Predicting the effectiveness of wildlife fencing along roads using an individual-based model

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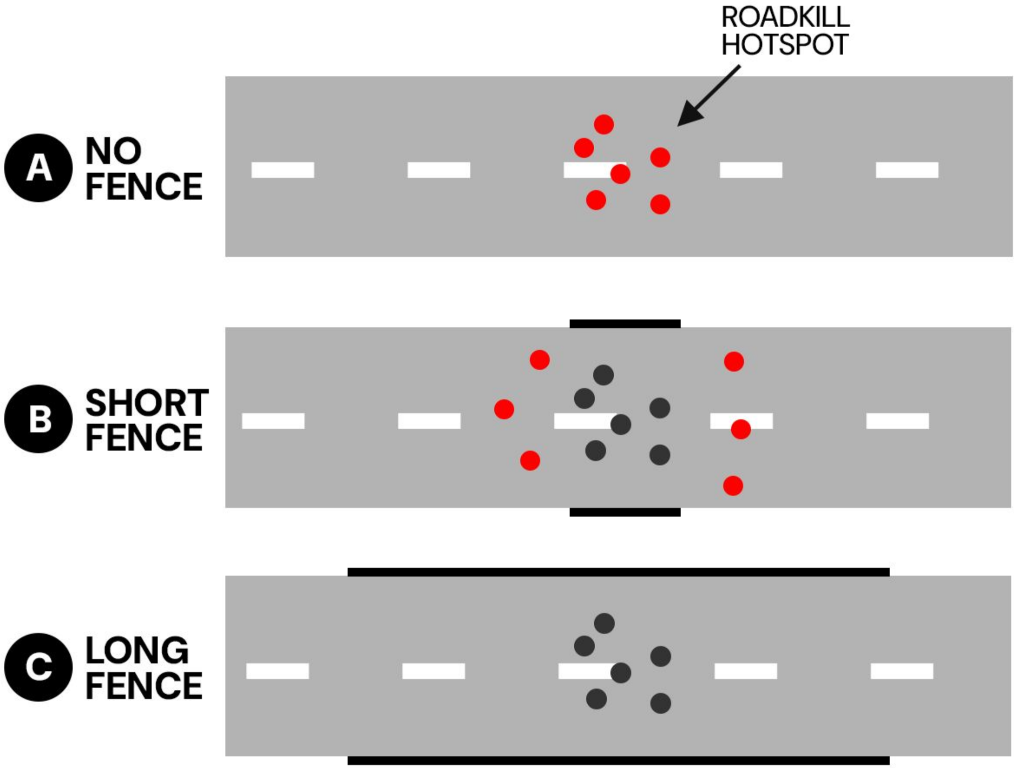
- Wildlife-vehicle collisions: kill animals and reduce biodiversity
- An effective mitigation measure: fences + wildlife crossings
- What length of fence is needed?

The fence-end effect

Shifting of roadkill hotspots towards the fence ends
(Huijser et al., 2015; Plante et al., 2019)



Research Questions

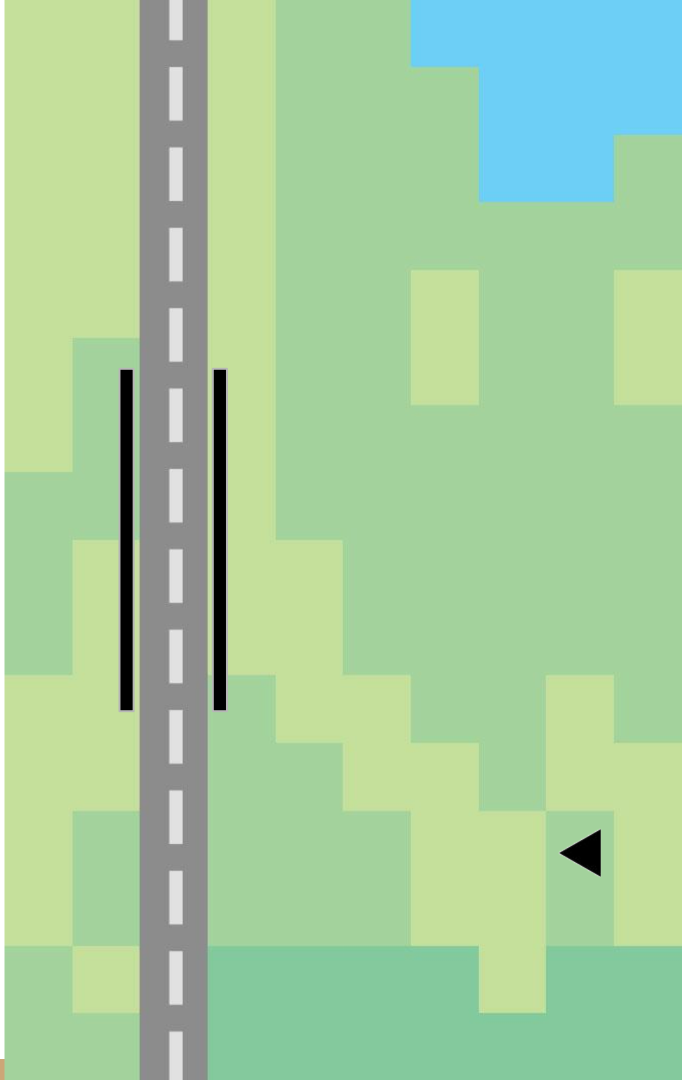
- How does the length of a fence influence its effectiveness?
- How does the fence-end effect impact this effectiveness?

Approach

- An individual-based model (IBM)

Objectives

- A method to quantify fence effectiveness
- an interactive/visual model



Methods

IBM created using JavaScript

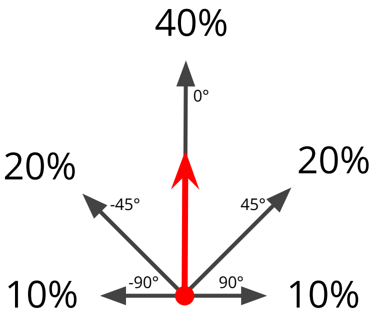
Model variables → Wood Turtles (Arvisais et al., 2002)

- Movement distance = 1630 m/year
- Home range radius = 300 meters
  ↳ Fence length = 600 meters

Simulations parameters:

