Belsare, A. V., Gompper, M. E., Millspaugh, J. J. (2019, August 08). "MO*Ov*POP*surveillance*". *CoMSES Computational Model Library*.

Research article describing this model: Belsare, A.V., Gompper, M.E., Keller, B.J., Sumners, J.A., Hansen, L.P., and Millspaugh, J.J. An agent-based framework for improving wildlife disease surveillance: A case study of chronic wasting disease in Missouri white-tailed deer. 2020. *Ecological Modelling* 417 (108919). (*F1000Prime Recommended Article*).

Purpose

MO*Ov*POP*surveillance* was developed as a tool for wildlife agencies to guide collection and analysis of disease surveillance data that relies on non-probabilistic methods like harvest-based sampling. Epidemiological surveillance for important wildlife diseases mostly relies on samples obtained from hunter-harvested animals. Though this is a convenient and cost-effective strategy, samples so obtained may not be representative of the population primarily due to sampling biases associated with harvest and heterogeneities associated with the spatiotemporal distribution of a disease in the population. This model incorporates sampling biases and disease distribution heterogeneities and provides population-specific recommendations for disease surveillance using hunter-harvested animals (or other non-probabilistic sampling methods).

Currently the model is set up to represent chronic wasting disease (CWD) surveillance of white-tailed deer (*Odocoileus virginianus*) populations in Missouri, but it can be readily adapted for other disease systems and used for informed-decision making during planning and implementation stages of disease surveillance in wildlife and free-ranging species.

Chronic wasting disease (CWD) is an emerging prion disease of North American cervids, including white-tailed deer, mule deer (*Odocoileus hemionus*), elk (*Cervus elaphus*) and moose (*Alces alces*), that represents a unique challenge for wildlife agencies in the United States. Considerable uncertainty remains about CWD

transmission dynamics in cervids, as mechanisms and factors driving transmission of this disease are poorly understood.

The basic model, MO*Ov*POP, simulates population dynamics of white-tailed deer and generates pre-harvest deer population (abundance, sex-age composition, and distribution in the landscape) for the selected sampling region. These population data are stored as an Excel file. MO*Ov*POP*surveillance* is formulated to simulate hunter harvest and CWD testing under different assumptions. This model extension can be used to determine the probability of detecting an infected individual in the sample population for a specified level of population prevalence.

How to use the model:

Pre-harvest population files for Missouri Counties are available for download along with the model from the CoMSES digital repository (data folder). Alternatively, model MO*Ov*POP_v2.2.0 can be used to generate a pre-harvest population snapshot of white-tailed deer for selected regions of interest. Model MO*Ov*POP_v2.2.0 is available here: https://www.comses.net/codebases/5585/releases/2.2.0/.

Entities, state variables and scales

Spatial scales: MO*Ov*POP*surveillance* landscape can be set up for individual counties as well as for current or potential CWD management zones. Miles (rather than kilometers) are used as a distance and area measure in this work because of the past and current norms of the region and its management agencies, and the related need to make the results immediately applicable to those same agencies

Temporal scale: MO*Ov*POP*surveillance* runs for one time-step (one month).

Entities: MO*Ov*POP*surveillance* has two entities: patches and deer. Irrespective of the region selected for simulation, each patch in the model landscape represents one square mile. Deer are modeled as individuals occupying the patches.

State variables: Each patch is characterized by its percent forest cover (*forest-percent*), whether it is a border or non-border patch (*border*), whether it qualifies as deer habitat (*dh*), deer occupancy (*do*), and mean forest-percent (*dfp*) (Table 1). The mean forest-percent is calculated for each patch by averaging forest cover of a patch and its

immediate neighbors. Average deer density for a patch and its immediate neighbors is stored using the patch variable *add* (average deer density). Another patch variable, *hp*, designates the harvest pressure for a patch (high, low or no harvest).

Each deer in the model has 11 state variables (Table 1), which define individual characteristics like age, sex, group membership and status, CWD infection status (*cwd*), whether the deer is marked for harvest (*marked-for- harvest*?), and whether a deer marked for harvest is also marked for sampling (*marked-for-testing?*).

