern and piping plover productivity data collection sites and locations of USGS gaging stations used in the analyses.

Least tern productivity model

Given we expected the probability of fledging to be related to flow, we used logistic regression models to relate flow to least tern productivity. An assumption of our logistic regression model was the proportion of fledglings from each brood (b_k) followed a binomial distribution:

$$b_k \sim Binomial\ (C_k, \eta_k),$$

where C_k is the number of chicks hatched from each nest, η_k is the probability a chick fledged from the k^{th} brood (k=1,2,…,457) and whether or not a chick fledged was treated as a binomial trial within each brood. Broods with an unknown fate and broods that failed due to known cause such as flooding, predation and adverse weather events were excluded from the analysis since these failures were not related to forage dynamics. Seven total models were tested in an attempt to establish a relationship between productivity and flow. We assumed the logit of η_k depended on f_k, which was the minimum or average mean daily flow 7, 14, and 21 days prior to the date of fate determination:

$$\text{logit}(\eta_k) = \alpha_1 + \alpha_2 f_k. \quad (2)$$

We also included a model that did not include an influence of flow, which was:

$$\text{logit}(\eta_k) = \alpha_1 \quad (4)$$

We randomly split the data into a training set with 229 observations and test set with 228 observations. We used a generalized linear model and maximum likelihood to obtain parameter estimates using the training data set (Stroup 2012). We calculated the predictive deviance (i.e., –2 times the predictive log likelihood) using the test data. Predictive deviance is a measure of the models predictive ability and has a similar interpretation as Akaike information criterion (AIC; Burnham & Anderson 2002; Hooten & Hobbs 2015). We also calculated and reported AIC scores for comparison.

Results

We observed 977 least tern nests from 2001–2014, of which 546 nests successfully hatched ≥1 chick. Eighty-nine broods failed due to known causes not attributed to forage dynamics. The remaining 457 broods either fledged (n=416) or failed due to unknown causes (n=41). Only the 41 broods that failed to unknown causes were identified as possible forage related failures. Those 457 broods produced 1040 chicks and 830 fledglings (Table 1). Of these broods, 79% had fates determined when the flow was ≤22.65 cms (800 ft^3s^{-1}; cfs) which resulted in 78% of the fledglings observed. During the least tern nesting and brood rearing period, which begins in late May and extends through August, flows were below 22.65 cms in approximately 75% of years and approached 0 cms in 25% of years, 2001–2014 (Figure 3). Overall, 79% of broods included in our analyses were exposed to river discharges below 22.65 cms within 7 days of brood fate determination and 50% of nests were exposed to discharges below 5.80 cms (Figure 4). Discharge during the median nest initiation period only exceeded 22.65 cms in four out of 14 years. There were no apparent differences in fledge ratios when median discharge was less than 22.65 cms (Figure 5) and the fledge ratio exceeded the proposed fledge ratio target of 0.70 in all four years. During the study period, the annual least tern fledge ratio (fledglings/breeding pair, Baasch et al. 2015) ranged from a low of 0.75 (2006) to a high of 1.83 (2001) and averaged 1.19 (Table 2).

Table 1. Proportion of chicks fledged from all broods observed, 2001–2014.

Proportion of Chicks Fledged	Number of Broods	Percent of Broods
0.00	41	9.0%
0.33	20	4.4%
0.50	38	8.3%
0.67	54	11.8%
0.75	1	0.2%
1.00	303	66.3%