- 5000 turtles
- 10 years of movement
- 9 movement behavior profiles

Movement Behavior Profiles



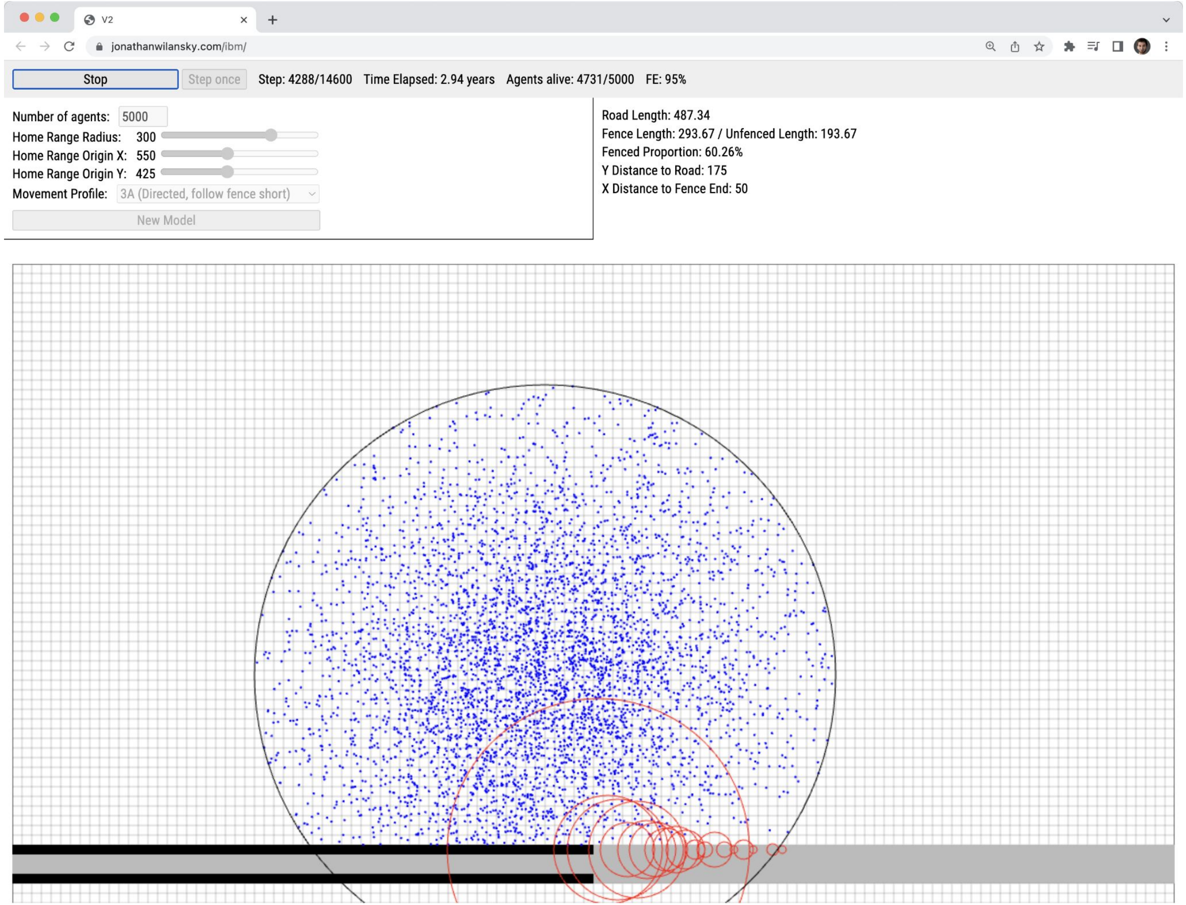
Direction Change Probabilities

		Fence Following Distance Steps	Fence Following Distance Meters
1	Random	0	0
2	Directed Random	0	0
3A	Follow Fence SHORT	5	5.6
3B	Follow Fence MEDIUM	20	22.3
3C	Follow Fence LONG	35	39
4A	Follow Fence ¼ D	135	150
4B	Follow Fence ½ D	269	300
4C	Follow Fence ¾ D	404	450
4D	Follow Fence MAX	538	600

Retreat Distance:
5 steps / 5.6m

The IBM

https://jonathanwilansky.com/ibm/model/

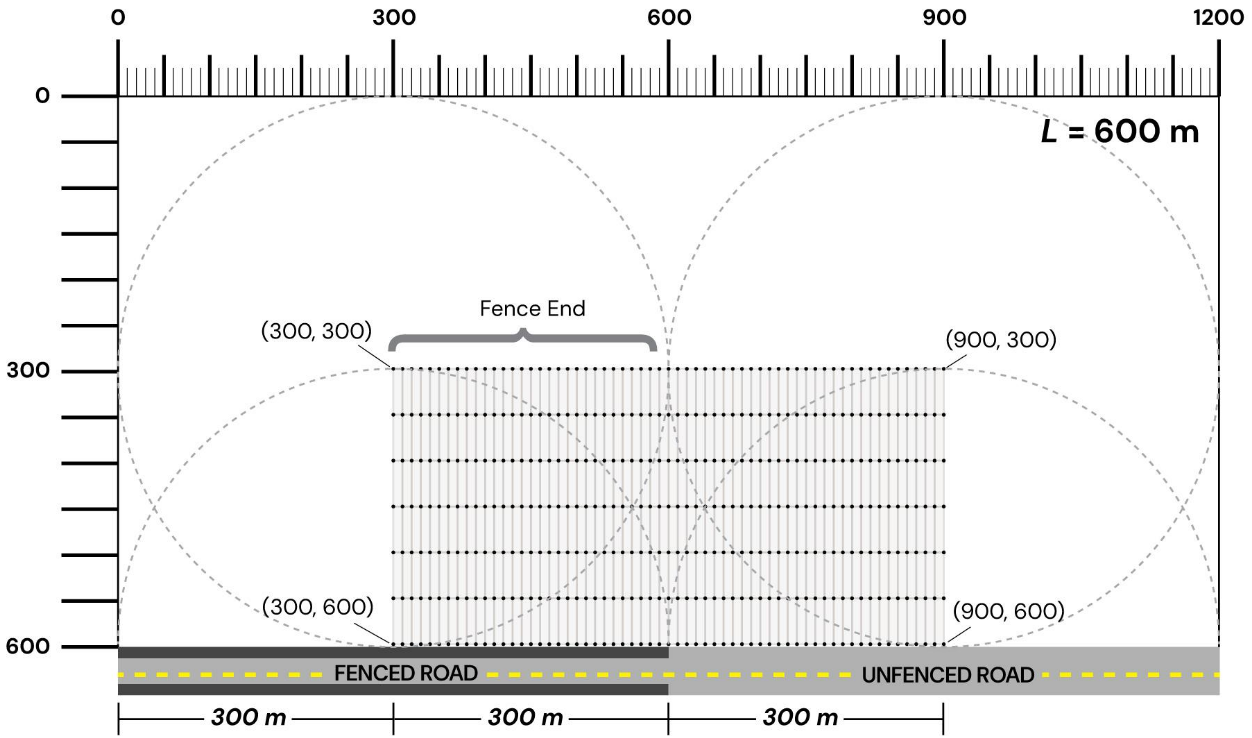


Survival Ratio

= percentage of agents alive* at the end of a simulation

*alive → did not step on the road

The IBM Environment and Fence Effectiveness



Fence Effectiveness (FE)