Process overview and scheduling

MO*Ov*POP*surveillance* implements three processes: individual growth, non-hunting mortality and hunting mortality with CWD testing.

Schedule: Growth (increase age by one month) of individuals is scheduled at the beginning of the time step and is followed by non-hunting mortality and hunting mortality. Hunting mortality also includes CWD testing.

Design concepts

Basic principles.

Processes like social organization, group dynamics, dispersal, and hunting mortality occur at an individual level and influence interactions among individuals. Such interactions underpin host heterogeneity, and thereby influence disease transmission in a host population. We incorporated these processes in the basic model so that the model-generated population reflects heterogeneity observed in real-world host populations. MO*Ov*POP-generated deer population is used to initialize MO*Ov*CWD (model simulating CWD transmission dynamics in deer population) and MO*Ov*POP*surveillance*. Further, MO*Ov*POP*surveillance* can simulate CWD distribution heterogeneity (clustered distribution of CWD+ deer in the landscape, and/or age-sex class wise distribution of CWD cases) and sampling heterogeneity (or non-random sampling of deer) to account for real-world sampling biases.

Stochasticity: Deer mortality rates (natural and hunting) are deterministic, but individuals that die during a time step are chosen randomly. The distribution of CWD cases in the

model population and selection of deer from hunter harvest are both stochastic processes.

Observation: MO*Ov*POP*surveillance* displays the total number of adult deer (male and female) in the population, number of CWD+ deer in the hunter harvest, and number of CWD+ deer in the sample (deer tested for CWD). If an alternate scenario (clustered_dist) is selected, the graphical display highlights the area where CWD cases are clustered in the model landscape. Additionally, information like number of fawns, yearlings and adults harvested (separately for both sexes), number of CWD+ deer in the hunter harvest, and number of CWD+ deer detected is recorded in the output file *CWDsurveillanceMO.csv*.

Initialization

MO*Ov*POP*surveillance* is initialized by importing model-generated pre-harvest deer population data (abundance, sex-age composition, and distribution in the landscape) for the sampling region under consideration.

Submodels

1. Individual growth

This submodel is executed at the beginning of the time step. All deer in the model landscape update their state variable ‘aim’ (age in months) by one month.

2. Non-hunting mortality

The probability of a deer dying of natural or other non-hunting related causes during every time step is determined by age- and sex- specific monthly mortality rates (Table 2). Irrespective of these rates, old deer (>240 months) have an overall high probability of dying (0.8) during a time step.

3. Hunting mortality

Deer surviving the monthly non-hunting mortality execute the hunting mortality submodel. The probability of a deer being included in the hunter harvest is specified by the age- and sex- specific hunting mortality rates (Table 2).

In MO*Ov*POP*surveillance*, patches with high average deer density (patch variable *add*) are designated as hunter-preferred patches. Deer are selected randomly for inclusion in hunter harvest in the baseline scenario; while in the alternate scenario ~50% of deer harvest occurs on hunter-preferred patches (non-random sampling). Further, the probability of testing harvested deer for CWD is specified by the observer using the 'Percent harvest tested' sliders for each age-sex class. The following counters for each age class-sex category are also updated: number of deer harvested on high/low/no harvest patches, CWD+ deer harvested, sample size, number of CWD+ deer in the harvest, and the number of CWD+ deer in the sample.

Parameterization and Calibration Population dynamics of the model deer population is defined by two sets of age-sex-specific parameters, *hunting mortality rates* and *non-hunting mortality rates*. We classify deer in four age-classes: young fawns (up to 6 months old), older fawns (7 to 12 months old), yearlings (13 to 24 months old) and adults (25 months or older). It should be noted that non-hunting mortality rates are per month rates while hunting mortality rates are annual (Table 2).