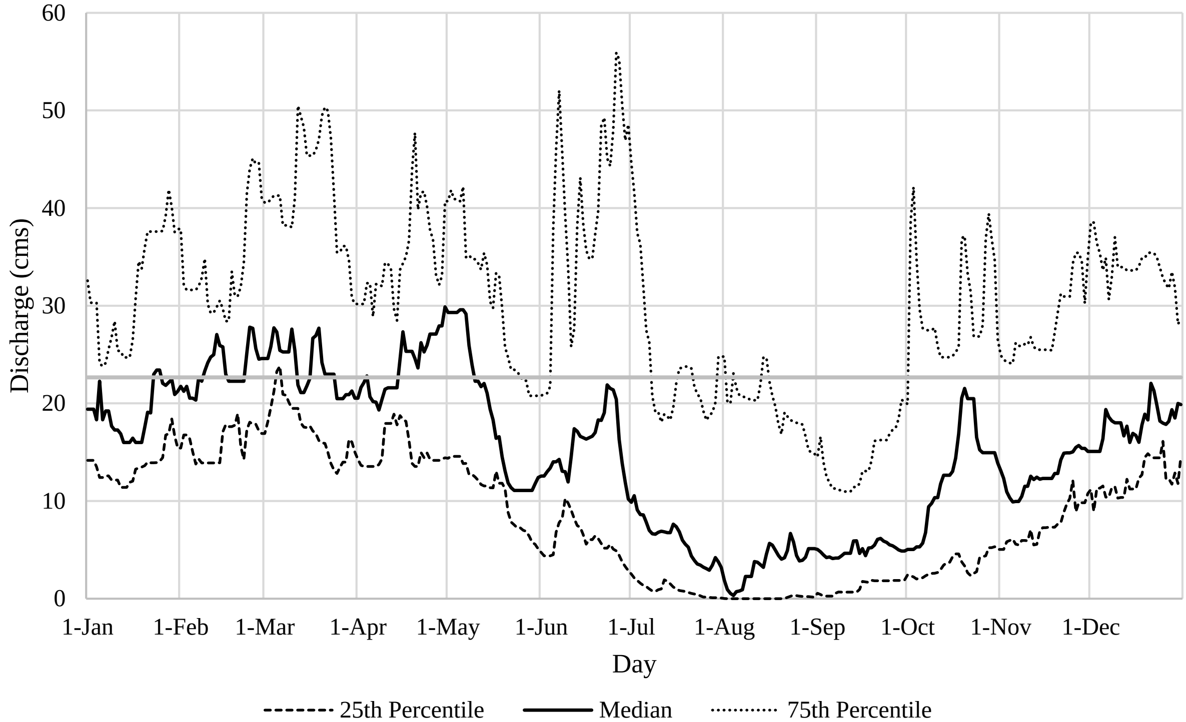

Figure 3. Annual hydrograph at USGS Grand Island stream gage 06770500 in relation to the 22.65 cms discharge (horizontal grey line) hypothesized to limit tern productivity, 2001–2014.

