APPLICATION OF A MULTI-STATE MODEL TO ESTIMATE CULVERT EFFECTS ON MOVEMENT OF SMALL STREAM FISHES

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OVERVIEW

- ⇨ Introduction and background
- ⇨ Field study and modeling process
- ⇨ Results
- ⇨ Conclusions and implications

Widely recognized culverts may affect passage

Limited field studies concerning non-game and small-bodied fishes

Warren and Pardew (1998)

Schafer et al. (2003)

Unpublished and gray literature:

Coffman 2005
Ensign reported in Norman et al. 2006
Vander Pluym 2006

Capture probability not considered

If capture probabilities not constant, then movement estimates may be biased

Fish Movement: A ⇨ B

Estimate based on proportion of recaptured individuals observed in A and B originally marked and released in A

IF:

a = number recaptured in A

b = number recaptured in B

THEN:

proportional movement A ⇨ B = $b/a+b$

HOWEVER, for a fish to be recaptured, it must:

1.) Remain in study area (or "survive"), with probability S

2.) Move to B (probability ψ) or remain in A (probability 1 – ψ)

3.) Be captured, with probability p_a in A or p_b in B

THUS:

$$b/a+b = S\,\psi\,p_b \,/\, [(S\,(1-\psi)\;p_a) + (S\,\psi\,p_b)]$$

$$\boxed{= \psi\,[p_b \,/\, ((1-\psi)\,p_a + \psi\,p_b)]}$$

$$b/a+b = \psi\,[p_b / ((1-\psi)\,p_a + \psi\,p_b)]$$

THEREFORE, observed proportional movement is unbiased estimate of if ψ and only if $p_a = p_b$

BUT, p expected to vary with differences in fish behavior (Larimore 1961) and stream habitat (Peterson et al. 2005)

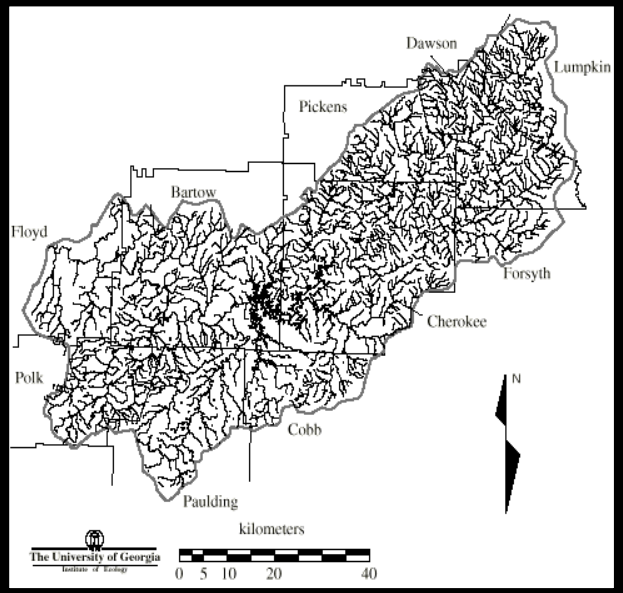
SO, unbiased estimation of ψ should incorporate p

Building on previous studies, used multi-state models that incorporate *p* into estimates of fish movement, ψ

Estimated upstream and downstream ψ for benthic and water column fishes, both through and not through culverts

Etowah River Basin Fishes

91 Native
4 Endemic
17 Imperiled
3 Federally listed



Etheostoma scotti (Cherokee darter)

Etheostoma etowahae (Etowah darter)

Percina antesella (Amber darter)