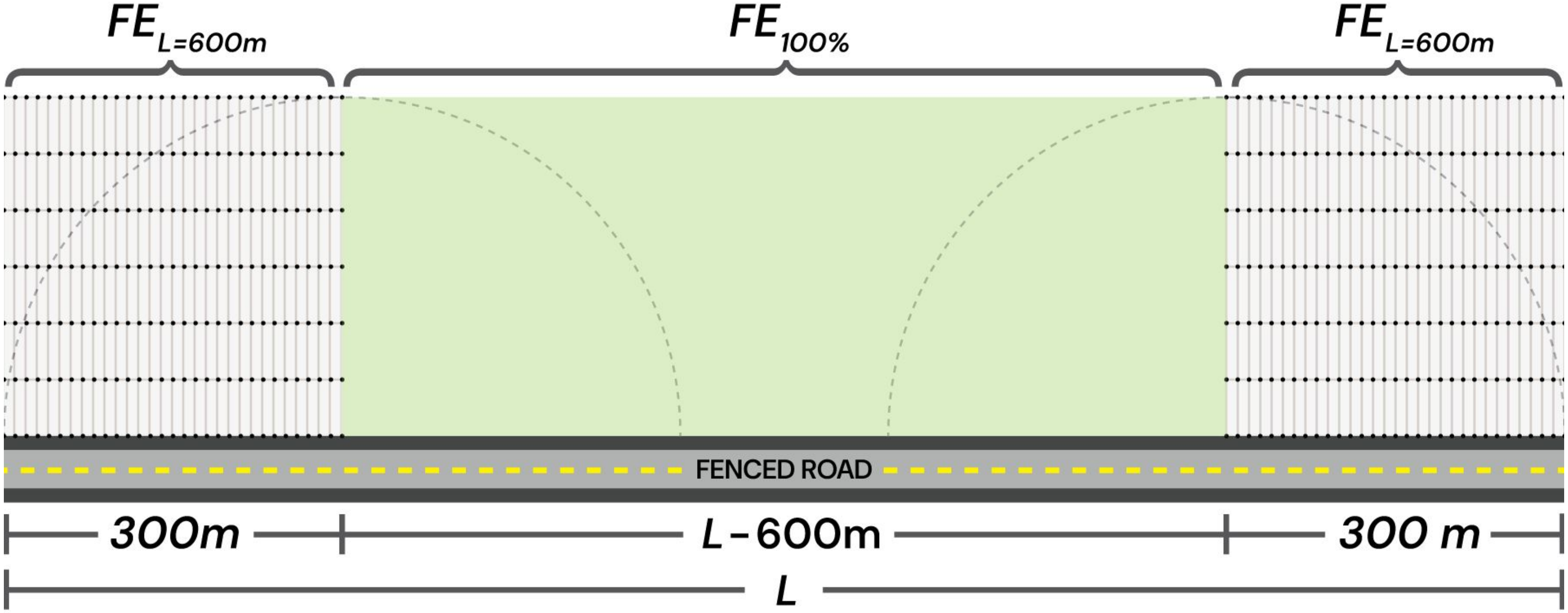
$$= (SR_F - SR_{NO\_F}) / (1 - SR_{NO\_F})$$

road encounters prevented by the fence

road encounters with no fence

Method for $L > 600$ m

- Fences with length $L > D$ can be determined mathematically using results from L = 600 m
- any additional length contributes 100% effectiveness



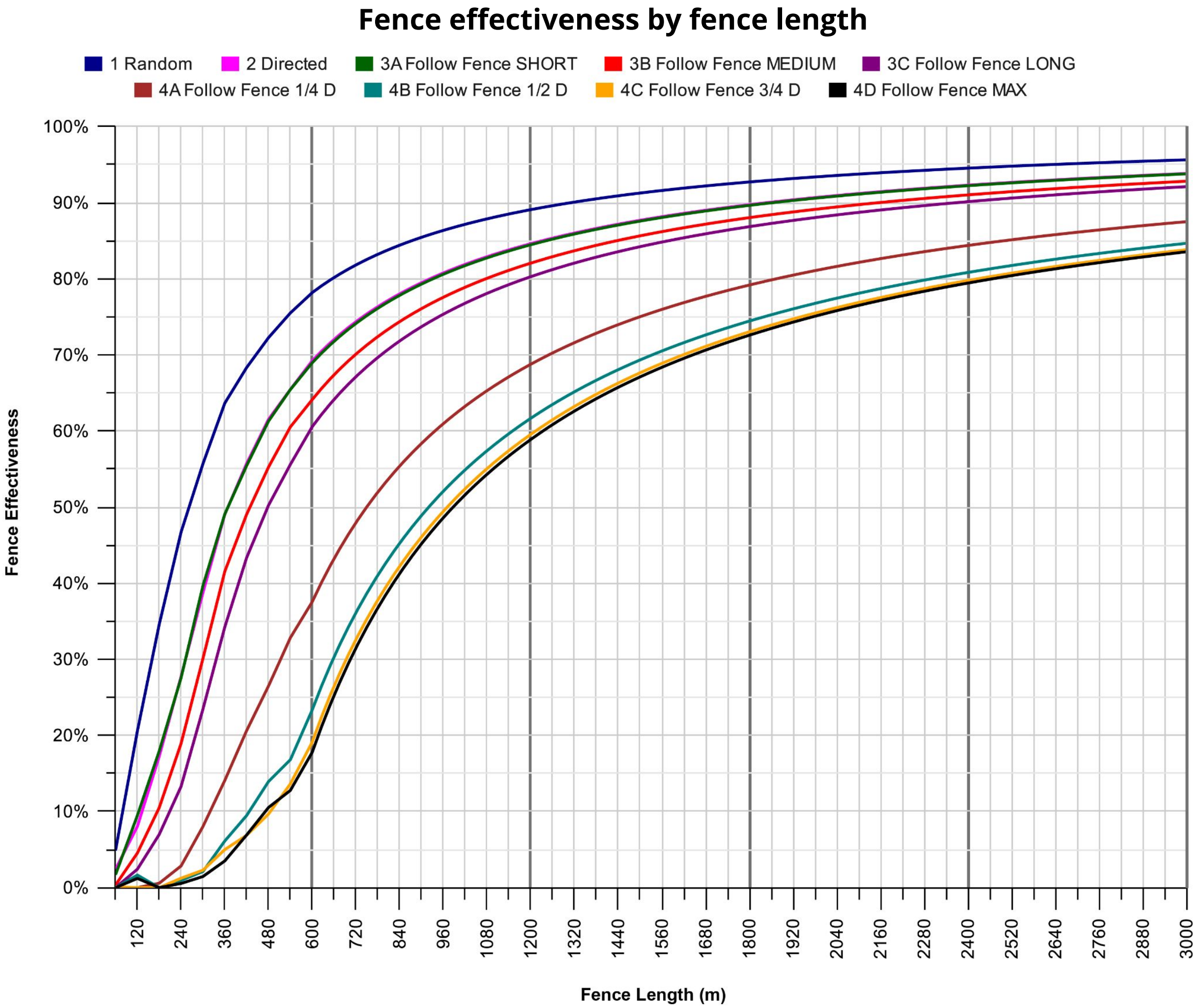
Results + Discussion

Long fences prevent significant numbers of road encounters

Fences with open ends can never be 100% effective because of the fence-end effect