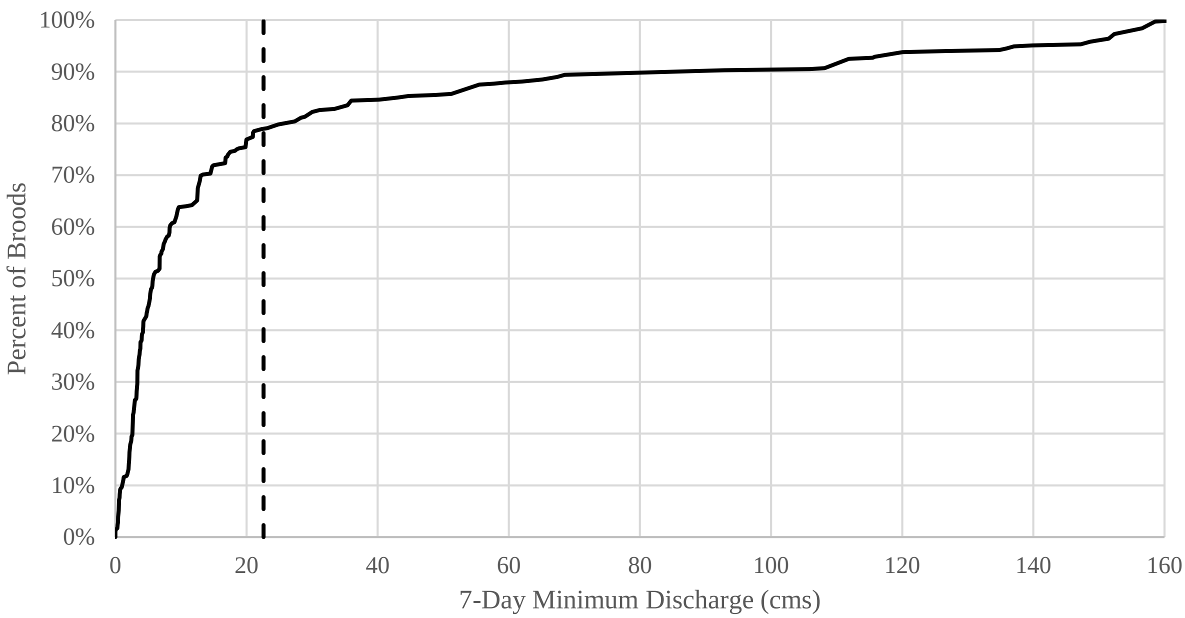

Figure 4. Distribution of 7-day minimum river discharge experienced by broods in relation to 22.65 cms discharge (dashed line) hypothesized to limit tern productivity, 2001–2014.

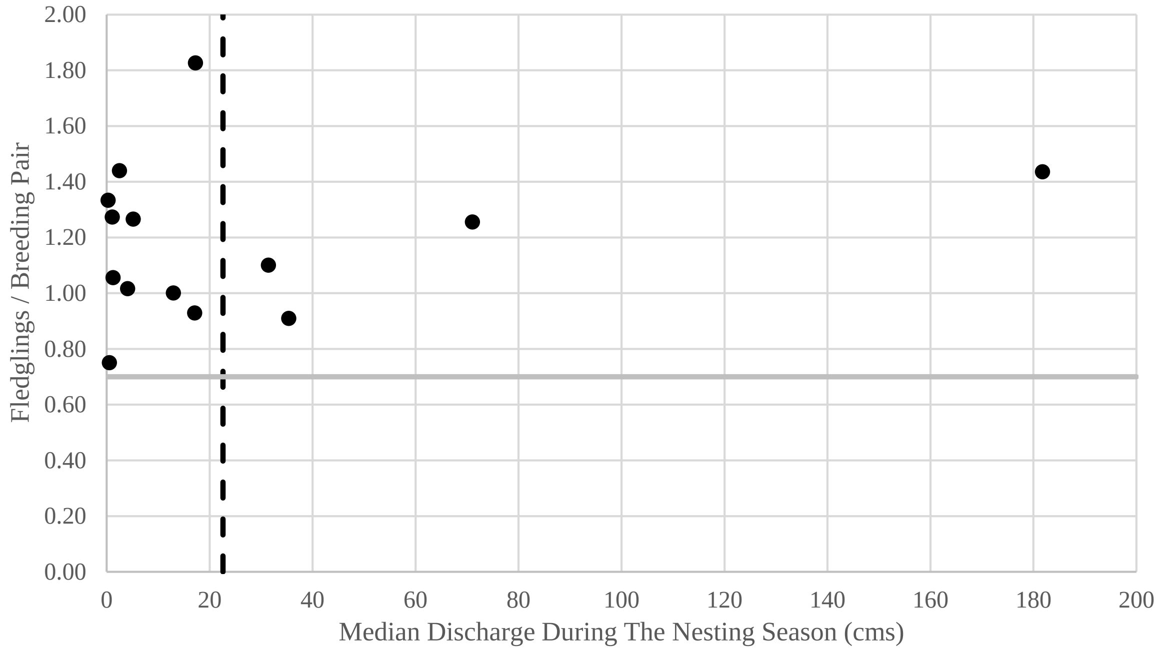

Figure 5. Fledglings per breeding pair in relation to median discharge during the 2001–2014 nesting seasons including the Lutey (2002) fledge ratio objective (grey line) believed to be required to maintain a stable population and 22.65 cms discharge (black dashed line) hypothesized to limit tern productivity.