529 candidate stream crossings – 4 selected

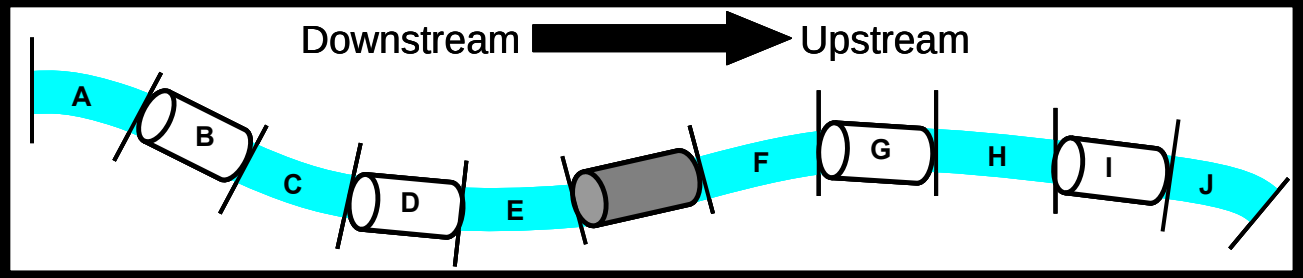
Min
0.04m
Max
0.39m

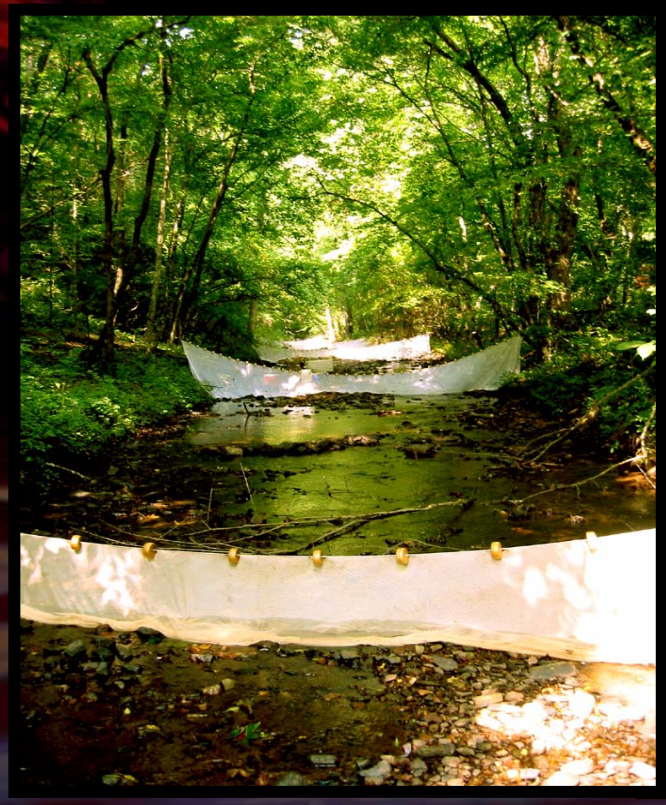
Min
0.23m
Max
0.60m

Movement assessed over 4–6 weeks
Sampled 4–5 times

Sites divided into 10 reaches – 5 US/5DS

3 – 25m reaches, each separated by false culvert





Fish ≥30 mm and ≤120 mm marked with VIE tag

Maximum stage between sampling dates and stage at time of sampling recorded

Max Δ stage and *effective m* ulated

Multi-state models:

- ⇨ Extension of capture-recapture models
- ⇨ Estimate state, or reach-specific:
  - ✓ capture probability (p)
  - ✓ 'survival' probability (S)
  - ✓ probability of movement (ψ)

Conceptually: estimate all parameters (p, S, ψ) for every reach on every date

Solution: p, S, ψ averaged across dates, test specific hypotheses

Problem → 660 – 880 model parameters

A priori hypotheses:

- ✓ Move shorter than longer distances
- ✓ Move through culvert-free reaches *AND* embedded rather than perched culverts
- ✓ Water column fishes more likely to move and move through culverts than benthic fishes

<u>In ALL models:</u>

1.) Upstream and downstream ψ estimated separately

2.) Reach specific *p*

<u>Site-Specific models</u>: 2 groups – benthic and water column fishes

<u>Combined-Site models</u>: 4 groups – study sites

Model Comparison

Full Movement (FM)
VS.
Reduced Movement (RM)

Best Supported Model (Lowest AICc)

Reach-Paired "Survival"
VS.
Constant "Survival"

Random Movement (RM) (Random Walk)

Random Movement (RM) (Random Walk) – Fish move randomly to adjacent reaches; movement ≈ 1 CL, max = 1 CL, no preferred direction

