Importance of migratory mode and life history to extinction risk in Acipenseriformes

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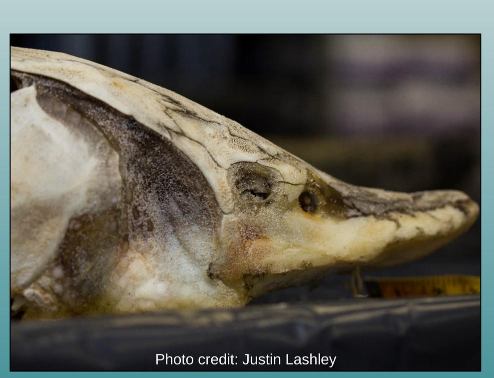

Background

The status of sturgeons and paddlefishes (order: Acipenseriformes) is in question worldwide and almost all species are either endangered or threatened because of anthropogenic factors (Table 1). Recovery in these species is limited by their reproductive biology and life-history traits (e.g., long-lived, large bodied, late-maturing, iteroparous); despite restrictive legal protection most populations are still not considered to be recovering.

Anadromous species of sturgeons and paddlefishes are considered to be more at risk than non-migratory species because of their unique life-history characteristics that result in longer turnover-time (i.e., individuals reproduce at a slower rate causing slower population growth and recovery) and increased interactions with developed coastal landscapes. However, an overall understanding of the ecology, population dynamics, and life-history is still lacking for the majority of sturgeons and paddlefishes and basic metrics of evaluating risk based on migratory mode and habitat are unknown.

Our objectives were to compile data on the current status and known life-history parameters of Acipenseriformes in order to: 1) test the hypothesis that anadromous sturgeons and paddlefishes have longer turnover-times by comparing life-history parameters and extinction risk of species based on migratory mode and habitat; and 2) quantify the effect of migratory mode, habitat, and life-history in determining the extinction risk of sturgeons and paddlefishes. Importantly, we test these hypotheses using comparative analysis techniques that control for the non-independence of species that results from their common phylogenetic history.

Family / Subfamily / Genus	Binomials	Status
Acipenseridae		
Acipenserinae		
Acipenser	*A. baerii*	EN (IUCN); App. II
	A. brevirostrum	VU (IUCN); App. I; E (US ESA); SC (COSEWIC); SC, Sched. 1 (SARA)
	A. dabryanus	CR* (IUCN); App. II
	A. fulvescens	LC (IUCN); App. II; EN [Saskatchewan-Nelson River populations, Western Hudson Bay populations], SC [Southern Hudson Bay-James Bay populations], TH [Great Lakes-Upper St. Lawrence populations] (COSEWIC)
	A. gueldenstaedtii	CR (IUCN); App. II
	A. medirostris	NT (IUCN); App. II; T (US ESA); SC (COSEWIC); SC, Sched. 1 (SARA)
	A. mikadoi	CR (IUCN); App. II; E (US ESA)
	A. naccarii	CR* (IUCN); App. II; E (US ESA)
	A. nudiventris	CR (IUCN); App. II
	A. oxyrinchus desotoi	NT (IUCN); App. II; T (US ESA)
	A. o. oxyrinchus	NT (IUCN); App. II; E [Carolina, Cheseasapeake Bay, New York Bight, and South Atlantic DPS], T [Gulf of Maine DPS] (US ESA); TH [St. Lawrence and Maritime populations] (COSEWIC)
	A. persicus	CR (IUCN); App. II
	A. ruthenus	VU (IUCN); App. II
	A. schrenckii	CR (IUCN); App. II
	A. sinensis	CR (IUCN); App. II; E (US ESA)
	A. stellatus	CR (IUCN); App. II
	A. sturio	CR (IUCN); App. I; E (US ESA)
	A. transmontanus	LC (IUCN); App. II; E [Kootenai River population] (US ESA); EN [Upper Columbia River, Upper Fraser River, and Upper Kootenay River populations], TH [Lower Fraser River population] (COSEWIC); EN [Upper Columbia River and Upper Kootenay River populations], Sched. 3 [Lower Fraser River, Upper Columbia River,Upper Fraser River, and Upper Kootenay River populations] (SARA)
Huso	*H. dauricus*	CR (IUCN); App. II; E (US ESA)
	H. huso	CR (IUCN); App. II; T (US ESA)
Scaphirhynchinae		
Pseudoscaphirhynchus	*P. fedtschenkoi*	CR* (IUCN); App. II
	P. hermanni	CR (IUCN); App. II
	P. kaufmanni	CR (IUCN); App. II
Scaphirhynchus	*S. albus*	EN (IUCN); App. II; E (US ESA)
	S. platorynchus	VU (IUCN); App. II; T^ (US ESA)
	S. suttkusi	CR (IUCN); App. II; E (US ESA)
Polyodontidae		
Polydontinae		
Polyodon	*P. spathula*	VU (IUCN); App. II; E (COSEWIC); E, Sched. 1 (SARA)
Psephurus	*P. gladius*	CR* (IUCN); App. II