Table 2. Annual least tern reproductive success within the AHR in relation to median discharge during the nesting season, 2001–2014.

Year	Fledglings	Breeding Pair	Fledglings/ Breeding Pair	Median Discharge Nesting Season (cms)
2001	42	23	1.83	17.3
2002	59	41	1.44	2.5
2003	57	54	1.06	1.3
2004	60	45	1.33	0.3
2005	62	49	1.27	5.2
2006	27	36	0.75	0.6
2007	40	44	0.91	35.4
2008	44	40	1.10	31.4
2009	46	46	1.00	13.0
2010	64	51	1.25	71.1
2011	89	62	1.44	181.8
2012	84	66	1.27	1.1
2013	64	63	1.02	4.1
2014	91	98	0.93	17.1
Average	**59.2**	**51.3**	**1.19**	**27.3**

Table 3. Model selection results for least tern brood survival as ranked by AIC and deviance.

Covariates	Deviance	AIC
Null	420.08	412.23
7-Day Minimum Discharge	419.69	414.00
14-Day Minimum Discharge	419.83	414.06
21-Day Minimum Discharge	419.96	414.00
7-Day Mean Discharge	419.98	414.00
21-Day Mean Discharge	419.86	414.09
14-Day Mean Discharge	420.13	414.20

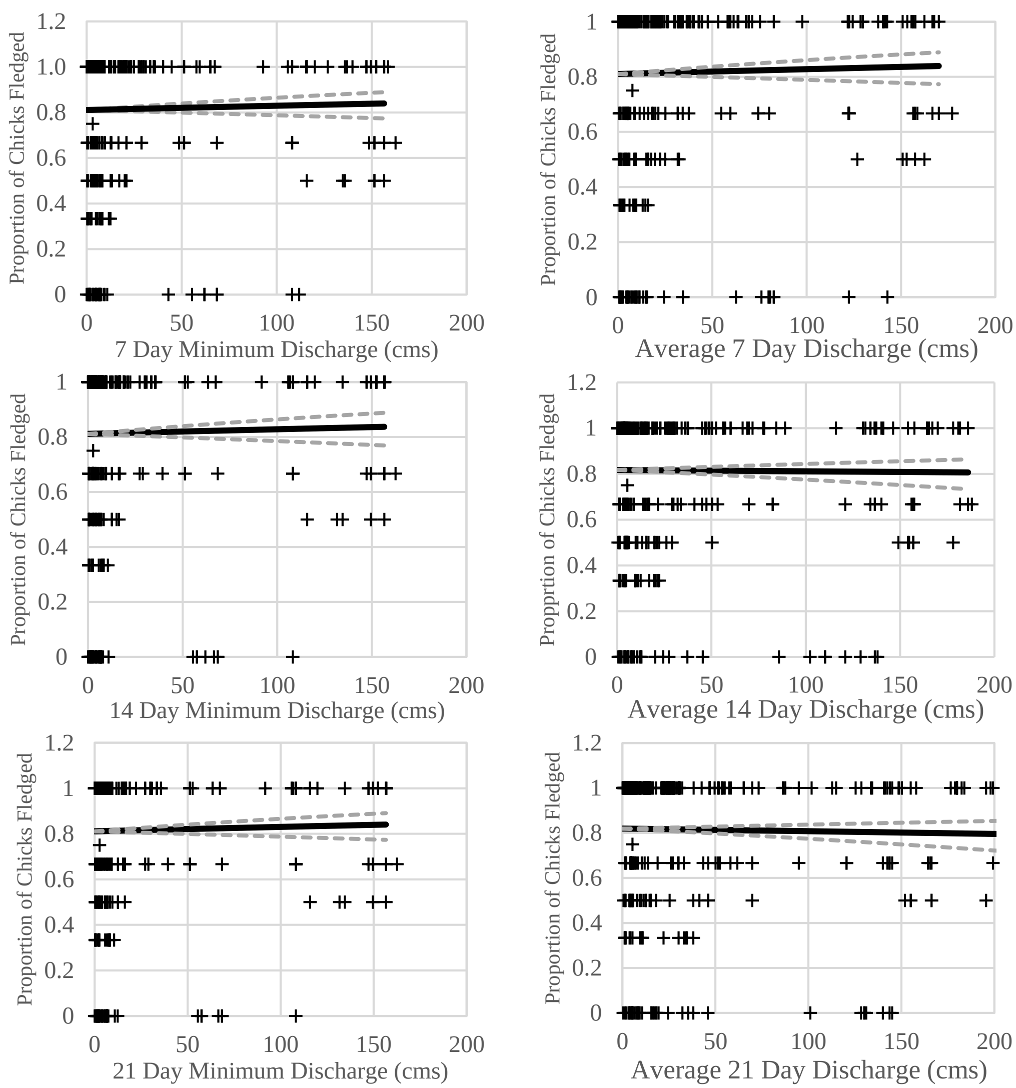

Figure 6. Predicted proportion of fledglings for each brood compared to flow metrics with 95% confidence intervals. The black plus signs (+) show the empirical probabilities of fledging for each brood $(\frac{number\ of\ chicks\ fledged}{number\ of\ chicks\ hatched})$. No flow metric resulted in better predictions of fledging success than the null model, which indicates fledging success is independent of all variables tested.

Discussion

Results of our analyses suggest low flows during the least tern nesting and brood rearing season do not negatively affect productivity, and thus by extension suggest the further conclusion that the fish community is adequate and is not a limiting factor for least tern productivity on the central Platte River. Furthermore, least terns have been observed foraging much further from their nesting area than previously documented, making more forage available to them without any detectible decline in reproductively (Program 2006a, Sherfy et al. 2012). Though indirect, these conclusions are based on critical evaluations of existing data through the lens of Program hypotheses and questions related to least tern reproductive response to management actions. These conclusions are also made in the context of a North American resource management program that incorporates decision making influenced by scientific information, but also by budget, policy, and the constraints of the central Platte River as a social-ecological system.