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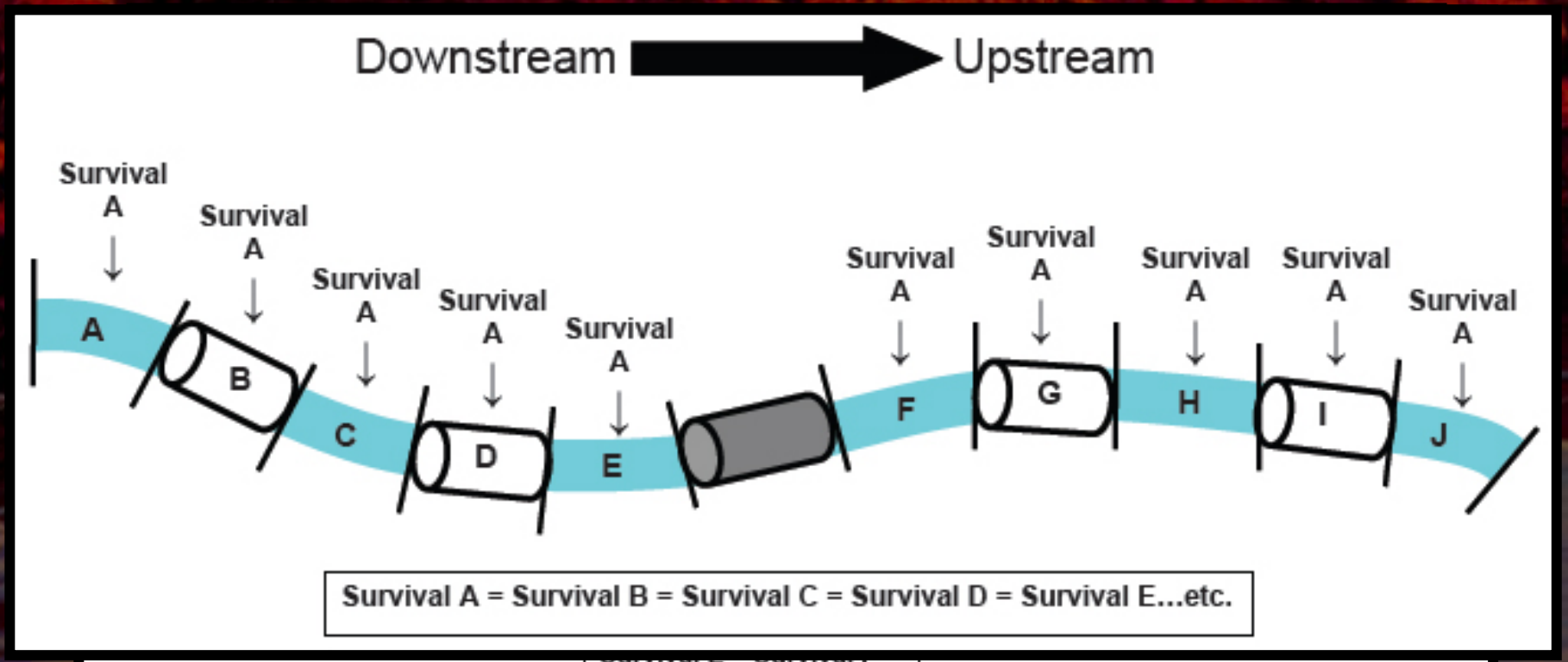
Constant Survival (EMCS or CRMCS)



Best supported general model compared to constrained model with same structure

<u>Site-Specific covariate:</u>

Individual standard length

<u>Combined-Site covariates:</u>

min PAWS (US ψ) + *Apron* (DS ψ)

vs.

min PAWS (US ψ)

ψ from best supported model for each site used to calculate culvert effect size and 95% CI at each site

- ⇨ 5805 fish marked, representing 30 species
- ⇨ Overall recapture rate 0.29 – 0.37

Site	% Non-movers	% Movers	US Moves	DS Moves
Canton	89%	11%	47	42
Bluff	90%	10%	45	37
Champion	93%	7%	51	36
Nimblewill	94%	6%	67	45
TOTAL	92%	8%	210	160

