Appendix from T. E. X. Miller et al., “Sex-Biased Dispersal and the Speed of Two-Sex Invasions”

(Am. Nat., vol. 177, no. 5, p. 549)

Supplemental Details of the Invasion Speed Derivation and Data Tables

In the main text we claimed that for the given initial condition, solutions to the density-dependent model (21) were bounded above by solutions of the low-density approximation (22) and that as a result, a population governed by model (21) cannot spread faster than one governed by approximation (22) with the same initial condition. Here we show that that is the case.

Let $f_t(x)$ be the solution to model (21) and let $\hat{f}_t(x)$ be the solution to approximation (22) for the common given initial condition $f_0(x)$. Because $g(N)$ lies between 0 and 1, it follows directly that $f_1(x) \le \hat{f}_1(x)$. We now show that if $f_t(x) \le \hat{f}_t(x)$, then $f_{t+1}(x) \le \hat{f}_{t+1}(x)$ (and thus, by induction, that $f_t \le \hat{f}_t$ for all $t \ge 0$).

First note that because $k_\mathrm{m}(x)$ and $k_\mathrm{f}(x)$ are probability density functions and therefore nonnegative functions, we have

$$h\mu f_t(x) * k_\mathrm{m}(x) \le h\mu\hat{f}_t(x) * k_\mathrm{m}(x), \tag{A1}$$

$$\phi f_t(x) * k_\mathrm{f}(x) \le \phi\hat{f}_t(x) * k_\mathrm{f}(x). \tag{A2}$$

By the third mating function axiom, the mating function is a nondecreasing function of its arguments. Hence, using equations (A1) and (A2) in approximation (22), we have

$$\mathfrak{B}(h\mu f_t(x) * k_\mathrm{m}(x), \phi f_t(x) * k_\mathrm{f}(x)) \le \mathfrak{B}(h\mu\hat{f}_t(x) * k_\mathrm{m}(x), \phi\hat{f}_t(x) * k_\mathrm{f}(x)) = \hat{f}_{t+1}(x). \tag{A3}$$

Now, repeating equation (21),

$$f_{t+1}(x) = g\left[\left(\frac{\mu}{\phi}\right)a_\mathrm{m}\, f_t(x) * k_\mathrm{m}(x) + a_\mathrm{f}\, f_t(x) * k_\mathrm{f}(x)\right]\mathfrak{B}(h\mu f_t(x) * k_\mathrm{m}(x), \phi f_t(x) * k_\mathrm{f}(x)). \tag{A4}$$

Finally, since $0 \le g(N) \le 1$,

$$f_{t+1}(x) \le \mathfrak{B}(h\mu f_t(x) * k_\mathrm{m}(x), \phi f_t(x) * k_\mathrm{f}(x)), \tag{A5}$$

which, with (A3), gives the inequality for which we seek

$$f_{t+1}(x) \le \hat{f}_{t+1}(x). \tag{A6}$$

We also claimed (just below eq. [24]) that the invasion speed for a finite population governed by the recursion (22) and initially distributed with a finite range would be greater than or equal to the invasion speed of a population with an exponential distribution in space. To see this, again define $\hat{f}_t(x)$ as the solution to equation (22) with the finite initial condition $\hat{f}_0(x)$. We compare $\hat{f}_t(x)$ with a population that is initially distributed as ae^{-sx}, with $a > 0$ chosen so that

$$\hat{f}_0 \le ae^{-sx}, \tag{A7}$$

for all x. It follows from the monotonicity of $\mathfrak{B}$ that

$$\hat{f}_1(x) \le \mathfrak{B}(h\mu ae^{-sx} * k_\mathrm{m}(x), \phi ae^{-sx} * k_\mathrm{f}(x)) = \mathfrak{B}(h\mu M_\mathrm{m}(s), \phi M_\mathrm{f}(s))ae^{-sx} \tag{A8}$$

and from the definition (24) that

$$\hat{f}_1(x) \leq ae^{sc(s)}e^{-sx}. \tag{A9}$$

Applying the recursion (22) to both sides of equation (A9),

$$\hat{f}_2(x) \leq \mathfrak{B}(h\mu ae^{sc(s)}e^{-sx} * k_{\mathrm{m}}(x), \phi ae^{sc(s)}e^{-sx} * k_{\mathrm{f}}(x)) = ae^{2sc(s)}e^{-sx}. \tag{A10}$$

Continuing in this fashion, we see that

$$\hat{f}_t(x) \leq ae^{tsc(s)}e^{-sx} = ae^{-s(x-c(s)t)}. \tag{A11}$$

Since, for any $s \geq 0$, we can always find a constant a such that condition (A7) is satisified, we choose s to minimize the upper bound (24). This yields our conjectured invasion speed (25).

