Transmission dynamics and efficient management of vector-borne zoonoses

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Abstract

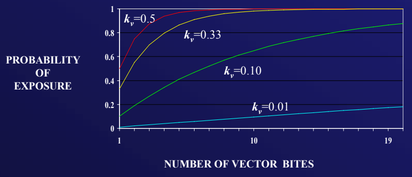
Vector-borne diseases can affect natural resources both by direct effects on wildlife health and by requiring vector control measures with substantial nontarget effects. Protection of public health can be maximized, and nontarget effects minimized, by efficient application of carefully-targeted interventions based on knowledge of pathogen transmission dynamics and appropriate surveillance data. Field studies and theoretical analyses of transmission dynamics, coupled with preliminary data on efficacy of various interventions, can be used to design efficient surveillance and management programs for vector-borne diseases. Data collected during application of management programs can be used to assess efficacy, and improve future management efforts.

Theory

Management methods for vector-borne diseases can protect public health but can have negative effects on natural resources. One way to minimize conflicts between protection of public health and of natural resources is to develop methods to manage vector-borne pathogens as efficiently as possible. The more efficient the management program, the fewer the number of human cases, and the less likely the necessity for broadscale interventions with widespread environmental effects.

The effectiveness of an intervention can be assessed by its effect on the probability of exposure to a pathogen (P_e), which is the probability of being bitten by at least one infected vector: $P_e = 1 - (1 - k_v)^n$ where n = # vector bites and k_v = proportion of vectors infected with the pathogen.

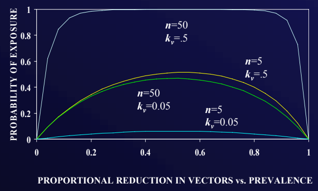
Fig. 1. Probability of exposure to pathogen



[modified from Ginsberg (1993)]

Note that the probability of exposure is not always related in linear fashion to the number of vector bites. The shape of the P_e curve depends on initial conditions of vector abundance and infection rate. Therefore, the effect on P_e of interventions that lower the abundance of ticks or mosquitoes depends on initial vector abundance and pathogen prevalence.

Fig. 2. Integration of methods to minimize disease risk



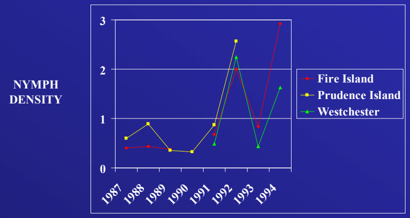
[modified from Ginsberg (2001)]

Integration of management methods is modeled in Fig. 2. Given different initial conditions, k_v is lowered to zero as you go from 0 to 1 on the horizontal axis,and n is lowered to zero as you go from 1 to 0. In the middle, each is lowered 50%. All else being equal, you should integrate methods that lower n with other methods that lower n, because if you integrate a method that lowers n with one that lowers k_v, you will move toward the center of the plot where P_e is highest. Of course, all else is often not equal.

Lyme disease

Lyme disease is a tick-borne spirochetal illness that occurs through much of the Northern Hemisphere. In eastern North America, the etiologic agent, *Borrelia burgdorferi*, is transmitted by the blacklegged tick, *Ixodes scapularis*. Lyme spirochetes cause illness in wildlife as well as in humans, but the severity of the illness differs in different species, and varies among individuals of species that show symptoms. Therefore, the direct effect of Lyme disease on wildlife populations is difficult to assess. However, human interventions to manage ticks can clearly affect nontarget species (Ginsberg 1994).

Fig. 3. Fluctuation of *Ixodes scapularis* populations at three northeastern sites



[modified from Ginsberg et al. (1998)]

Risk of Lyme disease to humans varies from year to year because of yearly changes in the abundance of infected ticks. Tick abundance depends in part on the abundance of white-tailed deer, the primary host of the adult stage of the tick. However, yearly fluctuations in tick numbers are consistent throughout southern New York and New England (Fig. 3) and result from factors such as weather that operate on a regional scale.

Infection prevalence in ticks also varies from year to year. The proportion of ticks infected depends on which host animals the ticks feed on. Experimental placement of uninfected larval ticks on various wild animal species (Table 1) shows that different species differ in reservoir competence for *B. burgdorferi*. In other words, uninfected ticks that feed on some species (such as white footed mice and robins) are more likely to pick up the spirochete than ticks that feed on species such as towhees (Ginsberg et al. 2005).