Table 1. Taxonomy and current conservation status of order Acipenseriformes. IUCN listings: CR=critically endangered; EN=endangered; LC=least concern; NT=near threatened; VU=vulnerable; CITES listings: App. I=Appendix I; App. II=Appendix II; US ESA listings: E=endangered; T=threatened; COSEWIC and SARA listings: E=extirpated; EN=endangered; SC=special concern; TH=threatened; Sched. 1=Schedule 1; Sched. 2=Schedule 2; (*)=possibly extinct; (^)=due to similarity of appearance.

Methods

Data sources

-Conservation status, maximum reported size, longevity, size at maturity, age at maturity, fecundity, spawning interval, migratory mode, and habitat data were obtained for sturgeons and paddlefishes (complete data were available for 15 species).

-Extinction risk was estimated as fishing mortality necessary to drive a species to extinction ($F_{extinct}$; Myers and Mertz 1998; Garcia et al. 2008):

$$\tilde{\alpha} = \exp(F_{extinct}(a_{maturity} - a_{sel} + 1))(1 - \exp(-(M + F_{extinct})))$$

where $\tilde{\alpha}$ is annual reproductive rate corrected by sex ratio; a_{sel} is the age at which fishes enter the fishery (i.e., 1).

-Natural mortality (M) was calculated using indirect approaches (Hoenig 1983; Jensen 1996).

Data analysis

-Correlogram analysis of Moran's I index of autocorrelation was performed to assess importance of phylogeny on response variables to determine distribution of life-history parameters and extinction risk among taxonomic levels.

-Taxonomy model: taxonomic arrangement was included as a random effect in a mixed-effect linear model to correct for any phylogenetic effects reflected in the taxonomy.

-Phylogeny model: fitted using generalized estimating equations taking into account phylogenetic correlation in traits. Phylogenetic tree was built from topologies taken from different studies (Figure 1).

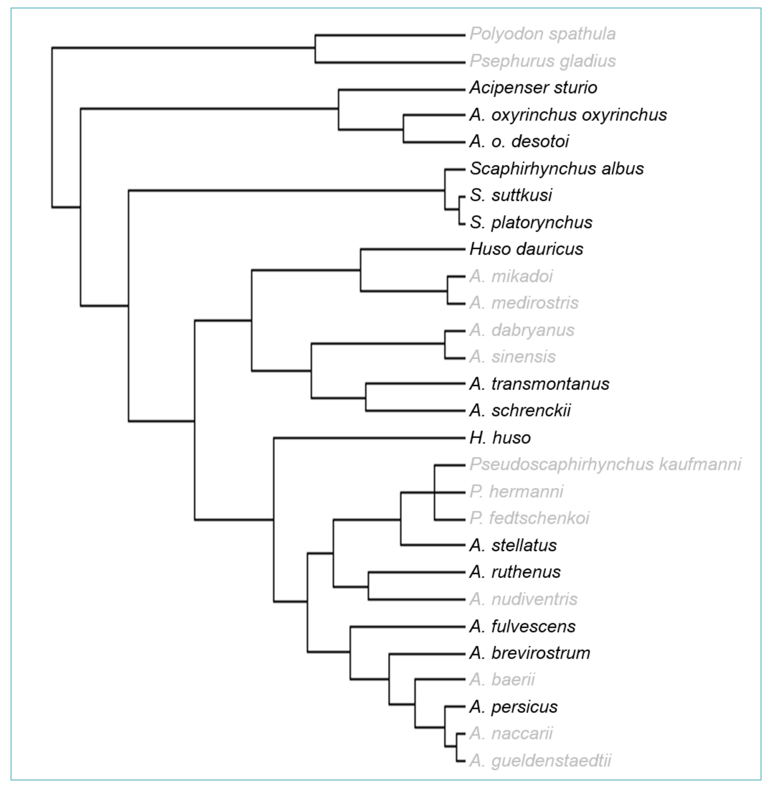

Figure 1. Composite phylogenetic tree of Acipenseriformes from published partial trees. A truncated version of this tree (species in black font; N = 15) was used in analyses and the generalized estimating equation model to control for phylogenetic correlation; full life-history parameters were not available for remaining species.

