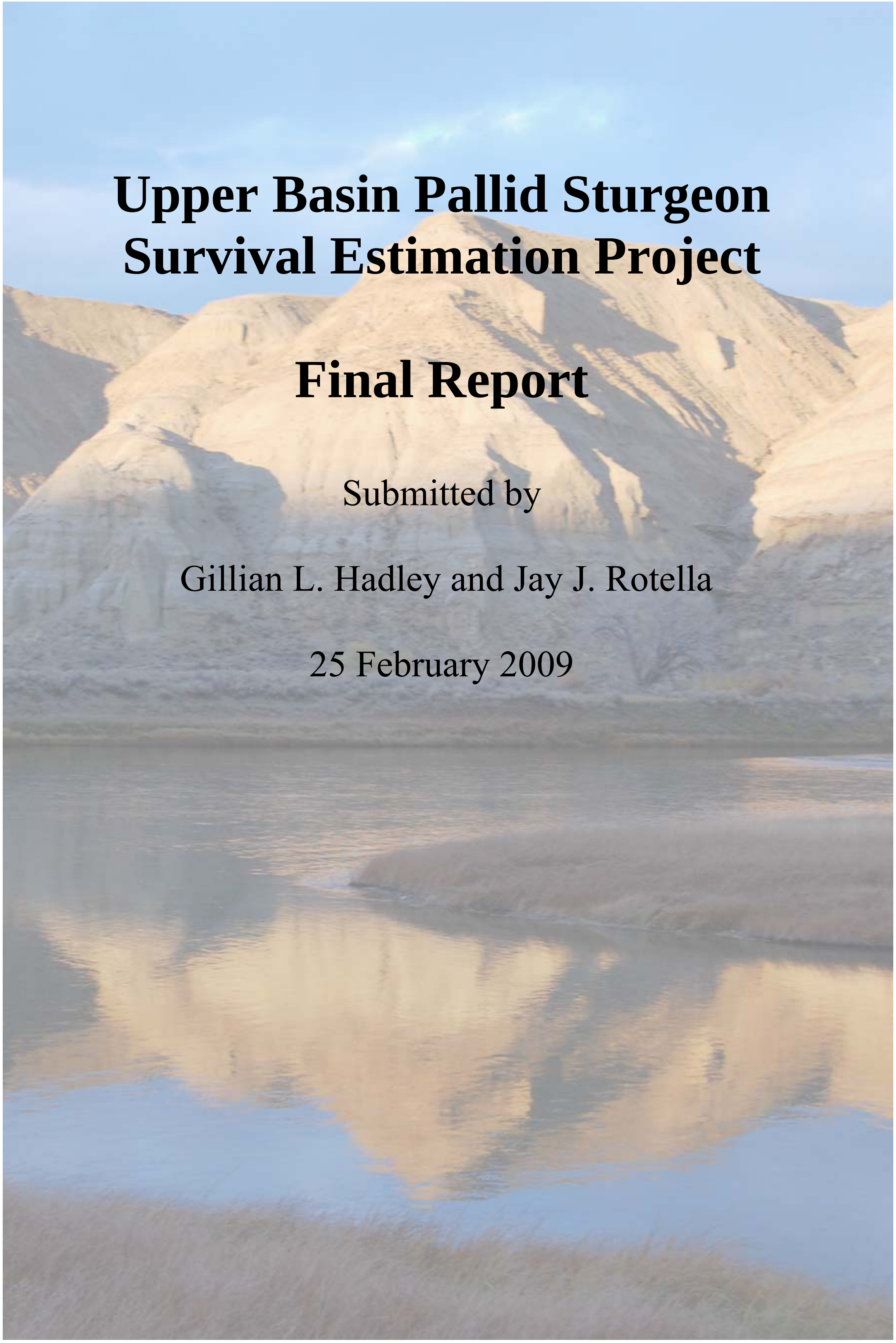

Upper Basin Pallid Sturgeon Survival Estimation Project

Final Report

Submitted by

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Table of Contents

Justification

Currently, pallid sturgeon (*Scaphirhynchus albus*) are listed as endangered under the Endangered Species Act. One component of the Recovery Plan for the species is the artificial propagation and release of pallid sturgeon. Each year, tens to hundreds of thousands of juveniles are propagated in captivity and then released in various locations throughout the Upper Basin according to a stocking and augmentation plan (USFWS 2008). These individuals are considered by the USFWS to be members of the listed species. Thus, there is interest in knowing the contribution of hatchery-origin fish to the population. One key step in measuring that contribution is to estimate the probability that a fish reared in captivity and released into the wild will survive to various ages of interest. The Upper Basin Pallid Sturgeon Recovery Workgroup's 10-Year Strategy recently identified survival estimation for hatchery-reared fish that have been marked and released throughout the Upper Basin Recovery Priority Management Areas (RPMAs) as a high priority item. The Strategy also identified the need to evaluate the efficacy of sampling plans currently in place for the recapture of marked fish throughout the Upper Basin RPMAs, especially the efficacy of recapture sampling plans for achieving rigorous estimates of survival rates of hatchery-reared fish in the wild. The recent 5-year review of Pallid Sturgeon (USFWS 2007: page 61) concluded that data needed for the next 5-year review include: "Survival and growth of stocked juvenile pallid sturgeon and assessment of data to determine the success of supplementation efforts where it is occurring and to develop survival estimates for hatchery-reared pallid sturgeon."

Background

Characteristics of stockings of pallid sturgeon have varied in important ways. Age-at-stocking has varied and there is interest in understanding how survival rate might vary in the wild for fish stocked as fingerlings versus spring yearlings versus summer yearlings. All else being equal, it is desired to release fish at young ages to avoid a variety of complications that can arise as fish remain in hatcheries for longer periods of life (e.g., hatchery habituation and imprinting, artificial selection pressures, crowding problems, disease). However, there may be important tradeoffs that need to be considered if survival rate in the wild is affected by age at stocking. In addition to age, fish have also varied in terms of (1) stocking location and (2) condition at stocking. Fish have been stocked at various locations throughout the Upper Basin (i.e., Missouri vs. Yellowstone rivers), and survival may vary by location. Also, some fish that have been stocked have had iridovirus or fin curl. There is interest in knowing if survival rates are compromised in such fish and, if so, what the reduction in survival rate is. Thus, survival analyses should consider possible sources of variation in survival rate such as age at stocking, stocking location, and fish health condition at time of stocking.

With improved knowledge of survival rates for released fish, stocking rates can be calculated based on population goals for standing adult populations as laid out in stocking plans (USFWS 2008). A crucial part of such calculations is propagating the errors that accompany estimates of survival rate to estimates of how many individuals should be stocked to achieve desired standing adult populations. That is, survival rates are estimated and therefore there is uncertainty associated with the estimates. Thus, there is also uncertainty associated with any calculations of the stocking rates needed to achieve population goals. Given that fact, it is important to consider (1) the efficacy of current sampling methods employed throughout the Upper Basin RPMAs for achieving precise estimates of survival rates, and (2) how sampling methods could be improved to allow improved precision. Finally, a crucial aspect of survival modeling involves choosing estimation methods with reasonable assumptions given the biology of the species and the realities of the sampling protocol used. If assumptions are met, then estimators can be expected to perform well. If, however, some assumptions may not be met, then it is important to consider how estimator performance is affected by violations of assumptions. For example, many methods that can be employed for estimation of survival of marked individuals using live recaptures make the following key assumption: sampling periods are instantaneous (Williams et al. 2002). Although instantaneous sampling is assumed, in reality (1) it is recommended that the duration at least be short and (2) the key issue is not how long the sampling period is: rather, it is the extent to which mortality occurs during the sampling interval. Given that some sampling protocols for pallid sturgeon involve sampling over long periods of time, it is worthwhile to evaluate how sensitive results are to assumption violations and, if problems are identified, to develop improved use of existing data and to make recommendations for improved sampling protocols.

Objectives

Given the above, our objectives for this project were the following:

1. Estimate survival of hatchery-reared pallid sturgeon in Upper Basin RPMAs 1, 2, and 3 using mark-recapture analysis methods to select appropriate models for estimation.
2. Perform simulations to indicate how much survival estimates may be improved by additional recaptures or sampling effort.
3. Comprehensively evaluate Upper Basin marking, stocking, and sampling data to determine how, or if, existing sampling designs should be modified to best estimate survival of hatchery-reared juvenile pallid sturgeon.

Data compilation

In general, the data used in these analyses were not collected with this type of mark-recapture analysis in mind. Thus, significant data editing, manipulation, and culling had to be done before suitable datasets for generating survival estimates could be created. We will attempt to outline here the steps that were necessary in order to use the available mark-recapture records to estimate survival.