Table 1. Reservoir competence of several vertebrate species for *Borrelia burgdorferi*, Fire Island, NY, 1997.

	all host individuals tested			hosts w/at least one positive tick		
Host species	# larvae	# positive	(%)	# larvae	# positive	(%)
robin	31	5	(16.1 %)	15	5	(33.3 %)
catbird	50	2	(4.0 %)	8	2	(25.0 %)
towhee	56	1	(1.8 %)	11	1	(9.1 %)
song sparrow	51	2	(3.9 %)	6	2	(33.3 %)
cardinal	23	2	(8.7 %)	9	2	(22.2 %)
w-f mouse (field)	372	207	(55.6 %)	353	207	(58.6 %)
w-f mouse (uninfected lab controls)	66	0	(0 %)	0	0	

Effectiveness of Lyme disease management can be predicted using models of transmission dynamics (as in Fig. 1) along with preliminary data on initial conditions and efficacy. Analysis of data from Fire Island National Seashore, NY, suggests that of the methods tested, a rigorous personal protection program provides the best protection for park staff (Table 2). This approach also has the advantages of broad applicability and virtually no environmental effect. If we wish to integrate methods, addition of permethrin-treated cotton balls (PTC) would lower risk the most (Table 3). Note that this would involve integrating a method that lowers n (personal protection) with one that lowers k_v (PTC), in seeming contradiction to Fig. 2. This result comes from the fact that "all else" is not equal; in this case, efficacy of PTC at lowering k_v was greater than the other approaches at lowering n. Therefore, rather than following broad guidelines, vector management programs should be developed and analyzed according to local conditions.

Table 2. Fire Island, New York – Initial choice
Initial conditions: $P_e = 0.12$ $k_v = 0.321$ $n = 0.33$

Technique	Efficacy	Source	Resulting P_e
self-protection	lowers n 92%	Dattwyler pers. comm.	0.0096
PTC	lowers k_v 86%	Ginsberg 1992	0.015
barrier	lowers n 64%	Carroll et al. 1992	0.045
exclude deer	lowers n 35%	Ginsberg et al. 2004	0.078

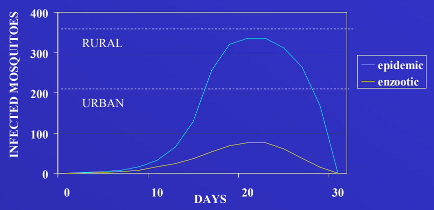
Table 3. Fire Island, New York – Integrating techniques
After implementing self-protection program:
$P_e = 0.01$ $k_v = 0.321$ $n = 0.026$

Technique	Efficacy	Resulting P_e
PTC	lower k_v 86%	0.0012
barrier	lower n 64%	0.0036
exclude deer	lower n 35%	0.0066

West Nile Virus

West Nile Virus was introduced into New York City in 1999, and has since spread through most of the United States. The main vectors are mosquitoes of the genus *Culex* that breed in containers and so are common in urban areas. Transmission can rapidly increase to epizootic levels when mosquito vectors and bird reservoirs are abundant.

Fig. 4. WNV epizootic activity



Efficient management of WNV requires a surveillance program that can distinguish early (days 10-12 in Fig. 4) between routine enzootic activity, and increasing epizootic activity that might lead to human illness.

We established surveillance and management protocols at Gateway National Recreation Area and Fire Island National Seashore that used surveillance data to make management decisions with a tiered response to increasing levels of human risk.

Level 1) Source reduction, surveillance (dead birds, mosquitoes, viral testing) and public education; **Level 2)** Detection and public notification (plus consultation with local and federal experts); **Level 3)** Mosquito management (nature and scale of intervention tied to surveillance). This approach avoided unneeded interventions while maximizing public health protection with available resources.

Conclusions

Several elements contribute to an efficient vector-borne disease management program that can minimize the number of human cases while also minimizing negative effects on wildlife.

- ***Research :*** **It is essential to understand the natural transmission dynamics of the pathogen**
- ***Surveillance:*** **Initial conditions of vector abundance and infection prevalence must be known because they influence the efficacy of management.**
- ***Targeted interventions:*** **Carefully targeted interventions prevent the most possible human cases and minimize broadscale nontarget effects.**
- ***IPM:*** **Interventions should be integrated so as to most efficiently lower the number of human cases.**
- ***Adaptive management:*** **Data should be taken to evaluate management and improve subsequent interventions.**

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