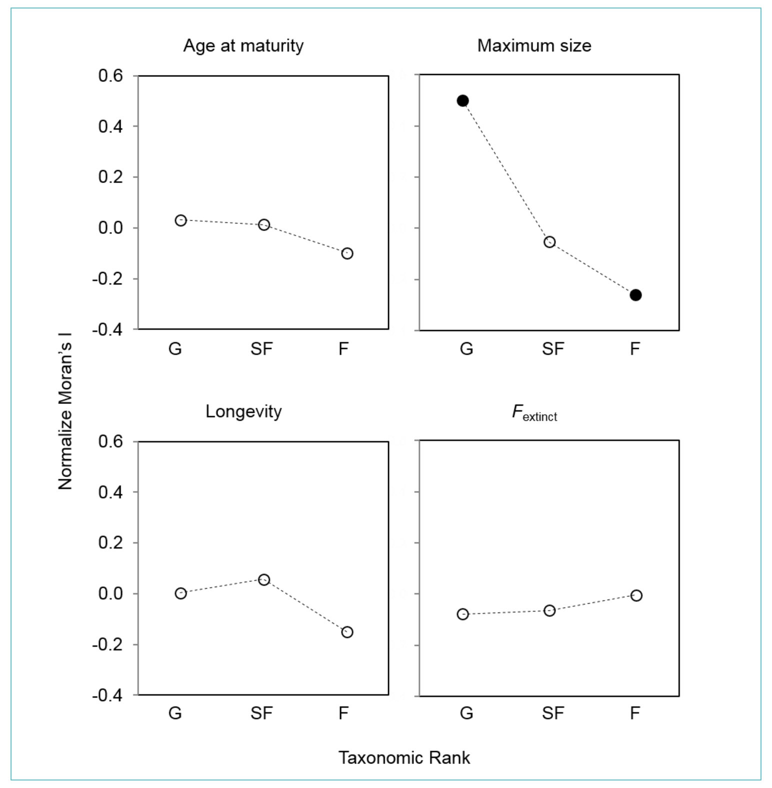

Figure 2. Correlogram of normalized Moran's I autocorrelation index of age at maturity, maximum size, longevity, and extinction risk ($F_{extinct}$) for taxonomic groups (G = genus; SF = subfamily; and F = family) of sturgeons. Filled circles are statistically significant (p≤0.05).