1. Designation of mark-recapture occasions

As mentioned above, most survival estimation methods using live recaptures of marked individuals make the following assumption: sampling periods are instantaneous (Williams et al. 2002). Although instantaneous sampling is assumed, in reality (1) it is recommended that the duration at least be short and (2) the key issue is not how long the sampling period is: rather, it is the extent to which mortality occurs during the sampling interval. The recapture records we obtained for pallid sturgeon indicated that recaptures occurred in an ongoing fashion from approximately April through November each year, and were not limited to short, defined recapture periods (this varied depending on the data sources). Thus, we needed to artificially 'create' shorter sampling periods in order to analyze the data, which necessitated using only subsets of the recapture records. We experimented with different approaches and settled on date limits for recaptures for each RPMA (Tables 1a – 1c).

Table 1a. Dates for sampling occasions for RPMA 1.

Sampling Occasion (t)	***Begin***	***End***	***Interval Length (months): (t-1) to t***
1	8/18/1998	8/18/1998	-
2	9/23/1998	10/30/1998	1.80
3	4/13/1999	4/13/1999	6.13
4	8/31/1999	9/21/1999	5.00
5	9/25/2000	9/28/2000	12.73
6	9/25/2001	10/31/2001	12.73
7	7/23/2002	7/23/2002	9.43
8	8/20/2002	9/25/2002	1.53
9	4/8/2003	5/30/2003	7.97
10	8/19/2003	10/17/2003	4.53
11	3/23/2004	5/26/2004	7.33
12	8/20/2004	10/15/2004	4.87
13	3/29/2005	5/25/2005	7.37
14	8/19/2005	11/1/2005	5.07
15	4/13/2006	5/17/2006	7.23
16	8/23/2006	10/25/2006	4.87
17	4/3/2007	5/31/2007	7.37
18	9/24/2007	10/24/2007	5.33

Table 1b. Dates for sampling occasions for RPMA 2.

Sampling Occasion (t)	*Begin*	*End*	*Interval Length (months): (t-1) to t*
1	8/11/1998	8/11/1998	
2	10/11/2000	10/17/2000	26.50
3	7/18/2002	9/18/2002	22.43
4	8/7/2003	8/28/2003	12.13
5	4/13/2004	11/18/2004	11.65
6	4/12/2005	4/12/2005	8.48
7	8/15/2005	11/2/2005	5.47
8	3/28/2006	5/31/2006	7.27
9	7/13/2006	7/13/2006	2.50
10	8/14/2006	11/8/2006	2.50
11	4/3/2007	5/31/2007	7.27
12	8/14/2007	10/31/2007	4.77
13	3/26/2008	5/7/2008	6.90

Table 1c. Dates for sampling occasions for RPMA 3.

Sampling Occasion (t)	*Begin*	*End*	*Interval Length (months): (t-1) to t*
1	06/06/00	09/20/00	-
2	04/21/02	04/27/02	21.13
3	04/10/03	05/07/03	12.13
4	07/26/03	07/26/03	3.13
5	08/14/03	11/18/03	2.23
6	04/15/04	05/19/04	7.13
7	10/06/04	11/01/04	5.67
8	03/13/05	05/26/05	6.07
9	08/30/05	11/08/05	5.60
10	03/30/06	05/17/06	6.70
11	08/25/06	11/14/06	5.47
12	04/01/07	05/09/07	6.60
13	08/15/07	11/01/07	5.20

The above date limits were used because in most cases, they provided roughly two intervals (summer and winter) over which to estimate survival that were as long or longer than the sampling occasions themselves, while still providing enough recapture data to theoretically generate survival estimates with enough precision to be useful for management recommendations. Additional dates were included to encompass all stocking occasions. All stocking occasions had to be included in order to represent the entry into the study population of all fish that were available for recapture.

It is essential to keep in mind that the use of such long sampling occasions potentially violates an important assumption of the method used for estimation of survival from marked individuals (i.e., the assumption of instantaneous sampling, which is important for avoiding creating heterogeneity in survival rates). If the assumption is violated and important levels of mortality occur during the sampling occasion, resulting survival estimates can have reduced accuracy. Further constraining the sampling occasion dates would have resulted in data that were too sparse to generate survival estimates. We chose a compromise solution that may have violated an assumption so that we could obtain estimates that can be used for the purposes of 1) making guarded management recommendations and 2) illustrating the need for changes in sampling design to better estimate survival rates in the future.

2. Generating relevant stocking data and disease data for each recaptured fish

Only recapture data from PIT tagged fish could be used because 1) their prior captures could be tracked, and 2) they had the data available for the covariates of interest in the analysis (i.e., stock/spawn dates in order to calculate age when stocked and date of entry into the study population, year class in order to assess fin curl or iridovirus status). In most cases, the fish we were interested in were PIT tagged because they had been stocked at larger stocking sizes (yearling or older). In general, there were too few recaptures of fish stocked as fry or fingerlings for us to estimate survival for these categories. Some recaptured fish did not have PIT tags (or their PIT tags were not recorded upon recapture) and this prevented use of these recapture records because prior or future captures of the same individual could not be connected into an individual capture history. Second, some PIT tagged fish were missing covariate data, and thus were excluded from the analysis. In some cases, stocking data could be deduced from other marks (i.e., elastomers) and process of elimination using the Stocking History table, but this process was extremely time-consuming.

3. Determination of disease status (fin curl, iridovirus) as covariate for survival

The disease status of individual recaptured fish was not consistently available and further, encounter histories for fish that were stocked but never recaptured could not be broken down into known numbers by disease status. In the end, we used a very simplistic assessment for the disease covariates. If the hatchery and year class from which a given fish originated displayed any infection, that fish was classified as a '1', indicating exposure to the disease in question. For RPMA 1, we had one disease covariate for fin curl. As far as we could tell, no iridovirus-exposed fish had been stocked in RPMA 1. For RPMA 2, we had a covariate for fin curl exposure and a covariate for iridovirus exposure. For RPMA 3, we had one disease covariate only, for iridovirus exposure, as we understood that no fin-curl-exposed fish had been stocked in RPMA 3.

4. Determination of sampling effort as covariate for capture probability

Sampling effort was used as a covariate in the analyses for RPMAs 1 and 3. For RPMA 1, the effort covariate had four parts: 1) total distance (in yards) for trawl nets, 2) total distance for trammel nets, 3) hours fished by setline, and 4) hours fished by angling). For RPMA 3, the effort covariate consisted of three parts: 1) combined total distance for trawl and trammel nets, 2) number of gill nets used, and 3) number of hooks used on set lines. These covariates were used as a measure of sampling effort to help explain variation in capture probability among sampling occasions. This can potentially be a useful way to explain temporal variation in capture probability without requiring the use of a separate model parameter for each sampling occasion. Effort was not used to model capture probability for RPMA 2. Two sampling crews from RPMA 2 recorded sampling effort in the form of total distance sampled, while one crew recorded the total time in minutes of each drift. These could not be combined into a single effort covariate for the entire RPMA.

5. Creation of encounter history files

We compiled a text file of individual fish encounter histories for each RPMA for input into program MARK, the software used for these analyses. The original recaptures file for RPMA 1 included 438 recaptures for 384 fish with PIT tag recorded. Of these, 402 records (350 individuals) contained sufficient data (capture date, hatchery, stock and spawn dates) for inclusion in the analysis. After excluding captures that occurred outside the designated sampling occasion dates, encounter histories for 345 individual fish remained in the final input file. For RPMA 2, the original recapture file included 507 recaptures of 475 individuals with PIT tag recorded. Of these, 375 recaptures of 359 individuals included complete information on capture date, hatchery, and stock and spawn dates, and these were included in the final input file. Lastly, the RPMA 3 recaptures file contained 289 recapture records for 253 individuals with PIT tag recorded. Of these, 233 recaptures (for 205 individual fish) contained complete covariate data and were included in the final input file.

Analysis methods

We estimated apparent annual survival (hereafter survival) and capture probabilities and evaluated the relationships between covariates of interest and survival and capture probabilities for all mark-recapture data sets that were available for pallid sturgeon in Upper Basin RPMAs using Cormack-Jolly-Seber capture-recapture models (Pollock et al. 1990, Lebreton et al. 1992, Williams et al. 2002). All analyses were done using Program MARK (White and Burnham 1999), which is state-of-the-science software for the analysis of mark-recapture data that is freely available and widely used. Apparent survival probability (φ_i) was defined as the probability that a fish alive on occasion i remained available for recapture until occasion i+1 (i.e., survived and did not permanently emigrate from the study area). Detection probability (p_i) was defined as the probability that a fish alive on occasion i that had not permanently emigrated was captured or observed occasion i. We used extensions of the two-age class model described by Lebreton et al. (1992) to model age-related variation in survival and recapture probabilities.

For each data set, we developed a list of candidate models that described variation in survival and recapture probabilities. The model lists followed recommendations of Burnham and Anderson (1998). Each model list was constrained by covariates measured in the field and by the amount of data available. Models included the following covariates: group or stocking category (***g***), age, season (***seas***), stocking river (***river***; MO or YE, for RPMA 2 only), fin curl status (***FC***), iridovirus status (***IV***), sampling effort (***effort***), and sampling occasion (***t***). In some models, a logarithmic or exponential effect was included on age (***LN(age)*** or ***EXP(age)***), to allow for varying rates of increase in p with increasing age.