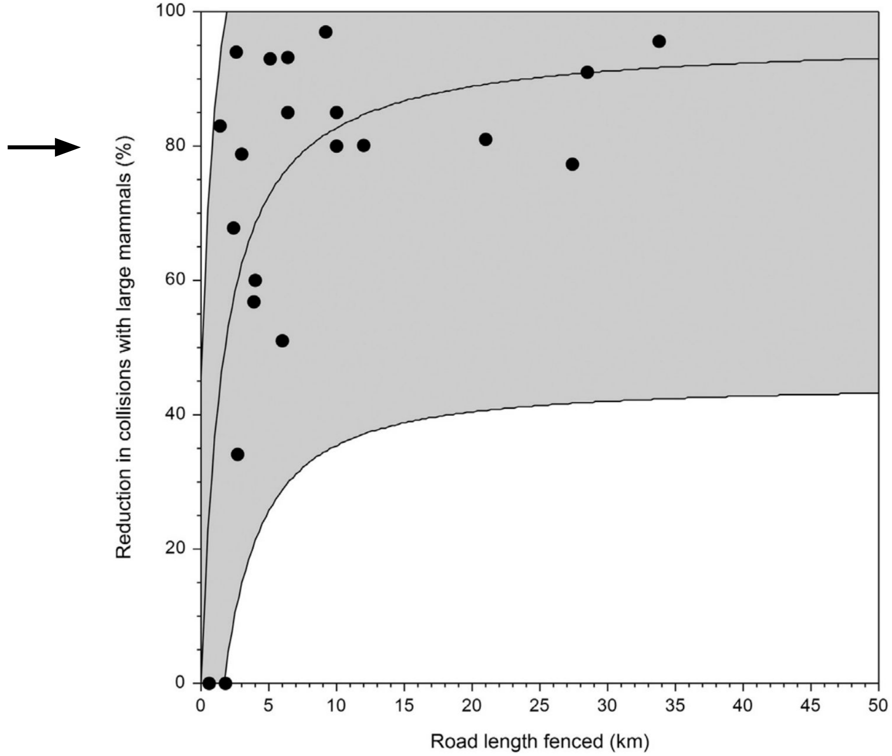
Short fences vary significantly in their effectiveness

Effectiveness is reduced by fence-following behavior



Comparison with Real-World Data

- Empirical data from Huijser et al. (2016) comparing reduction in collisions across different fence lengths...
- However, making a direct comparison is difficult
  - different species (large mammals)
  - collisions vs road encounters



Conclusion & Future Research

- IBM method to quantify fence-effectiveness
- Evidence to support/explain the fence-end effect
- Highlights the importance of <u>fence-following</u> behaviors
    - empirical data is needed

Future Work

- Refine animal-fence interactions based on literature

Fence-Following Distances

- **Yosemite Toads**
  - average distance of **46 m** before “giving up” (Brehme et al., 2022)
- **Common Toad**
  - “gave-up” after an average of **40 m** if they did not reach a tunnel passage (Ottburg and van der Grift 2019)
- **California Tiger Salamanders**
  - moved an average of **40 m** along barrier fencing when migrating before turning back into the habitat (Hobbs and Brehme 2017)
- **Other species…?**

Future Research

- Refine movement profiles based on literature

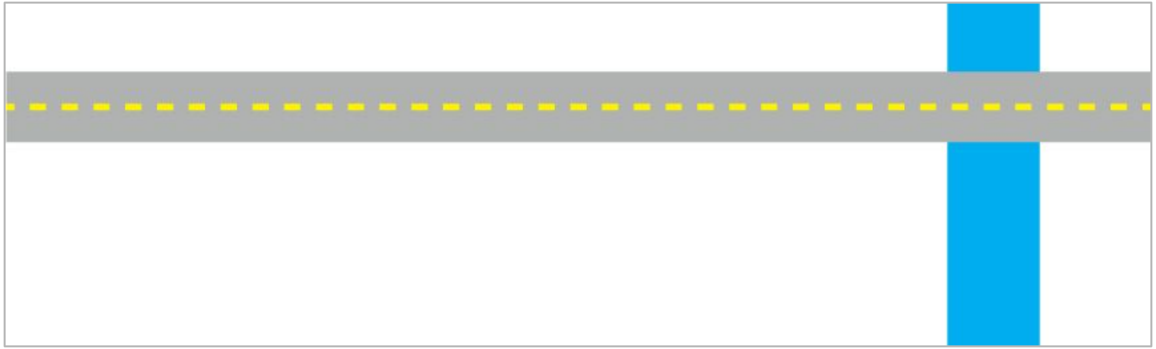
Other Applications

- Different species
- Specific landscape scenarios (e.g., migration, river)
- Wildlife passages
- Fence-end treatments
- FLOMS tradeoff (Spanowicz et al. 2020)
- Mitigation at fence ends

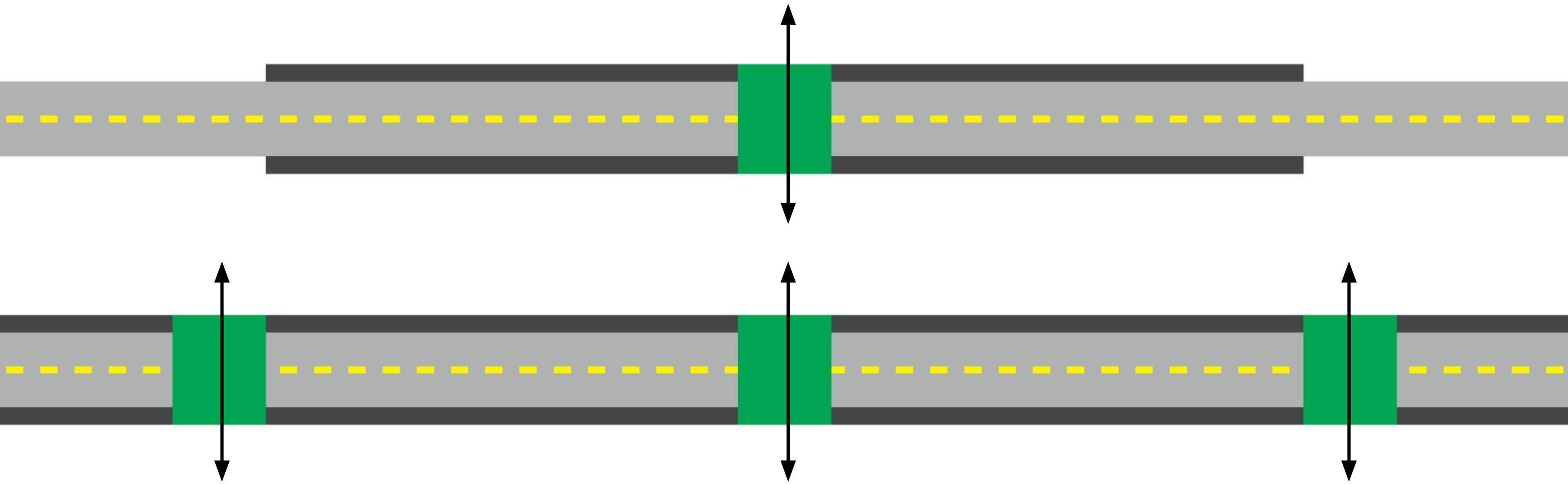
Specific landscape scenarios (e.g. river)