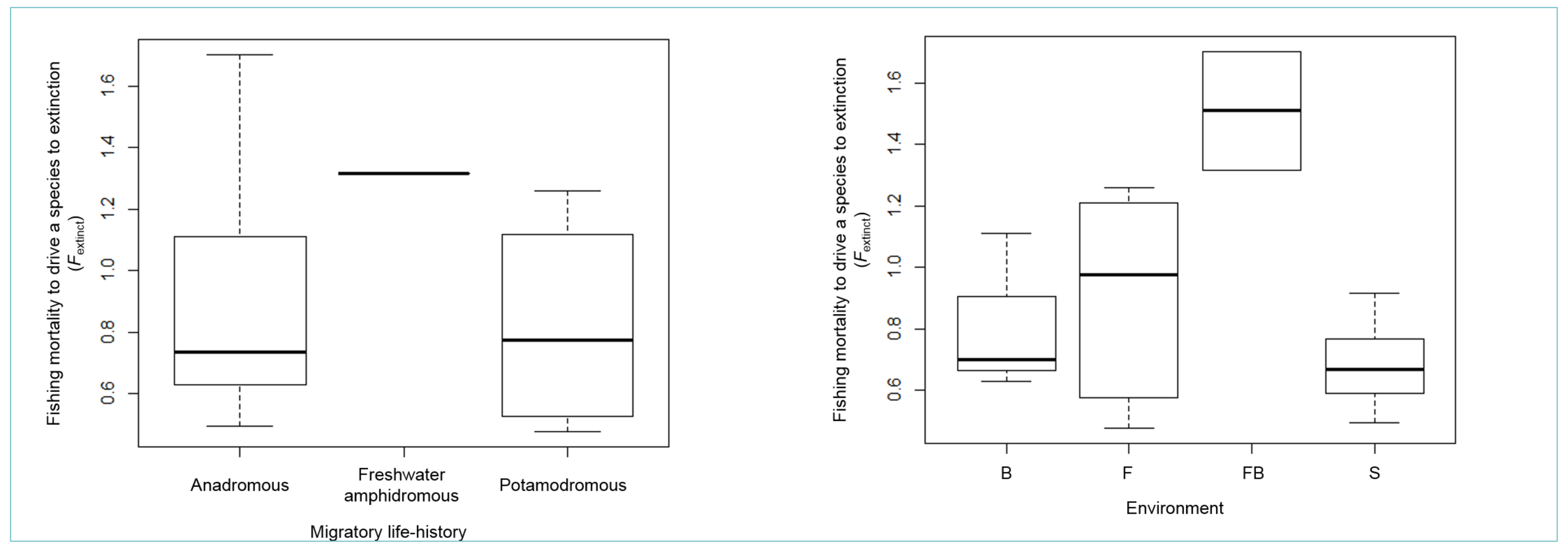

Figure 3. $F_{extinct}$ (the fishing mortality needed to drive a species to extinction) for sturgeon species (N = 15) with differing migratory modes (left panel) and habitats (right panel; B = growth in brackish water; F = live entirely in freshwater; FB = mostly freshwater with short migration in brackish water; and S = growth in sea water). Bold line = median; box =interquartile range; whiskers = range.