For each data set, we evaluated goodness of fit (GOF) of the most general model that did not include individual covariates using methods provided in MARK (White et al.

2001). Because individual covariates (age, river of stocking, disease status) could not be included in models for GOF testing, the relevant input files were altered to account for variables such as river of stocking, fin curl, and iridovirus with groups rather than individual covariates. Also, a time trend model that allowed survival and capture probabilities to increase on each occasion was used to approximate the effect that age would have on these rates. The bootstrap GOF procedure was used for each data set, and the resulting estimate of overdispersion for each data set was then used to adjust AIC_c values ($QAIC_c$; Burnham and Anderson 1998). For each data set, we considered the best-approximating models from each candidate set (lowest $QAIC_c$ values). We evaluated the relative plausibility of each model by examining differences between the $QAIC_c$ value for the best model and values for every other model (ΔQAICc) and by comparing Akaike model weights (w_i; Burnham and Anderson 1998). Estimates of survival from the best model were used to predict the number of released fish that survived from initial release to each subsequent age, with the number of ages considered dictated by the specifics of each dataset with respect to age-at-release and number of years studied subsequent to the release. Confidence limits were developed for all estimates using either Program MARK directly or, for estimates of fish numbers alive at various ages, the delta method (Seber 1973) in the statistical analysis program R (R Development Core Team 2008).

Results – RPMA 1 – Headwaters of Fort Peck Reservoir upstream to the Marias River

1. Data Availability

The following 2 tables illustrate the amount of data available for this analysis. To obtain unbiased, reasonably precise estimates of survival probability, the recaptures would ideally be more distributed among occasions and there would be a higher recovery rate than 104/9858 (= 1.05%) for spring yearlings and 186/6257 (= 2.97%) for summer yearlings (see *Recommendations*).

Table 2a. Spring yearlings released in RPMA 1 on each of 17 occasions (including those released after recapture), and the number that were eventually recaptured on each subsequent occasion.

Release Occ.	# released	Number of recaptures on each occasion																	Total
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0					0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0						0	0	0	0	0	0	0	0	0	0	0	0	0
7	0							0	0	0	0	0	0	0	0	0	0	0	0
8	0								0	0	0	0	0	0	0	0	0	0	0
9	0									0	0	0	0	0	0	0	0	0	0
10	0										0	0	0	0	0	0	0	0	0
11	0											0	0	0	0	0	0	0	0
12	0												0	0	0	0	0	0	0
13	521													0	0	0	0	1	1
14	0														0	0	0	0	0
15	4737															26	39	26	91
16	26																1	0	1
17	4574																	11	11
Total	9858																		104

Table 2b. Summer yearlings released in RPMA 1 on each of 17 occasions(including those released after recapture), and the number that were eventually recaptured on each subsequent occasion.

Release Occ.	# released	Number of recaptures on each occasion																	Total
		2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
1	733	3	1	2	3	5	0	8	10	6	31	9	19	5	8	8	13	11	142
2	3		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	1			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	2				0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	3					0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	5						0	0	0	0	0	0	0	0	0	0	0	0	0
7	2058							5	0	2	0	0	0	0	0	1	0	0	8
8	13								0	0	2	0	0	0	0	0	0	0	2
9	10									0	1	0	0	0	0	0	0	0	1
10	8										0	0	0	0	0	1	0	0	1
11	34											1	0	1	1	1	2	0	6
12	3123												10	1	0	0	1	1	13
13	29													0	2	1	0	2	5
14	192														1	1	2	0	4
15	12															0	0	1	1
16	13																0	2	2
17	18																	1	1
Total	6257																		186

2. *Goodness of fit*

Using the fully group-specific model (to account for all stocking ages and fin curl status) with a time trend to approximate the age effect ($\phi(g+T)p(g+T)$), and the bootstrap goodness-of-fit (GOF) procedure available in program MARK, we estimated an overdispersion coefficient ($\hat{c}$) of 1.22. This value was used to convert AIC_c values to $QAIC_c$ values and adjust the model rankings accordingly.

3. *Model Results*

The model most supported by the RPMA 1 recapture data (model weight = 0.22) used the following covariates (the estimated effect size for each covariate is presented in Table 3):

Survival rate:

1) Stock category (spring yearling or summer yearling)
2) Age (with a different slope for fish in each stock category)
3) Fin Curl (with a different slope for each stock category)

Capture probability:

1) Sampling occasion

Table 3. Estimated effect sizes (betas) for each of the model parameters in the most-supported model, with standard errors and 95% confidence intervals.

Parameter	*Beta*	*SE*	*95% LCL*	*95% UCL*
***Phi* (Survival probability)**				
Intercept - Summer yearlings without fin curl	1.680	0.978	-0.236	3.596
Intercept adjustment - spring yearlings	-9.562	2.463	-14.389	-4.735
Age (spring yearlings)	0.029	0.007	0.014	0.043
Age (summer yearlings)	0.004	0.001	0.001	0.006
Intercept adjustment - Fin Curl (spring yearlings)	0.613	0.164	0.291	0.935
Intercept adjustment - Fin Curl (summer yearlings)	-2.708	0.441	-3.573	-1.844
***p* (Capture probability)**				
Intercept (sampling occasion 18)	-3.397	0.274	-3.935	-2.859
Intercept adjustment for sampling occasion 2	-2.034	0.689	-3.385	-0.683
Intercept adjustment for sampling occasion 3	-2.959	1.129	-5.171	-0.746
Intercept adjustment for sampling occasion 4	-2.192	0.813	-3.785	-0.599
Intercept adjustment for sampling occasion 5	-1.682	0.673	-3.000	-0.363
Intercept adjustment for sampling occasion 6	-1.143	0.537	-2.196	-0.090
Intercept adjustment for sampling occasion 7	0.000	0.000	0.000	0.000
Intercept adjustment for sampling occasion 8	-1.312	0.391	-2.078	-0.547
Intercept adjustment for sampling occasion 9	-0.509	0.410	-1.313	0.294
Intercept adjustment for sampling occasion 10	-0.696	0.444	-1.566	0.174
Intercept adjustment for sampling occasion 11	0.828	0.284	0.272	1.385
Intercept adjustment for sampling occasion 12	-0.445	0.408	-1.244	0.354
Intercept adjustment for sampling occasion 13	0.390	0.307	-0.212	0.991
Intercept adjustment for sampling occasion 14	-0.949	0.466	-1.862	-0.036
Intercept adjustment for sampling occasion 15	-0.353	0.379	-1.095	0.389
Intercept adjustment for sampling occasion 16	-0.220	0.238	-0.687	0.246
Intercept adjustment for sampling occasion 17	0.220	0.215	-0.202	0.643

The intercept adjustment for spring yearling phi was negative for fish released as spring yearlings relative to summer yearlings. However, interpreting this difference does not make sense without first accounting for age because survival rates for each stocking category were estimated over a different range of ages. The beta for age was positive for both groups, indicating increasing survival probability with increasing age. Fin curl exposure was estimated to have a negative effect on summer yearlings, as would be expected. However, the effect of fin curl exposure on spring yearlings was estimated to be positive. It is important to keep in mind that the ‘fin curl exposure’ covariate only indicates whether a fish was from a hatchery and year class that showed any evidence of fin curl, not whether a particular fish showed evidence of infection. Data for spring yearlings exposed to fin curl was entirely from the 2005 year class, which was rated very low in terms of fin curl severity (Matt Toner, pers. comm.), perhaps partially explaining this incongruous result. Further, the fin-curl-exposed fish in this release came from the Bozeman fish hatchery, and were much bigger than fish without fin curl released from other hatcheries (Bill Gardner, pers. comm.). The size discrepancy between fish with and without fin curl exposure may explain the positive effect of fin curl exposure we estimated for spring yearlings – the fin curl effect is confounded with hatchery-related differences in fish size.

Variation in capture probability in RPMA 1 was best explained by sampling occasion alone. The intercept represents the beta estimate for capture probability on sampling occasion 18 (Fall 2007), and the remaining estimates are adjustments to that estimate. Sampling occasion 7 (July 2002) was fixed = 0 because only stocking, not sampling, took place on that occasion. Sampling occasions 2 through 10 (Fall 1998 through Fall 2003) all have a negative adjustment to the intercept, indicating low capture probabilities relative to the intercept (Fall 2007). The remaining sampling occasions fluctuate from positive to negative, relative to the intercept.

The beta estimates in Table 3 can be translated into monthly and annual survival probabilities and occasion-specific capture probabilities, following an example provided for RPMA 2 on page 16. Tables 4 and 5 summarize the resulting survival and capture probabilities for RPMA 1. Detailed results for each stocking category/fin curl combination may be found in the Appendix. Full model sets and results for models other than the best model (including beta estimates) will be made available via downloadable files on the internet (http://www.montana.edu/rotella/sturgeon).