A

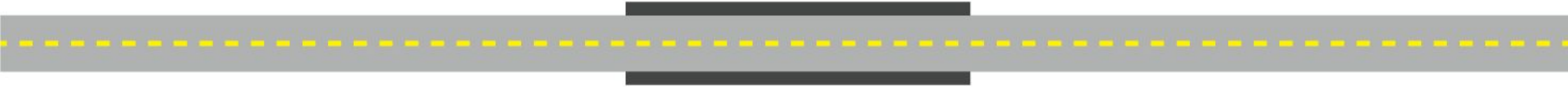
B

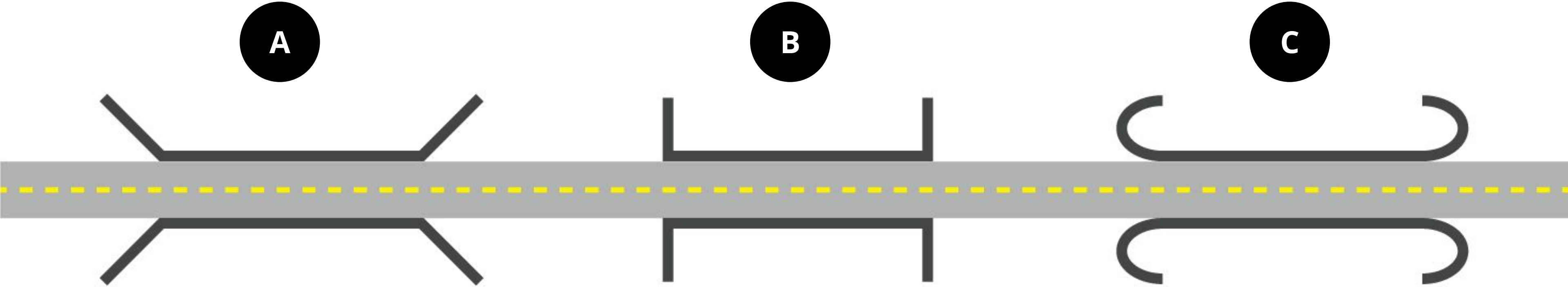


Wildlife Crossing Structures

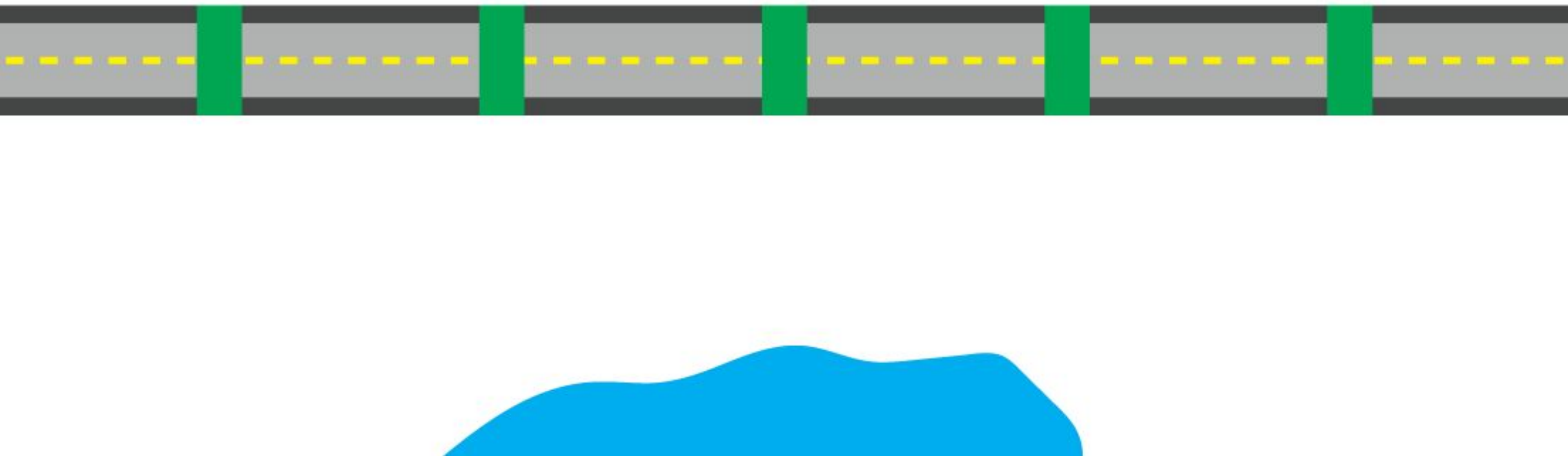


Fence-end Treatments

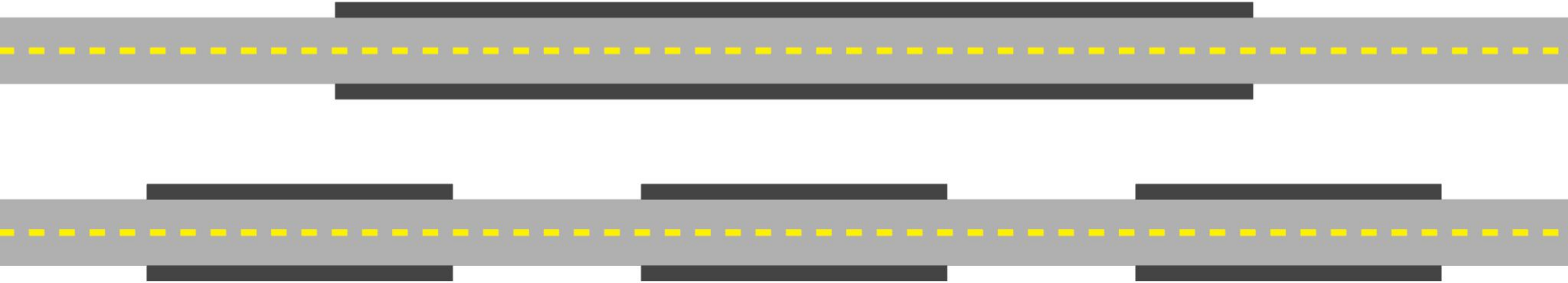




Specific landscape scenarios (e.g. migration)

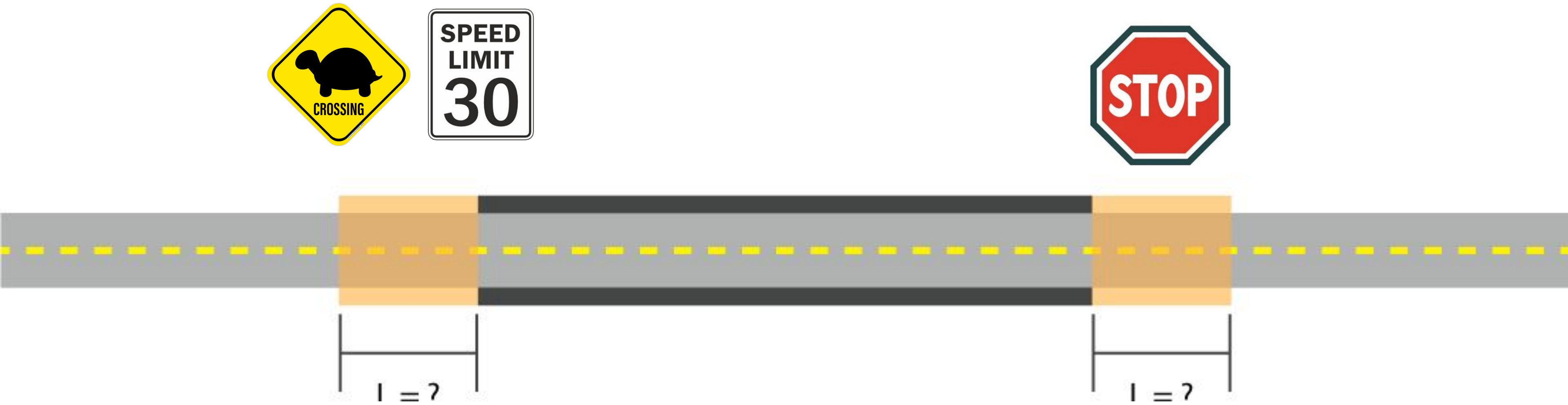


FLOMS Tradeoff (Few-Long-Or-Many-Short)