Additionally, MO*Ov*POP*surveillance* has 12 user-specified parameters that define the distribution of CWD cases in the model landscape, nature of sampling (random or non-random) and sampling intensity. The chooser *cwd_distribution* specifies the distribution of CWD+ deer in the landscape: CWD+ deer are either randomly distributed throughout the model landscape (*random_dist*), or are limited in distribution on a group of contiguous patches (*clustered_dist*). Furthermore, four sliders on the interface (*fawn-prevalence*, *yearling-prevalence*, *adult-prevalence*, and *m-f-prev-ratio*) can be used to specify age-sex class wise distribution of CWD prevalence. Another chooser, '*sampling*' selects the sampling process, random or non-random sampling. Sample size for each age-sex class can be set using appropriate sliders on the interface (*%fawn-male-harvest-tested*, *%fawn-female-harvest-tested*, *%yearling-male-harvest-tested*, *%yearling-female-harvest-tested*, *%adult-male-harvest-tested* and *%adult-female-harvest-tested*).

Table1. Agents included in MO*Ov*POP*surveillance* and their state variables. All state variables except the deer state variable '*aim*' are unitless.

Agent	Variable	Description
Patch	forest-percent	forest cover on a patch expressed as a proportion
	border	patches at the edge of the model landscape have border = 1, other patches have border = 0
	dfp	mean forest-percent calculated for a patch and its immediate neighbors
	dh	deer habitat; ≥ 1 if a patch qualifies as deer habitat, < 1 if it is not a deer habitat
	do	deer occupancy; 1 if deer occur on a patch, 0 if not
	dcl	identifies patches where CWD is clustered
	add	average deer density for a patch and its eight neighbors
Deer	sex	1 if male, 2 if female
	aim	age in months
	momid	mother's id number
	gl	1 if doe social group leader, 0 otherwise
	ml	1 if bachelor group leader, 0 otherwise
	fgroid	≥ 0 if member of a doe social group, -1 if solitary female, 0 for male deer
	gr	for doe social group leaders, gr denotes the number of group members; -1 for non-leader members of a doe social group, -2 if for solitary female deer, and 0 for all yearling and adult male deer
	mgroid	0 for all females, -2 for male fawns, -1 for male yearlings, and for bachelor group members it takes the value of group leader id
	cwd	cwd infection status (infected deer cwd = 1, uninfected deer cwd = 0)
	marked-for-harvest?	deer marked for harvest
	marked-for-testing?	deer marked for sampling (CWD testing)

Table 2. Age- and sex-specific mortality parameter values used in MO*Ov*POP and MO*Ov*POP*surveillance*.

Parameter	Description	Value
Non-hunting mortality		
mf6nhm	male fawns (0 - 6 months)	0.055 per month [a]
ff6nhm	female fawns (0 - 6 months)	0.055 per month [a]
mf12nhm	male fawns (7 - 12 months)	0.05 per month [b]
ff12nhm	female fawns (7 - 12 months)	0.05 per month [b]
mynhm	male yearlings (13 - 24 months)	0.01 per month [b]
fynhm	female yearlings (13 - 24 months)	0.00 per month [b]
manhm	male adults (> 25 months)	0.01 per month [b]
fanhm	female adults (> 25 months)	0.02 per month [b]
Hunting mortality		
mf6hm	male fawns (0 - 6 months)	0 [c]
ff6hm	female fawns (0 - 6 months)	0 [c]
mf12hm	male fawns (7 - 12 months)	0.05 per year [c]
ff12hm	female fawns (7 - 12 months)	0.02 per year [c]
myhm	male yearlings (13 - 24 months)	0.25 per year [c]
fyhm	male yearlings (13 - 24 months)	0.15 per year [c]
mahm	male adults (> 25 months)	0.40 per year [c]
fahm	male adults (> 25 months)	0.20 per year [c]

[a] Hiller, T.L., Campa III, H., Winterstein, S.R., Rudolph, B.A., 2008. Survival and space use of fawn white-tailed deer in southern Michigan. The American Midland Naturalist 159, 403-412.
[b] Van Deelen, T.R., Campa III, H., Haufler, J.B., Thompson, P.D., 1997. Mortality patterns of white-tailed deer in Michigan's Upper Peninsula. The Journal of wildlife management, 903-910.
[c] Derived from hunter-harvest data collected by Missouri Department of Conservation.