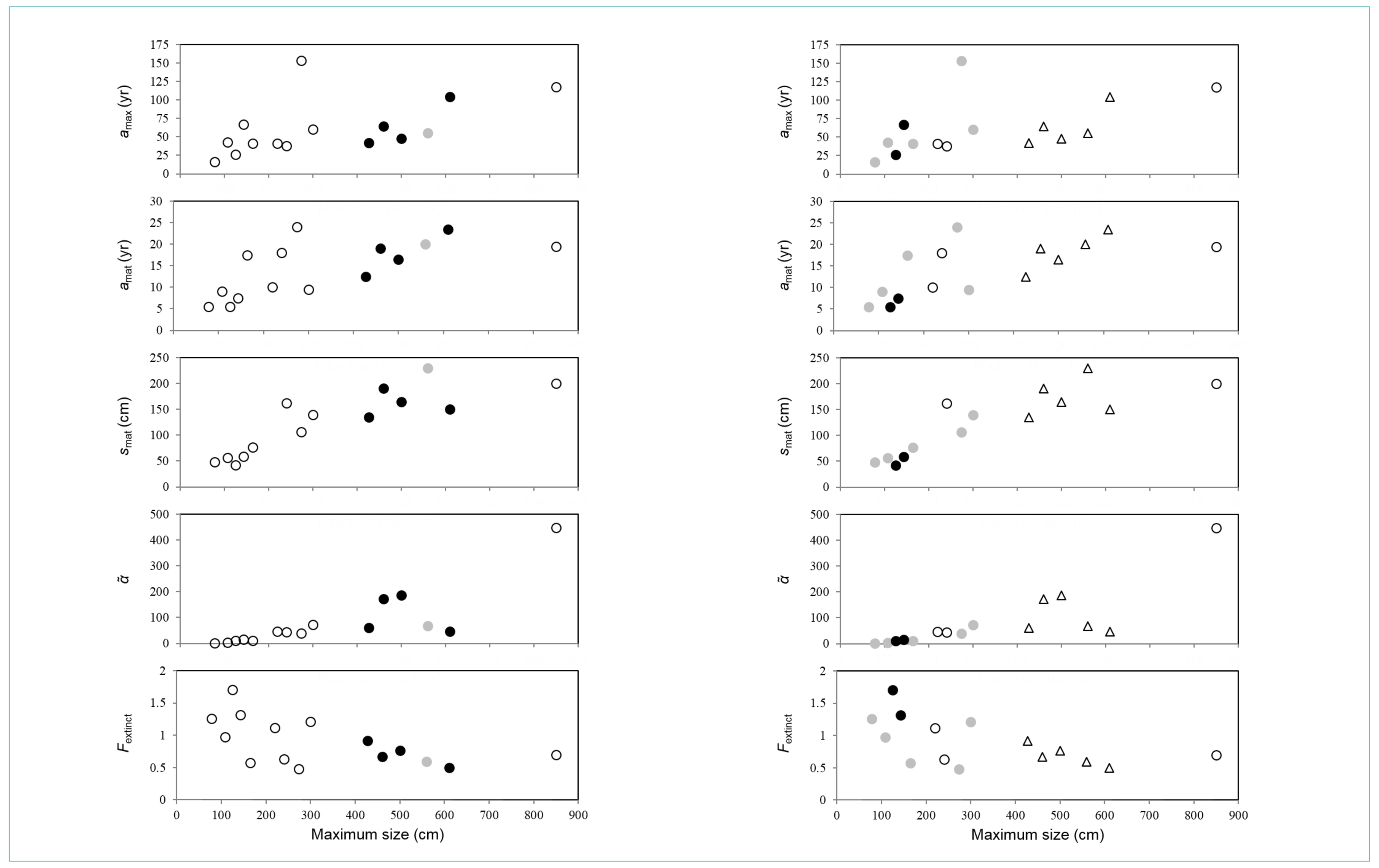

Figure 4. Relationship between longevity (a_{max}; estimated as maximum observed age), age at maturity (a_{mat}), size at maturity (s_{mat}), annual corrected reproductive rate ($\tilde{\alpha}$), and extinction risk ($F_{extinct}$, estimated as fishing mortality necessary to drive a species to extinction) with maximum body size in sturgeon species (N = 15). Left panel depicts relationships based on migratory mode (anadromous = open circles; freshwater amphidromous = grey circles; potamodromous = black circles) and right panel depicts relationships based on habitat (open circle = growth in brackish water; grey circle = live entirely in freshwater; black circle = mostly freshwater with short migrations in brackish water; open triangle = growth in sea water).

Preliminary Results

Response variables differed in degree of correlation with taxonomy (Figure 2). Maximum size was significantly and positively correlated at the genus level and had significant negative correlation at the family level; that is, species of the same genus tend to have significantly similar maximum size and subfamilies within the same family tended to differ in maximum size. Age at maturity, longevity, and $F_{extinct}$ were not shown to be significantly correlated with taxonomy.

The median values of $F_{extinct}$ were 0.733, 1.312, and 0.774 for anadromous, freshwater amphidromous, and potamodromous species, and 0.699, 0.971, 1.505, and 0.668 for species that grow in brackish water, live entirely in freshwater, are mostly freshwater with short migrations in brackish water, and grow in sea, respectively (Figures 3 and 4).

In the taxonomic model, age at maturity and longevity had significant positive coefficients for potomadromous species (p≤0.05); $F_{extinct}$ had a negative coefficient for potamodromous species in both models but was only significant for taxonomy (p≤0.01) (Table 2).

	Age at maturity		Longevity		$F_{extinct}$	
Variables	Taxonomy	Phylogeny	Taxonomy	Phylogeny	Taxonomy	Phylogeny
Intercept (Anadromous)	1.100 (0.357)*	2.633 (0.378)**	2.496 (0.756)**	4.809 (0.625)**	0.951 (0.282)**	0.194 (0.274)
Freshwater amphidromous	0.182 (0.347)	-0.780 (0.383)	0.769 (0.488)	-0.371 (0.634)	-0.157 (0.288)	0.401 (0.278)
Potamodromous	0.740 (0.269)*	0.334 (0.336)	1.190 (0.428)*	0.589 (0.555)	-0.721 (0.216)**	-0.461 (0.244)
Size at maturity	0.009 (0.002)***	-0.001 (0.001)	0.006 (0.003)*	-0.006 (0.002)	-0.007 (0.002)**	-0.001 (0.001)

Table 2. Coefficients (standard error within brackets) of linear models relating age at maturity, longevity, and the fishing mortality required to drive a population to extinction ($F_{extinct}$) with migratory mode. Migratory mode coefficients are relative to anadromous species. The taxonomy model is a mixed-effects linear model with the taxonomic hierarchy included as a random effect, and the phylogeny model is a generalized estimating equation model with a log link which corrects for phylogenetic correlation using a phylogenetic tree; *p≤0.05; **p≤0.01; ***p≤0.001.

Conclusions and Future Directions

Preliminary results suggest that potamodromous species of Acipenseriformes investigated have longer turn over times (i.e., comparatively "slower" life-history parameters) and a higher extinction risk (i.e., lower $F_{extinct}$ values) when compared to anadromous species. Although not representative of the entire order (15 of 27 species), these results are in contrast with literature suggesting that anadromous species of acipenseriformes have higher extinction risk than non-migratory species. However, all conclusions are based on preliminary results and models are in need of further development.

Moving forward, we will further refine the models in our analyses and incorporate patterns of spawning migrations (e.g., short single-step, long two-step, etc.) and migration distance. Known life-history values will be used to predict unknown parameters for the remaining sturgeon and paddlefish species in order to quantify the effects of life-history and migratory mode on extinction risk.

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