Table 4. Comparison of estimated annual survival rates and standard errors (SE) for hatchery-reared juvenile pallid sturgeon released as spring yearlings (release age of 283-289 days for this example) and summer yearlings (release age of 392-407 days) with and without fin curl. Rates are for 1, 2, and 3 years post-release. In some cases, data were not available to extrapolate beyond 2 year post-release.

Yrs. post-release	Annual survival estimate	SE	95% LCL	95% UCL
Spring Yearlings				
0-1	0.05	0.02	0.01	0.08
1-2	1.00	0.00	0.99	1.00
2-3	-	-	-	-
Spring Yearlings with Fin Curl				
0-1	0.21	0.06	0.10	0.32
1-2	-	-	-	-
2-3	-	-	-	-
Summer Yearlings				
0-1	0.74	0.11	0.53	0.95
1-2	0.90	0.04	0.82	0.99
2-3	0.97	0.02	0.93	1.00
Summer Yearlings with Fin Curl				
0-1	0.01	0.01	0.00	0.02
1-2	0.26	0.12	0.02	0.50
2-3	0.70	0.20	0.30	1.00

Table 5. Capture probabilities estimated from the top-ranked model. No sampling occurred on occasion 7 and capture probability was fixed to 0.

Occasion	*p*	SE(*p*)
2	0.004	0.003
3	0.002	0.002
4	0.004	0.003
5	0.006	0.004
6	0.011	0.006
7	0.000	0.000
8	0.009	0.003
9	0.020	0.008
10	0.016	0.007
11	0.071	0.019
12	0.021	0.008
13	0.047	0.013
14	0.013	0.006
15	0.023	0.008
16	0.026	0.007
17	0.040	0.010
18	0.032	0.009

Results – RPMA 2 – Missouri River below Fort Peck dam to the headwaters of Lake Sakakawea and the lower Yellowstone River

1. *Data Availability*

The following 3 tables illustrate the amount of data available for this analysis. To obtain unbiased, reasonably precise estimates of survival probability, the recaptures would ideally be more distributed among occasions and there would be a higher overall recovery rate than 90/68,072 (= 0.13%) for fingerlings, 88/11,674 (= 0.88%) for spring yearlings, and 91/11,630 (= 0.82%) for summer yearlings.

Table 6a. Fingerlings released in RPMA 2 on each of 13 occasions (including those released after recapture), and the number that were eventually recaptured on each subsequent occasion.

Release Occ.	# released	Number of recaptures on each occasion												Total
		2	3	4	5	6	7	8	9	10	11	12	13	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0		0	0	0	0	0	0	0	0	0	0	0	0
3	0			0	0	0	0	0	0	0	0	0	0	0
4	0				0	0	0	0	0	0	0	0	0	0
5	16809					0	0	0	0	1	0	1	0	2
6	0						0	0	0	0	0	0	0	0
7	10853							1	0	8	3	19	0	31
8	1								0	1	0	0	0	1
9	0									0	0	0	0	0
10	4937										1	55	0	56
11	4											0	0	0
12	35468												0	0
Total	68072													90

Table 6b. Spring yearlings released in RPMA 2 on each of 13 occasions (including those released after recapture), and the number that were eventually recaptured on each subsequent occasion.

Release Occ.	# released	Number of recaptures on each occasion												Total
		2	3	4	5	6	7	8	9	10	11	12	13	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0		0	0	0	0	0	0	0	0	0	0	0	0
3	0			0	0	0	0	0	0	0	0	0	0	0
4	0				0	0	0	0	0	0	0	0	0	0
5	821					0	0	1	0	0	0	1	0	2
6	868						0	0	0	1	0	0	0	1
7	1							1	0	0	0	0	0	1
8	6646								0	32	2	24	0	58
9	0									0	0	0	0	0
10	33										0	2	0	2
11	3258											37	2	39
12	64												0	0
Total	11691													103

Table 6c. Summer yearlings released in RPMA 2 on each of 13 occasions (including those released after recapture), and the number that were eventually recaptured on each subsequent occasion.

Release Occ.	# released	Number of recaptures on each occasion												Total
		2	3	4	5	6	7	8	9	10	11	12	13	
1	780	0	0	0	0	0	1	1	0	2	0	1	0	5
2	478		0	0	0	0	0	0	0	0	0	1	0	1
3	3060			0	0	0	2	0	0	4	3	9	0	18
4	3987				0	0	1	1	0	6	0	10	0	18
5	1646					0	3	0	0	8	0	3	0	14
6	0						0	0	0	0	0	0	0	0
7	232							1	0	0	1	0	0	2
8	3								0	0	0	0	0	0
9	1364									29	0	7	0	36
10	49										0	1	0	1
11	4											0	0	0
12	32												0	0
Total	11635													95

2. *Goodness of fit*

Using a model that most closely resembled the most parameterized model in our model set ($\phi(g+T)p(g+T)$) and the bootstrap goodness-of-fit (GOF) procedure available in program MARK, we estimated an overdispersion coefficient ($\hat{c}$) of 1.88. This value was used to convert AIC_c values to $QAIC_c$ values and adjust the model rankings accordingly.

6. *Model results*

The model most supported by the RPMA 2 recapture data (model weight = 0.40) used the following covariates (the estimated effect size for each covariate is presented in Table 7):

Survival:

1) Stock category (fingerling, spring yearling, or summer yearling)
2) Age (with a different slope for each stock category)
3) River of stocking (Missouri or Yellowstone)
4) Iridovirus (fingerlings only)
5) Fin Curl (all stock categories)

Capture probability:

1) Season (Spring vs. Fall sampling occasion)
2) Age (same slope for all stock categories)
3) River of stocking (Missouri or Yellowstone)

Table 7. Estimated effect sizes (betas) for each of the model parameters in the most-supported model, with standard errors and 95% confidence intervals.

Parameter	*Beta*	*Standard error*	*95% LCL*	*95% UCL*
***Phi* (Survival probability)**				
Intercept - Summer yearlings -Yellowstone	0.108	0.550	-0.971	1.187
Intercept adjustment for fingerlings	0.255	0.881	-1.472	1.983
Intercept adjustment for spring yearlings	-1.286	0.884	-3.019	0.446
Age (fingerlings)	0.006	0.005	-0.003	0.015
Age (spring yearlings)	0.007	0.002	0.003	0.012
Age (summer yearlings)	0.003	0.001	0.001	0.005
Intercept adjustment for Missouri	0.797	0.340	0.130	1.463
Intercept adjustment for Iridovirus (fingerlings)	-1.178	0.246	-1.660	-0.696
Intercept adjustment for Fin Curl	-1.511	0.484	-2.460	-0.562
***p* (Capture probability)**				
Intercept – Spring/Summer season - Missouri	-5.654	0.407	-6.451	-4.856
Offset for Spring season	-3.212	0.457	-4.108	-2.316
Age	0.001	0.000	0.000	0.001
Offset for Yellowstone	2.885	0.500	1.906	3.865

Adjustments to the intercept for fingerlings and spring yearlings are not sensibly interpreted alone (i.e., without incorporating the age effect) because each stocking category includes a different range of ages over which survival rate is estimated. Age effects for all three stocking categories were positive, indicating increasing rate of survival with increasing age. The intercept adjustment for the Missouri River was positive, indicating higher survival probability for fish stocked there. Effects of both iridovirus and fin curl were negative, decreasing survival relative to the intercept. For capture probability, occasions in the spring had a negative adjustment from the intercept (fall occasions). The Yellowstone River had a positive adjustment to the intercept (Missouri River), indicating higher capture probabilities for fish stocked there. Keep in mind that we were estimating survival and capture probability differences between fish *stocked* in the Missouri versus the Yellowstone, rather than between fish *captured* in the Missouri vs. the Yellowstone. With regard to capture probability, we feel that because most captures that occur in the Yellowstone are of fish that were stocked there, the results do suggest higher capture probabilities for the Yellowstone River. As with survival probabilities, all age effects on capture probabilities were positive, indicating increasing rates of capture with increasing age.