- An adaptive plan for prioritizing road sections for fencing to reduce animal mortality (Spanowicz et al. 2020)
    - fine-scale hotspots means less fencing is needed to reduce road mortality; however, many short fences may be less effective because of the fence-end effect

Mitigation at Fence Ends



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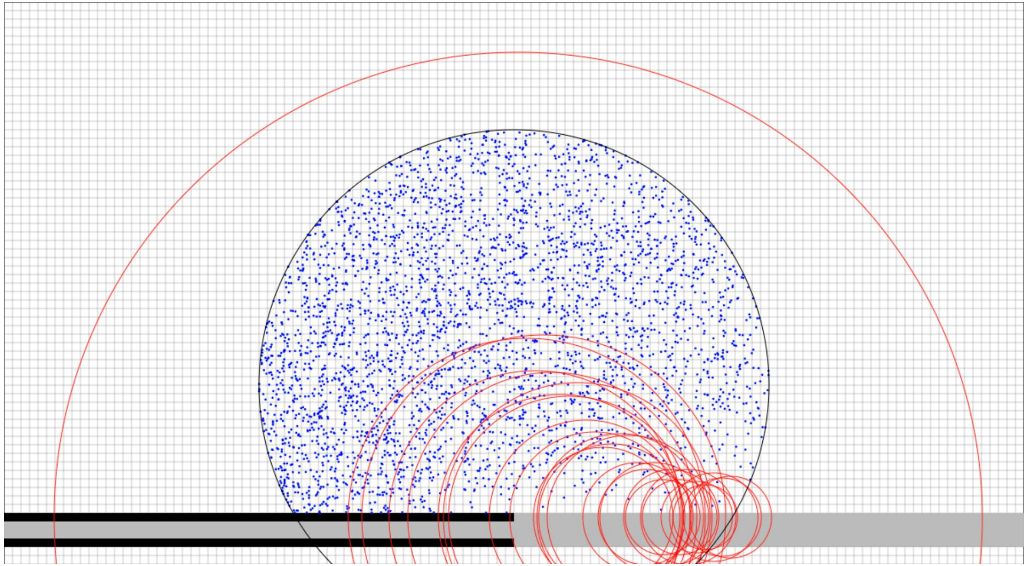
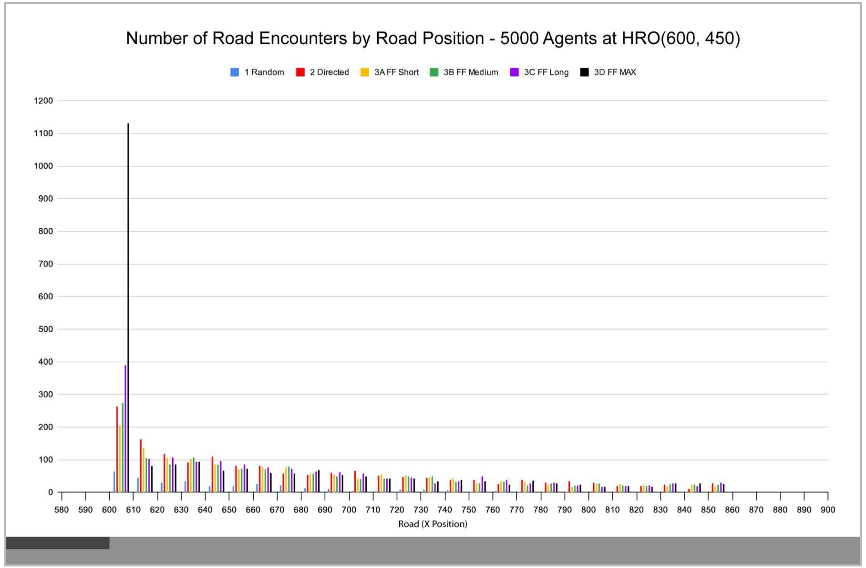
LEADS

Discussion: evidence supporting the fence-end effect



Profile 3B @ (600, 450), *L* = 600 m



Survival Ratios & Fence effectiveness

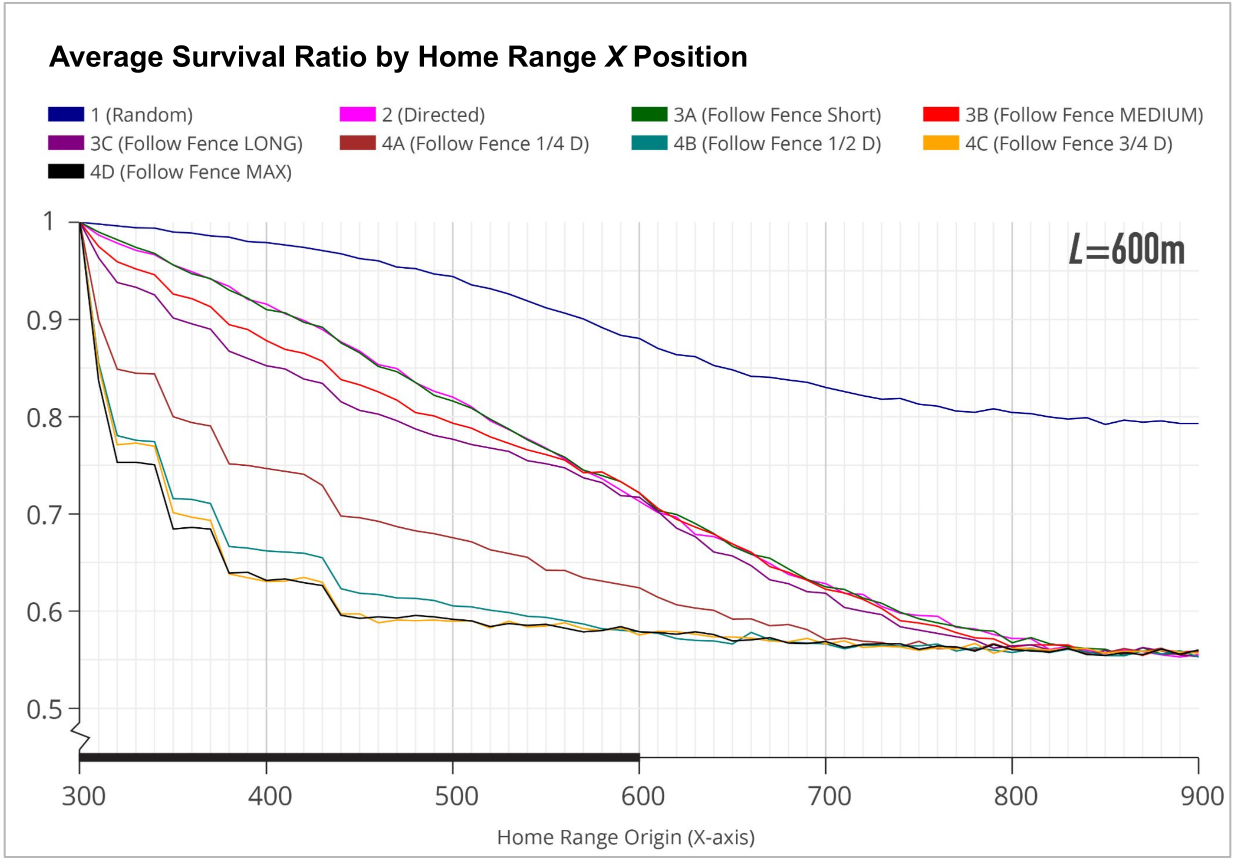
SR_2 → Average survival ratios for all X positions (with fence)