Table A1. Insect dispersal data

	Distance			
Latin name: order	Female (km)	Male (km)	Notes	Reference
Amblyscirtes simius:				
Lepidoptera	.054	.034	1969 data	Scott 1975
	.052	.038	1970 data	Scott 1975
	.053	.036	Species mean	
Anoplophora glabripennis:				
Coleoptera	.023	.017		Smith et al. 2001
Aphantopus hyperantus:				
Lepidoptera	.0905	.093		Sutcliffe et al. 1997
Boloria aquilonaris:				
Lepidoptera	.226	.087	1995 data	Mousson et al. 1999
	.16	.209	1996 data	Mousson et al. 1999
	.193	.148	Species mean	
Chorthippus spp.:				
Orthoptera	.004	.0103	Site A	Bailey et al. 2003
	.00714	.0102	Site B	Bailey et al. 2003
	.0056	.0103	Species mean	
Diaprepes abbreviatus:				
Coleoptera	.04954	.03868		Nigg et al. 2001
Erynnis tages:				
Lepidoptera	.104	.081		Gutierrez et al. 1999
Euchloe ausonides:				
Lepidoptera	.179	.139		Scott 1975
Euphydryas aurinia:				
Lepidoptera	.467	.645		Wahlberg et al. 2002
Euphydryas maturna:				
Lepidoptera	.141	.238		Wahlberg et al. 2002
Euptoeita claudia:				
Lepidoptera	.11262	.10005		Haddad 1999
Heliconius erato:				
Lepidoptera	.186	.318	Pupal releases	Mallet 1986
	.072	.166	Field captures	Mallet 1986
	.129	.242	Species mean	
Heliconius spp.:				
Lepidoptera	.0417	.0704	Pollen movement distances	Murawski and Gilbert 1986
Hesperia pahaska:				
Lepidoptera	.038	.059		Scott 1975
Homalodisca vitripennis:				
Homoptera	.025455	.02239		Blackmer et al. 2006
Hypaurotis crysalus:				
Lepidoptera	.011	.015		Scott 1975
Icaricia icaioides fenderi:				
Lepidoptera	.0115	.0174		Schultz 1998

Table A1 (*Continued*)

Latin name: order	Distance Female (km)	 Male (km)	Notes	Reference
Iolana iolas:				
Lepidoptera	.16	.083		Rabasa et al. 2007
Juonia coenia:				
Lepidoptera	.10507	.09524		Haddad 1999
Lycaena arota:				
Lepidoptera	.018	.011		Scott 1975
Lycaena helle:				
Lepidoptera	.1076	.0675		Fischer et al. 1999
Lycaena virgaureae:				
Lepidoptera	.091	.098		Douwes 1975
Lygus hesperus:				
Hempitera	.0024	.007		Bancroft 2005
Maniola jurtina:				
Lepidoptera	.0402	.0507	Hightown 1976	Brakefield 1982
	.0484	.0452	Hightown 1977	Brakefield 1982
	.0437	.0349	Hightown 1978	Brakefield 1982
	.0683	.0667	St. Andrews	Brakefield 1982
	.0582	.0491	St. Andrews	Brakefield 1982
	.0518	.0493	Species mean	
Melitaea athalia:				
Lepidoptera	.555	.498		Wahlberg et al. 2002
Melitaea cinxia:				
Lepidoptera	.573	.438		Wahlberg et al. 2002
	.403	.311		Kuusaari et al. 1996
	.488	.375	Species mean	
Melitaea diamina:				
Lepidoptera	.469	.436		Wahlberg et al. 2002
Melitea athalia:				
Lepidoptera	.0678	.0824	1993 data	Schwarzwalder et al. 1997
	.0625	.107	1994 data	Schwarzwalder et al. 1997
	.0652	.0947	Species mean	
Metrioptera bicolor:				
Orthoptera	.00216	.00225		Kindvall 1999
Neominois ridingsii:				
Lepidoptera	.089	.046	1969 data	Scott 1975
	.061	.047	1970 data	Scott 1975
	.075	.047	Species mean	
Paranassius apollo:				
Lepidoptera	.298	.349		Brommer and Fred 1999
Paranassius phoebus:				
Lepidoptera	.066	.068		Scott 1975
Parnassius mnemosyne:				
Lepidoptera	.172	.177		Konvicka and Kuras 1999
Plebejus argus:				
Lepidoptera	.0101	.153	Release A—local	Seymour et al. 2003
Plebejus argus:				
Lepidoptera	.0116	.124	Release A—fragmented	Seymour et al. 2003
	.0058	.123	Release A—continuous	Seymour et al. 2003
	.025	.0309	Release B—local	Seymour et al. 2003
	.0183	.037	Release B—fragmented	Seymour et al. 2003
	.0148	.0326	Release B—continuous	Seymour et al. 2003
	.0142	.0834	Species mean	
Plutella xylostella				
Lepidoptera	.00907	.00636	Year 1 A	Mo et al. 2003
	.00815	.00823	Year 1 B	Mo et al. 2003
	.00676	.0105	Year 2 A	Mo et al. 2003
	.0051	.00551	Year 2 B	Mo et al. 2003
	.00546	.00974	Year 2 C	Mo et al. 2003