Below we provide survival estimates for fish stocked in RPMA 2 for various stocking categories (fingerling, spring yearling, summer yearling) and disease status (iridovirus, fin curl, neither). These survival estimates were generated through the following process (using spring yearlings without fin curl stocked in the Missouri River as an example):

1) Monthly survival estimates were calculated from the top-ranked model, using the coefficients in Table 7. The survival portion of the original model:

Survival (stock cat + age + river + iridovirus (fingerlings only) + fin curl) became the following because we were interested specifically in spring yearlings without fin curl stocked in the Missouri River:

Survival (stock cat + age + river)

2) The model was converted to a regression equation with coefficients from Table 7, using the logit link function:
*logit(Survival) = Survival intercept + adjustment for spring yearlings + (age slope for spring yearlings****AGE****)+ adjustment for Missouri River*

3) Because the first spring yearlings without fin curl exposure released in RPMA 2 were released on occasion 5 at an age of 295 days, we used an initial AGE value of 295. The calculation for interval-specific monthly survival rate for the first interval then became:

$$logit(Survival) = 0.108 + (-1.286) + (0.007*(295)) + 0.797$$

4) To obtain survival, rather than logit(Survival), Program MARK back-transformed the regression equation to:

$$Survival = \frac{e^{(0.108 + (-1.286) + (0.007*(295)) + 0.797)}}{1 + e^{(0.108 + (-1.286) + (0.007*(295)) + 0.797)}} = 0.843$$

5) Thus, monthly survival probability during the interval from occasion 5 to occasion 6 was 0.843 for spring yearlings stocked in the Missouri River with no exposure to iridovirus or fin curl. This rate was then exponentiated to the number of months in this interval (8.48) to obtain survival probability over the entire interval:

$$Interval\text{-}specific\ survival = 0.843^{(8.48)} = 0.24$$

6) To obtain an annual survival rate for the first year post-release, the above process is repeated for the 2nd interval, arriving at a monthly survival probability of 0.97. The survival probability for the 1st interval (0.24) is multiplied by the survival probability for the remaining months (12 months – 8.48 = 3.52) in the 1st year ($0.97^{3.52} = 0.90$). Thus we arrive at 0.22 (0.24 * 0.90) for an annual survival rate in the first year post-release for Spring Yearlings released into the Missouri (see Table 8).

Table 8 summarizes the survival rates for RPMA 2, with detailed results for each stocking category/stocking river/disease combination available in the Appendix. Capture probabilities for both Missouri and Yellowstone rivers are provided in Table 9 for an example starting age of 420 days. Full model sets and results for models other than the best model (including beta estimates) will be made available via downloadable files on the internet (http://www.montana.edu/rotella/sturgeon).

Table 8. Comparison of estimated annual survival rates and standard errors (SE) for hatchery-reared juvenile pallid sturgeon released in RPMA 2 as fingerlings (release age of 77-82 days for this example), spring yearlings (release age of 278-295 days), and summer yearlings (release age of 407-420 days). Rates are provided for releases into the Yellowstone (YE) and Missouri (MO) rivers, and for fish with and without fin curl and iridovirus (fingerlings only). Rates are for 1, 2, and 3 years post-release. In some cases, available data did not allow extrapolation beyond 2 years post-release.

Yrs. post release	Yellowstone				Missouri			
	Annual survival estimate	SE	95% LCL	95% UCL	Annual survival estimate	SE	95% LCL	95% UCL
Fingerlings								
0-1	0.05	0.04	0.00	0.13	0.22	0.10	0.02	0.43
1-2	0.67	0.36	0.00	1.00	0.83	0.24	0.37	1.00
2-3	-	-	-	-	-	-	-	-
Fingerlings with fin curl								
0-1	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.02
1-2	0.18	0.42	0.00	1.00	0.45	0.57	0.00	1.00
2-3	-	-	-	-	-	-	-	-
Fingerlings with iridovirus								
0-1	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.04
1-2	0.27	0.40	0.00	1.00	0.54	0.45	0.00	1.00
2-3	0.88	0.35	0.19	1.00	0.94	0.18	0.58	1.00
Spring Yearlings								
0-1	0.05	0.03	0.00	0.10	0.22	0.11	0.01	0.43
1-2	0.75	0.13	0.49	1.00	0.88	0.09	0.70	1.00
2-3	0.97	0.04	0.90	1.00	0.99	0.01	0.96	1.00
Spring Yearlings with fin curl								
0-1	0.00	0.00	0.00	0.00	0.01	0.02	0.00	0.06
1-2	0.32	0.3	0.00	0.91	0.59	0.28	0.03	1.00
2-3	-	-	-	-	-	-	-	-
Summer Yearlings								
0-1	0.09	0.02	0.05	0.13	0.31	0.12	0.09	0.54
1-2	0.41	0.09	0.24	0.58	0.66	0.13	0.41	0.91
2-3	0.74	0.13	0.48	1	0.87	0.09	0.69	1
Summer Yearlings with fin curl								
0-1	0.00	0.00	0.00	0.00	-	-	-	-
1-2	0.03	0.05	0.00	0.12	-	-	-	-
2-3	-	-	-	-	-	-	-	-

Table 9. Capture probabilities for summer yearlings (release age = 420 days) released in the Missouri and Yellowstone rivers. Estimates were generated from the top-ranked model. No sampling occurred on occasions 2 through 6 and occasion 9, and these capture probabilities were fixed to 0.

Occasion	*p* (Missouri)	SE(*p*)	*p* (Yellowstone)	SE(*p*)
2	0.000	0.000	0.000	0.000
3	0.000	0.000	0.000	0.000
4	0.000	0.000	0.000	0.000
5	0.000	0.000	0.000	0.000
6	0.000	0.000	0.000	0.000
7	0.028	0.027	0.337	0.167
8	0.001	0.001	0.023	0.017
9	0.000	0.000	0.000	0.000
10	0.035	0.037	0.397	0.204
11	0.002	0.002	0.030	0.025
12	0.045	0.052	0.458	0.238
13	0.002	0.002	0.038	0.034

Results – RPMA 3 – Missouri River below Fort Randall Dam to the Lewis and Clark Lake (South Dakota/Nebraska border).

1. *Data Availability*

The following 4 tables illustrate the amount of data available for this analysis. Overall recovery rate was 19/1167 (= 1.63%) for spring yearlings, 60/3030 (= 1.98%) for summer yearlings, 5/103 (= 4.85%) for 2-year-olds, and 41/656 (= 6.25%) for 3-year-olds. To obtain unbiased, reasonably precise estimates of survival probability, the recaptures would ideally be more distributed among occasions and there would be a higher overall recovery rate.

Table 10a. Spring yearlings released in RPMA 3 on each of 13 occasions (including those released after recapture), and the number that were eventually recaptured on each subsequent occasion.

Release Occ.	# released	Number of recaptures on each occasion												Total
		2	3	4	5	6	7	8	9	10	11	12	13	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	558		0	0	2	1	0	0	1	2	1	2	2	11
3	0			0	0	0	0	0	0	0	0	0	0	0
4	0				0	0	0	0	0	0	0	0	0	0
5	2					0	0	0	0	0	0	0	0	0
6	1						0	0	0	0	0	0	0	0
7	0							0	0	0	0	0	0	0
8	0								0	0	0	0	0	0
9	1									0	0	0	0	0
10	2										0	0	0	0
11	1											0	0	0
12	602												8	8
Total	1167													19

Table 10b. Summer yearlings released in RPMA 3 on each of 13 occasions (including those released after recapture), and number eventually recaptured on each occasion.

Release Occ.	# released	Number of recaptures on each occasion												Total
		2	3	4	5	6	7	8	9	10	11	12	13	
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0		0	0	0	0	0	0	0	0	0	0	0	0
3	0			0	0	0	0	0	0	0	0	0	0	0
4	601				1	1	3	1	4	2	3	7	3	25
5	1					0	0	0	0	0	0	0	0	0
6	1						0	0	0	0	0	0	0	0
7	518							0	5	0	1	8	3	17
8	1								0	0	0	0	0	0
9	877									3	1	1	8	13
10	5										0	0	0	0
11	1010											0	5	5
12	16												0	0
Total	3030													60

Table 10c. Two-year-old fish released in RPMA 3 on each of 13 occasions (including those released after recapture), and the number that were eventually recaptured on each subsequent occasion.

Release Occ.	# released	Number of recaptures on each occasion												Total
		2	3	4	5	6	7	8	9	10	11	12	13	
1	98	0	0	0	1	1	1	0	1	0	0	1	0	5
2	0		0	0	0	0	0	0	0	0	0	0	0	0
3	0			0	0	0	0	0	0	0	0	0	0	0
4	0				0	0	0	0	0	0	0	0	0	0
5	1					0	0	0	0	0	0	0	0	0
6	1						0	0	0	0	0	0	0	0
7	1							0	0	0	0	0	0	0
8	0								0	0	0	0	0	0
9	1									0	0	0	0	0
10	0										0	0	0	0
11	0											0	0	0
12	1												0	0
Total	103													5

Table 10d. Three-year-old fish released in RPMA 3 on each of 13 occasions (including those released after recapture), and the number that were eventually recaptured on each subsequent occasion.

Release Occ.	# released	Number of recaptures on each occasion												Total
		2	3	4	5	6	7	8	9	10	11	12	13	
1	438	0	3	0	8	5	0	1	2	0	2	2	4	27
2	181		2	0	5	2	1	1	0	0	1	0	0	12
3	5			0	0	0	0	0	0	0	0	0	0	0
4	0				0	0	0	0	0	0	0	0	0	0
5	13					0	0	1	0	0	0	0	0	1
6	7						0	0	0	0	0	0	0	0
7	1							0	0	0	0	0	0	0
8	3								0	0	1	0	0	1
9	2									0	0	0	0	0
10	0										0	0	0	0
11	4											0	0	0
12	2												0	0
Total	656													41

2. Goodness of fit

Using a model that most closely resembled the most parameterized model in our model set ($\phi(g+T)p(g+T)$) and the bootstrap goodness-of-fit (GOF) procedure available in program MARK, we estimated an overdispersion coefficient ($\hat{c}$) of 0.98. Because this value was so close to 1, we did not correct the model rankings for overdispersion.