SR_1 → Survival ratio with no fence → occurs at x=900

Fence Effectiveness (FE)
$$= (SR_2 - SR_1) / (1 - SR_1)$$

$(SR_2 - SR_1)$: road encounters prevented by the fence

$(1 - SR_1)$: road encounters with no fence

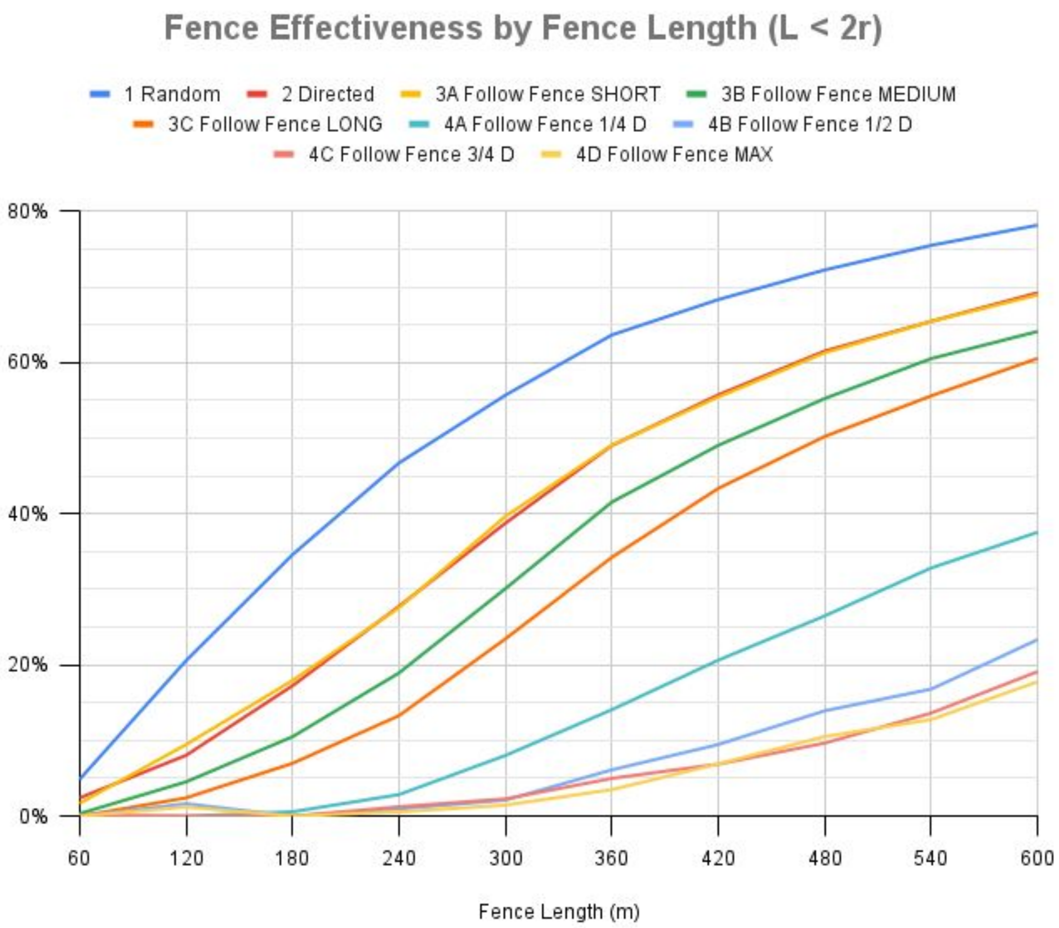


Results for $L \leq 2r$

Fence effectiveness decreases with

- fence length
- fence-following distances

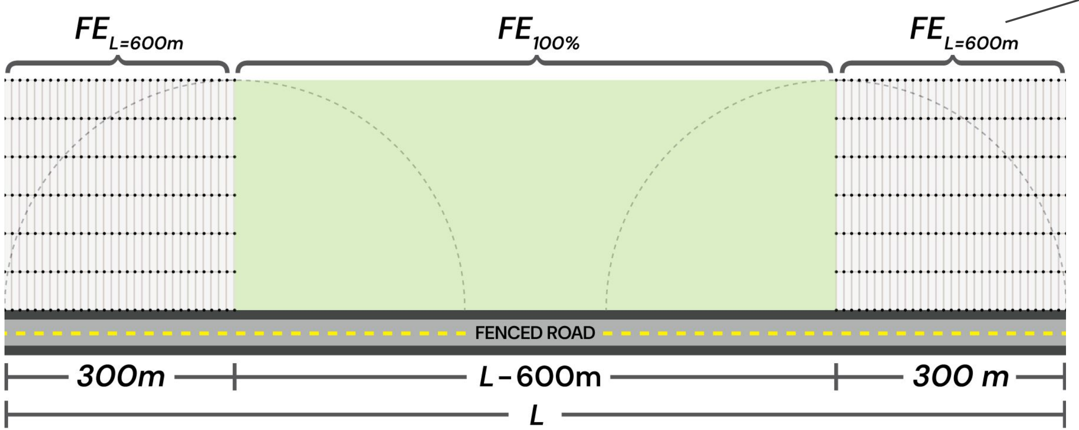
Movement Profile	Fence-Following Distance (m)	Fence Effectiveness (%)			
		60 m	240 m	420 m	600 m
1 Random	0	4.9	46.7	68.4	78.2
2 Directed	0	2.4	27.8	55.7	69.2
3A Follow Fence SHORT	5.6	1.7	27.6	55.5	69.0
3B Follow Fence MEDIUM	22.3	0.3	19.0	49.1	64.1
3C Follow Fence LONG	39	0.0	13.3	43.4	60.6
4A Follow Fence 1/4 D	150	0.0	2.9	20.6	37.6
4B Follow Fence 1/2 D	300	0.0	1.0	9.5	23.4
4C Follow Fence 3/4 D	450	0.1	1.2	6.9	19.1
4D Follow Fence MAX	600	0.0	0.6	6.9	17.8



Method for $L > 600$ m

Fences with length $L > D$ can be determined mathematically using a weighted average of…

- fence-end effectiveness at $L = D$, and
- the additional length contributing 100% effectiveness



$$FE(L) = \frac{(300\text{ m})FE_{L=600m} + (L - 600\text{ m})FE_{100\%} + (300\text{ m})FE_{L=600m}}{L}$$