Table A1 (*Continued*)

Latin name: order	Distance		Notes	Reference
	Female (km)	Male (km)		
	.0073	.00734	Year 3	Mo et al. 2003
	.00697	.0237	Species mean	
Precis coenia:				
Lepidoptera	.029	.021	Lab-reared	Scott 1975
	.03	.03	Wild-caught	Scott 1975
	.0295	.0255	Species mean	
Proclossiana eunomia:				
Lepidoptera	.123	.059		Mennechez et al. 2003
Zygaena filipendulae:				
Lepidoptera	.03	.034		Menendez et al. 2002

Note: Distance values are means unless otherwise noted. For species with multiple estimates (from different studies, years, populations, or life stages), we calculated species means (used in fig. 2).

Table A2. Avian dispersal data

	Distance			
Latin name	Female (km)	Male (km)	Notes	Reference
Accipiter gentilis	34.5	80.0	Median juvenile distance	Byholm et al. 2003
	64.0	49.0	Median adult distance	Byholm et al. 2003
	49.3	64.5	Species mean	
Accipiter nisus	41.0	23.5	Annandale population	Newton and Rothery 2000
	48.8	37.7	Eskdale population	Newton and Rothery 2000
	44.9	30.6	Species mean	
Acrocephalus sechellensis	4.0	2.0	Median natal dispersal in units of territories	Eikenaar et al. 2008
	2.0	1.5	Median breeding dispersal in units of territories	Eikenaar et al. 2008
	3.0	1.75	Species mean	
Aegoilius funereus	140	47.7		Saurola 2002
Bonasa bonasia	2.0	4.0		Montadert and Leonard 2006
Bubo bubo	56.3	33.3		Saurola 2002
Campylorhynchus nuchalis	.388	.331		Yaber and Rabenold 2002
Charadrius alexandrinus	6.9	4.2	Median distance	Stenzel et al. 2007
Ciconia ciconia	.177	.015	Median distance	Chernetsov et al. 2006
Circus aeruginosus	.765	.104		Sternalski et al. 2008
Colaptes auratus	.201	.082	Median distance	Fisher and Wiebe 2006
Colinus virginianus	3.161	3.048		Townsend et al. 2003
Empidonax traillii	2.3	1.7	Median distance	Sedgwick 2004
Glaucidium passerinum	31.6	11.5		Saurola 2002
Lanius collurio	.374	.186	Median distance	Pasinelli et al. 2007
Otus kennicottii	13.8	6.2		Ellsworth and Belthoff 1999
Parus caeruleus	1.21	.669	Antwerp population	Tufto et al. 2005
	4.4	2.13	Ghent population	Tufto et al. 2005
	2.8	1.4	Species mean	
Parus major	.717	.534	Antwerp population	Tufto et al. 2005
	2.32	1.39	Ghent population	Tufto et al. 2005
	1.52	.96	Species mean	
Passer domesticus	22.7	24.0		Tufto et al. 2005
Perdix perdix	.478	1.009		Salek and Marhoul 2008
Strix aluco	29.7	23.7		Saurola 2002
Strix nebulosa	63.4	36.4		Saurola 2002
Strix occidentalis occidentalis	11.7	10.1		Lahaye et al. 2001
	4.0	10.0	Median juvenile distance	Blakesley et al. 2006
	9.0	8.0	Median adult distance	Blakesley et al. 2006
	8.23	9.36	Species mean	
Strix uralensis	31.2	21.6		Saurola 2002
Sula granti	.105	.026		Huyvaert and Anderson 2004
Tachycineta bicolor	8.38	2.44		Winkler et al. 2005
Tetrao tetrix	8.0	1.5		Caizergues and Ellison 2002

Note: Distance values are means unless otherwise noted. For species with multiple estimates (from different studies, years, populations, or life stages), we calculated species means (used in fig. 2).

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