Model results

The model most supported by the RPMA 3 recapture data (model weight = 0.44) used the following covariates (the estimated effect size for each covariate is presented in Table 11):

Survival:

1) Stock category (spring yearling, summer yearling, or 2/3 year old)
2) Age (with a different slope for each stock category)
3) Season (adjustment for proportion of interval falling in ‘winter’ – 1 Oct through 1 April)

Capture probability:

1) Ln(age) (logarithmic effect of age)
2) Effort (distance + # nets + # hooks)

Table 11. Estimated effect sizes (betas) for each of the model parameters in the most-supported model, with standard errors and 95% confidence intervals.

Parameter	***Beta***	***SE***	***95% LCL***	***95% UCL***
***Phi* (Survival probability)**				
Intercept – 2/3 year olds – summer survival	6.987	1.797	3.465	10.509
Intercept adjustment - spring yearlings	-3.289	2.060	-7.326	0.748
Intercept adjustment - summer yearlings	-0.423	2.389	-5.105	4.260
Age (spring yearlings)	0.007	0.005	-0.002	0.016
Age (summer yearlings)	0.005	0.004	-0.003	0.013
Age (2/3 year olds)	0.001	0.001	0.000	0.002
Intercept adjustment – Winter effect	-7.582	2.601	-12.680	-2.483
***p* (Capture probability)**				
Intercept	-10.904	2.142	-15.102	-6.705
Ln(age)	0.937	0.305	0.339	1.536
Effort (distance of drifts)	0.000	0.000	0.000	0.000
Effort (number of nets)	-0.006	0.003	-0.013	0.000
Effort (number of hooks)	0.000	0.001	-0.001	0.001

Adjustments to the intercept for spring and summer yearlings are not sensibly interpreted alone (i.e., without incorporating the age effect) because each stocking category includes a different range of ages over which survival rate is estimated. Age effects for all three stocking categories were positive, indicating increasing rate of survival with increasing age. The beta for age was positive for all three groups, indicating increasing survival probability with increasing age. The interval-specific adjustment for winter was negative, indicating that survival probability decreases as the ‘winter’ proportion of the interval increases.

Variation in capture probability in RPMA 3 was best explained by the logarithmic effect of age. The logarithmic function was used to allow capture probability to increase more steeply at first with increasing age, then level off at older ages. Various measures of sampling effort were also used to model capture probability, and the fit of the model using these covariates was improved relative to the model using ln(age) only. However, the actual effect sizes (betas) were very close to zero, and two of the three betas had confidence intervals wide enough that it cannot be determined whether effects were truly positive or negative

The beta estimates in Table 11 can be translated into monthly annual survival probabilities and occasion-specific capture probabilities, following an example provided for RPMA 2 on page 16. Tables 12 and 13 summarize the resulting survival and capture probabilities for RPMA 3, with detailed results for each stocking category available in the Appendix. Full model sets and results for models other than the best model (including beta estimates) will be made available via downloadable files on the internet (http://www.montana.edu/rotella/sturgeon).

Table 12. Comparison of estimated annual survival rates and standard errors (SE) for hatchery-reared juvenile pallid sturgeon released as spring yearlings (release age of 299 days for this example), summer yearlings (release age of 399 days), 2-yr-olds (release age of 832 days), and 3-year-olds (release age of 1085 days). Rates are for 1, 2, and 3 years post-release.

Yrs. post-release	**Annual survival estimate**	**SE**	**95% LCL**	**95% UCL**
Spring Yearlings				
0-1	0.22	0.14	0.00	0.50
1-2	0.73	0.42	0.00	1.00
2-3	0.95	0.15	0.66	1.00
Summer Yearlings				
0-1	0.58	0.14	0.30	0.86
1-2	0.91	0.13	0.65	1.00
2-3	0.98	0.05	0.89	1.00
2-year-olds				
0-1	0.68	0.17	0.35	1.00
1-2	0.73	0.15	0.44	1.00
2-3	0.92	0.06	0.80	1.00
3-year-olds				
0-1	0.74	0.13	0.48	1.00
1-2	0.78	0.12	0.55	1.00
2-3	0.93	0.05	0.84	1.00

Table 13. Capture probabilities for spring yearlings (release age = 299 days) released in RPMA 3. Estimates were generated from the top-ranked model. No sampling occurred on occasions 2 and 4, and these capture probabilities were fixed to 0.

Occasion	*p*	SE(*p*)
2	0.000	0.000
3	0.007	0.002
4	0.000	0.000
5	0.010	0.003
6	0.010	0.003
7	0.011	0.004
8	0.010	0.003
9	0.013	0.004
10	0.013	0.005
11	0.014	0.006
12	0.014	0.006
13	0.029	0.012

Implications of results

In RPMA 1, hatchery-reared juvenile pallid sturgeon have been released since August 1998. Age-specific survival rates can be projected furthest for fish released as summer yearlings, because these were released on occasion 1, whereas spring yearlings were not released until occasion 13. We calculated estimated annual survival rates for 9 years post-release for summer yearlings without fin curl released in RPMA 1 (Table 14), and used these survival rates to project the number of pallid sturgeon surviving to age 15 from the 1 release of summer yearlings without fin curl that has occurred (Table 15). Because fish reach an estimated survival rate of 1.0 by 5 years post-release, we can estimate that all fish reaching this point will survive to age 15 (minimum spawning age; U. S. Fish and Wildlife Service 2008). In reality, the annual survival probability is likely close to, but not actually 1.0. When parameter estimates are close to 1.0, the model estimation procedure may not be able to produce precise estimates. Further, because the survival models in question all include a positive age effect, the positive slope for age forces the estimated survival rate to reach 1.0 by some age, which varies by dataset.

Table 14. Annual survival rates up to 9 years post-release for summer yearlings without fin curl released in RPMA 1, with standard errors (SE) and 95% confidence limits.

Yrs. post-release	**Annual Survival**	**SE**	**95% LCL**	**95% UCL**
1	0.74	0.11	0.53	0.95
2	0.90	0.04	0.82	0.99
3	0.97	0.02	0.93	1.00
4	0.99	0.01	0.97	1.00
5	1.00	0.00	0.99	1.00
6	1.00	0.00	1.00	1.00
7	1.00	0.00	1.00	1.00
8	1.00	0.00	1.00	1.00
9	1.00	0.00	1.00	1.00

Table 15. Estimated number of surviving pallid sturgeon from 733 summer yearlings without fin curl released since August 1998.

Release occasion and date	Number released	Estimated number surviving to age 15	95% LCL	95% UCL
1 – Summer 1998	733	469	285	689

In RPMA 2, hatchery-reared juvenile pallid sturgeon have been released since August 1998, and age-specific survival rates can be projected furthest for fish released as summer yearlings, because these were released on occasion 1, whereas spring yearlings and fingerlings were not released until occasion 5. We calculated estimated annual survival rates for 9 years post-release for summer yearlings without fin curl released in the Missouri River in RPMA 2 (Table 16), and used these survival rates to project the number of pallid sturgeon surviving to age 15 from the 4 releases of summer yearlings that have occurred (Table 17). Because fish reach an estimated survival rate of 1.0 by 7 years post-release, we can estimate that all fish reaching this point will survive to age 15 (minimum spawning age; U. S. Fish and Wildlife Service 2008).

It is important to keep in mind that these annual estimates were influenced to some degree by the timing of sampling occasions. For the example presented in Table 16, the first interval between sampling occasions was approximately 2 years long. Therefore, a single monthly survival rate (0.894) was estimated and applied for each of the 26.5 months in the entire interval. Hence, we do not know exactly how survival rate varied with age during this interval. In reality, survival was likely lower for the first few months of the interval, then increased at the end of the interval. However, the variation in survival rate during this period cannot be estimated and therefore, one annual survival rate ($0.894^{12} = 0.26$) is presented for the first two years post-release. In situations with more frequent sampling occasions following release, annual survival rates may appear to increase more quickly.

Table 16. Annual survival rates up to 9 years post-release for summer yearlings without fin curl released in the Missouri River in RPMA 2, with standard errors (SE) and 95% confidence limits.

Yrs. post-release	**Annual Survival**	**SE**	**95% LCL**	**95% UCL**
1	0.31	0.12	0.09	0.54
2	0.66	0.13	0.41	0.91
3	0.87	0.09	0.69	1.00
4	0.86	0.10	0.67	1.00
5	0.97	0.03	0.91	1.00
6	0.99	0.01	0.97	1.00
7	1.00	0.00	0.99	1.00
8	1.00	0.00	1.00	1.00
9	1.00	0.00	1.00	1.00

Table 17. Estimated number of surviving pallid sturgeon from 2,639 summer yearlings without fin curl released in the Missouri River in RPMA 2 since August 1998.