In any adaptive management program information needs must be evaluated for their importance, assessed for potential negative impacts to the resources of concern, and prioritized by the monetary requirements needed to obtain such information. Our results reflect learning, an important aspect of adaptive management, and the use of retrospective analyses in the application of adaptive management (Smith 1998). This may be a passive approach to adaptive management at best, but the information is credible and provides an updated understanding important for Program decision making (Walters and Holling 1990). Results of our study indicate additional research or targeted monitoring are unlikely to improve the understanding of the relationships between the fish community and least tern productivity to a great degree and will serve only as a "delaying tactic" in a search for scientific consensus that may not be achievable (Ludwig et al. 1993). Results of our retrospective analysis pass the test of "management relevance" (Westgate et al. 2013) and should be used by the Program to adjust management actions accordingly. Such analyses and uses of existing data provide an example of hierarchal methodology useful to other species and/or ecosystem recovery programs when faced with a complicated question. In our case, a very complex hypothesis involving flow, the fish community and least tern productivity was more easily addressed by evaluating the relationship between flow and least tern productivity within the

AHR. As with any syllogism, the formal argument in logic is formed by two statements and a conclusion which must be true if the two statements are true. However, if the conclusion is found to be false, one or both of the syllogistic statements will be equally false. Had we found the conclusion we investigated to be true, the Program would have accepted the hypothesis T2 to be true or further investigation as to the causal effects would have been warranted.

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