6% to 11% recaptures moved among reaches

More US than DS movement

⇨ 96% to 99% of recaptures/DS movement or adjacent moves

⇨ Thru-culvert moves at all sites: 21% at Bluff

⇨ 63% to 87% of sites were adjacent moves

Bluff only site with US *and* DS thru-culvert moves

Distance Moved	Canton Creek		Bluff Creek		Champion Creek		Nimblewill Creek	
	No.	% total moves	No.	% total moves	No.	% total moves	No.	% total moves
Adjacent	77	87%	52	63%	61	70%	79	71%
≈1 CL	8	9%	12	15%	12	14%	21	19%
>1 CL	3	3%	1	1%	7	8%	7	6%
Thru-Culvert	0	–	5 (US/DS)	6%	3 (US)	3%	0	–
Thru-Culvert >1 CL	1 (US)	1%	12 (US/DS)	15%	4 (US)	5%	5 (DS)	4%

Site	Model	AICc Weight	Est. Parms
Canton	RMCS	0.581	29
Bluff	FMCS	0.992	36
Champion	FMCS	0.965	35
Nimblewill	FM	0.854	38

- ⇨ ψ estimates generally small ($0.0054 < \psi < 0.16$) with wide confidence intervals
- ⇨ ψ highest for adjacent moves for both benthic and water column fishes at all sites, except Bluff
- ⇨ Bluff benthic fishes, highest ψ was DS thru-culvert

$\psi = 0.095$, 95% CI [0.012 – 0.47]

Site	US culvert effect		US effect culvert >1		DS culvert effect		DS culvert effect >1	
	B Fishes	WC Fishes	B Fishes	WC Fishes	B Fishes	WC Fishes	B Fishes	WC Fishes
Canton	*NCM*	*NCM*	0.0019 *NS*	*NCM*	*NCM*	*NCM*	*NCM*	*NCM*
Bluff	*NCM*	No Effect	No Effect	0.0034 *NS*	No Effect	*NCM*	*NCM*	No Effect
Champion	*NCM*	No Effect	*NCM*	0.0021 *NS*	*NCM*	*NCM*	*NCM*	*NCM*
Nimblewill	*NCM*	*NCM*	*NCM*	*NCM*	*NCM*	*NCM*	*NCM*	No Effect

Except Bluff Creek, mostly no culvert movement

Culvert effects small and not significant (NS)

Time Int	Canton Creek			Bluff Creek			Champion Creek			Nimblewill Creek		
	Δ Stage (m)	Eff P (m)	# TC (US/ DS)	Δ Stage (m)	Eff P (m)	# TC (US/ DS)	Δ Stage (m)	Eff P (m)	# TC (US/ DS)	Δ Stage (m)	Eff P (m)	# TC (US/ DS)
1	0	–	0 0	0.11	–	1/0 [1/0]	0.056	-0.02	0 0	0.387	-0.16	0 0
2	0.10	–	0 0	0.40	–	3/3 [3/2]	0.091	-0.05	0 0	0.513	-0.28	0/4 [0/0]
3	0.075	–	0 0	0.041	–	7/7 [4/5]	0.212	-0.17	7/0 [3/0]	0.16	0.07	0/1 [0/0]
4	0.070	–	1/0 [0/0]	–	–	–	–	–	–	–	–	–

Perched Sites: Thru-culvert moves only recorded after greatest increase in stage height and smallest *effective min PAWS* (Eff P)

Bluff Creek: Thru-culvert moves observed over each time interval during study

Combined-Site Models

Model	AICc Weight
FM	0.370
FM(*min PAWS*)	0.370
FM(*min PAWS* + *Apron*)	0.132

ψ estimates identical within 6 significant digits

min PAWS and *Apron* no effect

Bluff Creek only transmitted Cutler, possibly reduce passage for fish passages but important

Wate … pass, but not with constant success or at a constant rate – temporal variation likely

MULTI-STATE MODELS

What was gained?

- ✓ quantified movement probabilities incorporating *p* into estimates
- ✓ no separate estimate of *p* necessary
- ✓ directly incorporate individual and group covariates

What could be improved?

- ✓ fewer reaches and over longer time period utilizing time-dependent models and time-varying covariates

Implications

- ⇨ Because passage ability may be variable, important to quantify variability to better understand effects on populations
- ⇨ May be important where economic resources limited and tradeoffs involved in crossing design and replacement
- ⇨ Quantifying effects and variability may help improve efforts to maintain population and habitat connectivity

Questions ?

Comments ?