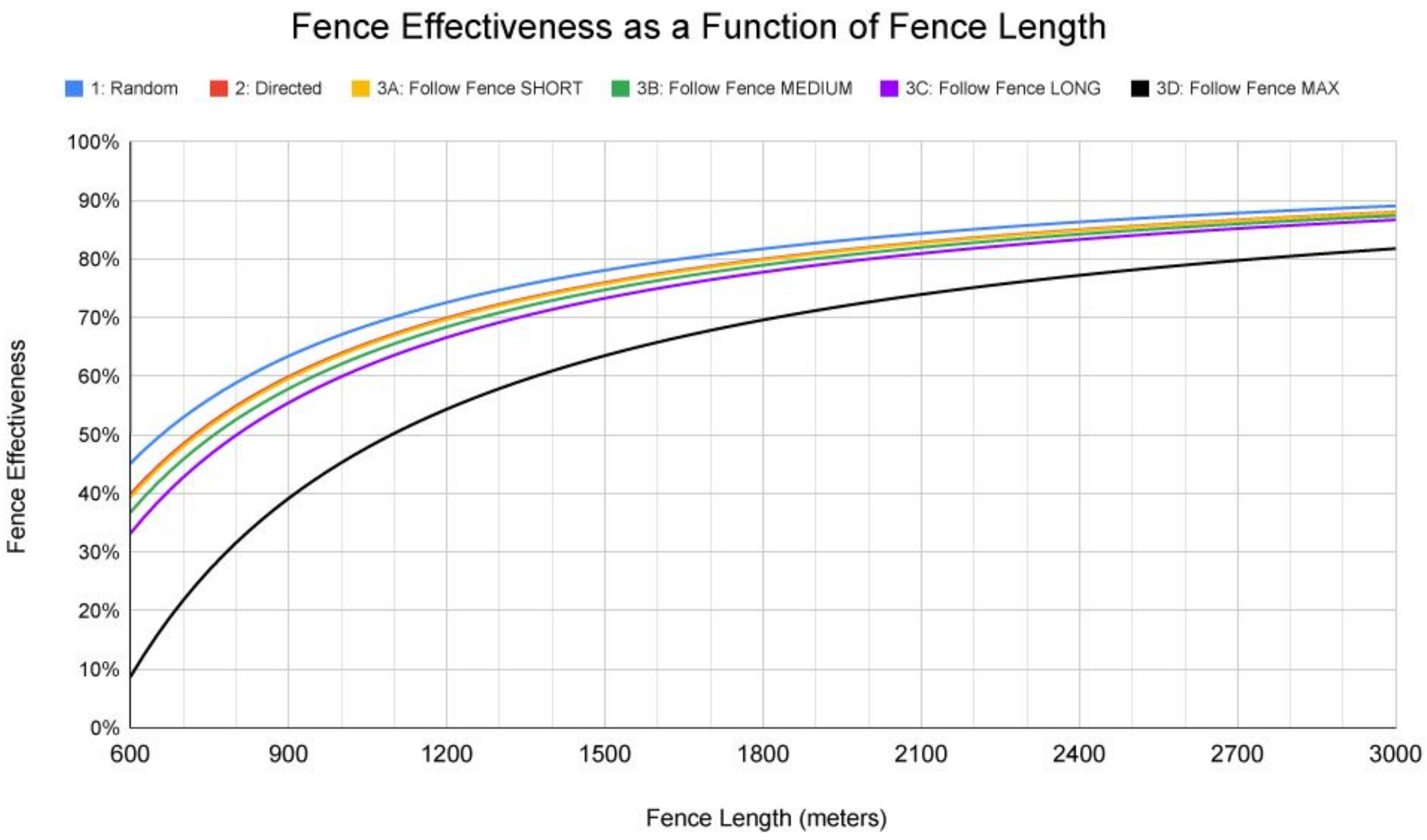
#	Movement Profile	FE (Fence Effectiveness) for *L* = 600 m
1	Random	78%
2	Directed Random	69%
3A	FF SHORT	69%
3B	FF MEDIUM	64%
3C	FF LONG	61%
4A	FF ¼ D	38%
4B	FF ½ D	23%
4C	FF ¾ D	19%
4D	FF MAX	18%

Fence effectiveness as a function of fence length

$$FE(L) = \frac{(600\text{m})(\text{FE}_{END}) + \ (L - 600\text{m})(1)}{L} \quad , \ L \geq 600$$

$$= \frac{(600m)(FE_{END} - 1)}{L} + 1 \quad , \ L \geq 600$$

#	Movement Profile	FE_{END}	FE(L)
1	Random	0.78	*FE(L)* = -130.86m/*L* + 1
2	Directed Random	0.69	*FE(L)* = -184.56m/*L* + 1
3A	Follow Fence SHORT	0.69	*FE(L)* = (-186.18)(*L*/m) + 1
3B	Follow Fence MEDIUM	0.64	*FE(L)* = (-215.22)(*L*/m) + 1
3C	Follow Fence LONG	0.61	*FE(L)* = (-236.58)(*L*/m) + 1
4A	Follow Fence ¼ D	0.38	*FE(L)* = (-374.64)(*L*/m) + 1
4B	Follow Fence ½ D	0.23	*FE(L)* = (-459.84)(*L*/m) + 1
4C	Follow Fence ¾ D	0.19	*FE(L)* = (-485.22)(*L*/m) + 1
4D	Follow Fence MAX	0.18	*FE(L)* = (-493.26)(*L*/m) + 1


Fence Effectiveness as a Function of Fence Length
1: Random
2: Directed
3A: Follow Fence SHORT
3B: Follow Fence MEDIUM
3C: Follow Fence LONG
3D: Follow Fence MAX
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Fence Effectiveness
600
900
1200
1500
1800
2100
2400
2700
3000
Fence Length (meters)

600 m ≤ L ≤ 3000 m

Probability of Road Mortality

- The effect of road kills on amphibian populations (Hels and Buchwald 2001)
    - Aimed to quantify the proportion of amphibian populations killed by WVCs, and to estimate the probability of being killed when crossing a road.

IBMs

- Effects of Road Fencing on Population Persistence (Jaeger & Fahrig, 2004)
  - Individual-based model: to predict when fencing is good or bad for population persistence
  - Roads: barrier to movement, road mortality, reduce amount & quality of habitat
  - Fences: reduce mortality but increase the barrier effect
- Predicting When Animal Populations Are at Risk from Roads: An Interactive Model of Road Avoidance Behavior (Jaeger et al., 2005)
  - predicts the effect of roads on population persistence, incorporating general avoidance behaviors and road characteristics. Rank risks based on relative values.

Fence-End Effect

- How do landscape context and fences influence roadkill locations of small and medium-sized mammals? (Plante, Jaeger, and Desrochers 2019)
    - Roadkill survey to examine the effect of newly installed fences and landscape on WVCs
    - Roadkill occurrence was significantly higher at the fence ends than in the fenced or unfenced portions (“Fence-end effect”)
    - Landscape influences discussed: vegetated medians, distance of the road to the forest edge, and distance to water.
    - Fences must be long enough to discourage the fence-end effect, but this study did not propose the length needed.
- Highway Mitigation Fencing Reduces Wildlife-Vehicle Collisions (Clevenger et al., 2001),
    - Banff National Park, fence along the Trans-Canada highway virtually eliminated WVC hotspots except for at the fence ends or at a fence opening. The road at the fence end showed the highest frequency of WVCs and the number tapered off with increasing distance on both sides.