Release occasion and date	Number released	Estimated number surviving to age 15	95% LCL	95% UCL
1 – Summer 1998	295	43	4	145
3 – Summer 2002	539	79	8	265
5 – Summer 2004	902	133	13	443
9 – Summer 2006	908	133	14	446
Total	2639	389	39	1299

In RPMA 3, hatchery-reared juvenile pallid sturgeon have been released since summer of 2000, and age-specific survival rates can be projected furthest for fish released as 2- and 3-year-olds, because these were released on occasion 1, whereas spring and summer yearlings were not released until occasions 2 and 4. We calculated estimated annual survival rates for 7 years post-release for 3-year-olds released in RPMA 3 (Table

18), and used these survival rates to project the number of pallid sturgeon surviving to age 15 from the two releases of 3-year-olds that have occurred (Table 19).

Table 18. Annual survival rates up to 7 years post-release for 3-year-olds released in RPMA 3, with standard errors (SE) and 95% confidence limits.

Yrs. post-release	**Annual Survival**	**SE**	**95% LCL**	**95% UCL**
1	0.85	0.10	0.65	1.00
2	0.86	0.09	0.68	1.00
3	0.93	0.05	0.84	1.00
4	0.66	0.08	0.50	0.81
5	0.70	0.10	0.51	0.89
6	0.77	0.10	0.57	0.97
7	0.83	0.11	0.62	1.00

Table 19. Estimated number of surviving pallid sturgeon from 619 3-year-olds released in RPMA 3 since summer 2000.

Release occasion and date	Number released	Estimated number surviving to age 15	95% LCL	95% UCL
1 – Summer 2000	438	88	15	306
2 – Spring 2002	181	36	9	127
Total	619	124	24	433

Biases and considerations

There are numerous potential sources of bias in these results. First, as mentioned in Data compilation, above, some recaptures were not usable because of missing data. These fish therefore appear in the input file as if they were not captured again after release, when some of them were. This would result is an estimate of survival probability that is biased low. Tag loss is another likely source of negative bias in survival rates, because loss of a tag appears as mortality (a previously-tagged fish can never be recorded as being recaptured if its tag is missing; although in reality it may be captured and recorded as a new, untagged fish). Tag loss rates (or conversely, tag retention rates) have been estimated for some groups of pallid sturgeon that have been released. In a future analysis, limited to only PIT-tagged fish, these rates could be used to adjust survival estimates upward for tag loss. To adjust for tag loss, the estimated survival rate ($\hat{\phi}$) is divided by the estimated tag retention rate ($\hat{\theta}$). For an estimated tag loss rate of 0.25, $\hat{\theta}$ = 0.75. An estimated survival rate of $\hat{\phi}$ = 0.74 becomes 0.99 after adjusting for tag loss. Another potential source of bias is the substantial size variation that can occur among juvenile pallid sturgeon of the same age. It is thought that larger fish may survive at a higher rate, but that this source of variation is not captured by the age covariate used in this analysis. Because heterogeneity in survival rates within a group of fish can affect the accuracy of estimates, this is an issue worth being concerned about. Therefore, we recommend that in a future analysis (again, limited to fish with size data available), survival be modeled as a function of size as well as age to compare the predictive ability of these two covariates.

Despite the above concerns, we feel that this analysis represents a useful starting point for future work and the development of other datasets that can be geared specifically toward addressing some of these sources of potential bias.

Recommendations

Estimation of survival probabilities for hatchery-reared juvenile pallid sturgeon has been identified as an essential step toward assessing the success of augmentation and recovery efforts for the species. Fundamental to this goal is the assessment of how well the current sampling plan meets the needs and assumptions for a robust, mark-recapture based analysis of survival rates. The mark-recapture data currently available for the Upper Basin are sparse and do not allow for more complex modeling that could reveal useful information such as survival differences related to stocking locations, movement probabilities for different habitats/rivers, or gear-specific capture probabilities. Following are recommendations as to how sampling methods could be altered to reduce bias, improve precision of survival estimates, and increase modeling flexibility.

1. *Length of sampling occasions*

One of the key assumptions of mark-recapture analyses is that sampling periods are 'instantaneous', or more realistically, kept as short as possible to ensure that mortality occurring during the sampling period is negligible. We therefore recommend that sampling for juvenile pallid sturgeon occur over short periods of concentrated effort, perhaps twice a year (once in spring and once in fall), rather than continuously from April through November. The specific length of these periods should be determined after careful consideration of 1) probability of mortality occurring for periods of various length, and 2) the tradeoff with capture probability that occurs as a result of shortening sampling periods (i.e., do not make the sampling periods so short that capture probabilities are too low to allow estimation of survival probability; see #4 below).

2. *Organization of mark-recapture data*

For the purposes of future mark-recapture analyses, we recommended that a single database table be developed which 1) includes all encounters for each fish (beginning with stocking occasion and including each subsequent recapture), and 2) is indexed by PIT tag or some unique ID. A separate table, also indexed by PIT tag or unique ID, should be developed that includes all other relevant data for the fish (spawn date, age when stocked, year class, iridovirus or fin curl status, hatchery, stock location). These data were available for some recaptured fish, but not all, and required combining data from many sources and extensive amounts of error checking. Approximately the first two months of this contract were spent almost exclusively on these activities. Construction of a single database to hold all of the information in the manner recommended would greatly increase the efficiency of future analyses by making it simpler to build the necessary input files for program MARK.

3. Tracking of capture effort

To most efficiently model the variation in capture probability, it is useful to have a measure of capture effort for each sampling period. We recommend that all crews in the Upper Basin find a uniform measure of effort that can be calculated for each of the various sampling gears (e.g., drift time or drift distance). A single measure of effort can then be associated with each sampling period and used to model variation in capture probability across sampling periods. This is likely to improve estimates of capture probability, and thereby improve estimates of survival probability.

4. Increasing capture probability

Capture probabilities for pallid sturgeon in this study were low. In general, for a given fixed survival probability, population size, and number of sampling occasions, precision of survival estimates increases as capture probability increases. Pollock *et al.* (1990) displayed this relationship in a series of figures (see Figure 1. below), and it is evident that the coefficient of variation of survival (cv(ϕ)) (proportional standard error, or the standard error of the estimate divided by the estimate) declines precipitously as capture probability increases to 0.2. The *cv* can be used as a measure of estimate precision, and Pollock et al. (1990) suggests that a good 'rule of thumb' is to achieve a *cv* of 0.2 or less. In most scenarios, achieving this level of precision requires a capture probability of at least 0.2, which is why 0.2 is often used as a general rule-of-thumb recommended minimum capture probability for obtaining useful and precise survival estimates. The sparseness of recapture data for this data set and the low estimated capture probabilities (ranging from < 0.001 to 0.05 in most cases) represent one of the most significant obstacles to survival estimation for juvenile pallid sturgeon.

Not surprisingly, results from simulations indicate that increasing capture probabilities (*p*) results in greater precision of survival estimates. We chose one example group (summer yearlings with fin curl in RPMA 1) and conducted a simulation using monthly survival rates generated in the main analysis. We simulated data for a 5-occasion time-specific model ($\phi_t \, p_t$) using monthly survival estimates for the first 4 intervals for summer yearlings with fin curl (sampling occasions 7 – 11). These simulations were based on assumed "true" survival rates equivalent to the original estimates from the main analysis (Table 20, column 3). Capture probabilities for these occasions from the previous analysis ranged from $p = 0.009$ to $p = 0.020$. We conducted 1000 simulations each at $p = 0.05$ and $p = 0.15$, with a hypothetical release of 1000 summer yearlings on each occasion. When *p* was increased from 0.05 to 0.15, the widths of confidence intervals on survival estimates were reduced by approximately 50%, indicating the improved precision to be gained from increasing capture probabilities (Table 20). The confidence intervals based on real data overlap for intervals 7 and 8 and for intervals 9 and 10. When *p* is increased to 0.15, confidence intervals for these estimates no longer overlap, allowing stronger interpretation of the results.

Table 20. Results from simulations showing the effect of increasing capture probability from $p = 0.05$ to $p = 0.15$.

		Original estimates			When $p = 0.05$			When $p = 0.15$		
Int #	p	ϕ	95% LCL	95% UCL	ϕ	95% LCL	95% UCL	ϕ	95% LCL	95% UCL
7	-	0.618	0.522	0.714	0.617	0.612	0.623	0.621	0.618	0.624
8	0.009	0.659	0.588	0.730	0.667	0.661	0.672	0.662	0.660	0.665
9	0.020	0.829	0.766	0.892	0.837	0.830	0.844	0.830	0.826	0.833
10	0.016	0.891	0.817	0.965	0.908	0.898	0.918	0.898	0.893	0.902

Sampling crews may wish to know *how many* captures (rather than what values of p) are needed to obtain precise estimates of survival probability. The answer to this question depends on a host of factors: the desired level of precision, the estimation model under consideration, particular RPMA, stocking category, and other variables for which survival rate is being estimated. A rough estimate can be obtained by multiplying the estimated number of fish of a particular category surviving in the study area by the desired p. Using the example from Tables 16 and 17 (summer yearlings without fin curl in RPMA 2), and based on the estimated number of these fish currently surviving in RPMA 2 ($\hat{N} = 101$), approximately 15 captures would be needed to obtain $p = 0.15$. Given that the number of fish in a category of interest is rarely known with any precision, we recommend a simple rule of thumb – the more captures, the better.

We therefore strongly recommend any modifications to sampling design that would increase capture probability. In general, this would entail increasing capture effort during existing sampling periods, extending sampling periods, or both. However, the sampling periods used for this analysis may already be too long and should not be lengthened as it would further deviate from the assumption of 'instantaneous sampling'. For the purposes of survival estimation, we recommended applying maximum effort to capturing as many pallid sturgeon as possible during an intensified, narrow sampling period (e.g., a 2-week period in spring and another 2-week period in fall). We realize that substantially increasing capture effort may not be possible (due to limitations on boats, fishing gear, and personnel) and that pallid sturgeon may just be inherently difficult to capture.

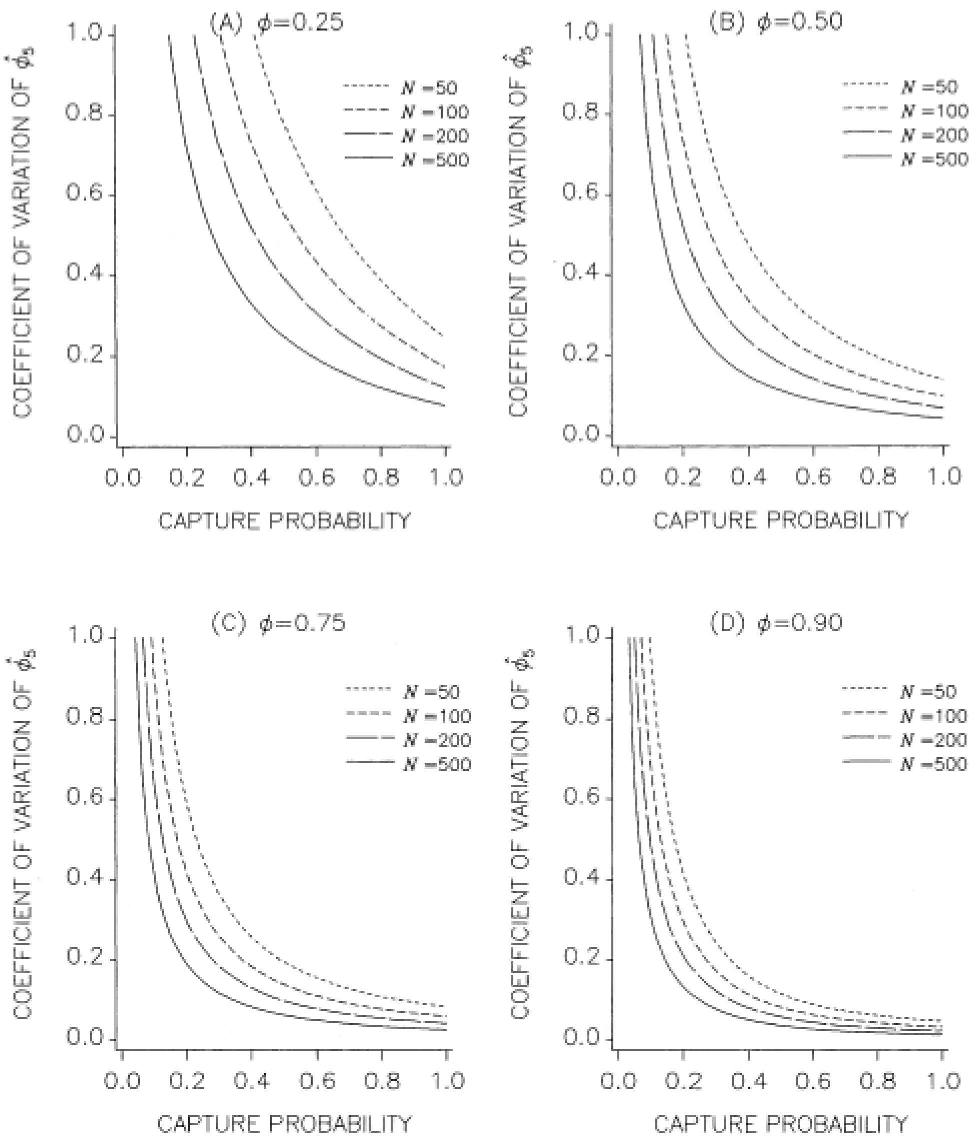

Figure 1. Comparison of the precision of a survival rate estimator for a range of population sizes (*N = 50, 100, 200, 500*) and survival rate takes the range of values ϕ = 0.25 (A), 0.50 (B), 0.75 (C), 0.90 (D) (based on Jolly-Seber model). Figure taken from Pollock *et al*. (1990).

An additional possibility for increasing capture probability is the use of radio-telemetry to identify locations where pallid sturgeon are concentrated and thus may be captured at a higher rate than they would be at other, randomly selected river locations. This technique has been employed on the lower Yellowstone in RPMA 2, and results from this analysis indicated that capture probabilities were higher there than they were in other parts of the Upper Basin. However, it is also important that all fish in the river system are potentially captured. The top-ranked model used the stocking river (Yellowstone or Missouri) to estimate a fish's capture probability, and the estimated effect of being stocked in the Yellowstone was positive (β_{YE} = 2.33; 95% CI = (1.37, 3.03)). This resulted in capture probabilities as high as 0.46 for fish stocked in the Yellowstone for the range of ages under consideration. It is important to keep in mind that this covariate represented where the fish was *stocked*, and not necessarily where it was *captured* (using capture river as a covariate would necessitate a multi-state analysis, the complexity of which would not be supported by this small dataset). However, we feel that because most of the fish stocked in the Yellowstone went on to be later recaptured in the Yellowstone, this result indicates higher capture probabilities for the Yellowstone, where sampling has been focused on high-use locations identified through the use of telemetry. We are aware that other telemetry studies have been completed in RPMAs 2 and 3 and acknowledge that locations of probable high capture rate may not exist in all areas, or may not always be apparent through telemetry. However, we provide this as one possible explanation for higher capture probabilities for fish stocked in the Yellowstone River.

Another consideration when planning sampling occasions is the importance of obtaining a representative sample. The first assumption for the Cormack-Jolly-Seber model is that every marked animal present in the population at sampling period i has the same probability p_i of being recaptured or resighted (Williams et al. 2002). Sampling that is random or stratified is not necessarily required as long as a representative sample of fish is being captured. In practice, it can be difficult to know how representative your sample is. This is one area where telemetry may be helpful as tracking radio-marked individuals can alert one to the presence of unsampled locations or habitats where fish congregate. If certain types of fish (e.g. specific age classes) are disproportionately spending time in unsampled habitats relative to sampled habitats, then there is cause for concern. However, if fish move randomly between sampled and unsampled areas, capture probabilities may be lower as a result but survival rate estimates will not be biased. Stratified sampling can help obtain a representative sample if non-random movement to unsampled locations is suspected. However, stratification of sampling to include habitats or locations with a lower success rate may be done at the expense of the total number of recaptures. Therefore, if there is no reason to suspect non-random use of unsampled locations, we recommend stratification be avoided and emphasis be placed upon maximizing total number of recaptures.

5. Planning future stocking events

Future stocking events allow for the opportunity to learn more directly about the effect of 1) river of stocking, 2) disease exposure, 3) different stocking locations, etc. If one of these conditions is varied, while all others are kept constant, the stocking events may be more easily compared. For example, to best learn about the effects of fin curl exposure, it would be ideal to release fish of both types (exposed and not exposed to fin curl) at the same time in the same location. In this way, an effort could be made to design future releases in order to learn about the contrasts that are of greatest interest.

6. Consider the estimation procedure as an ongoing endeavor

If the field and analysis aspects of mark-recapture work on pallid sturgeon can be reviewed, discussed, and improved each year as new data and experiences are obtained, the survival estimation will improve with time. It may take time to develop methods that provide capture probabilities that are higher than what has been achieved to date, especially if sampling occasions are more constrained. However, as covariate information is obtained, estimates are reviewed, and teams discuss their experiences, improvements will be made. In addition, data will accumulate, data input files will be constructed more efficiently, modelers and fish biologists will interact more efficiently and communicate more effectively, modeling experience will provide benefits to future analyses, and estimates will improve.

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