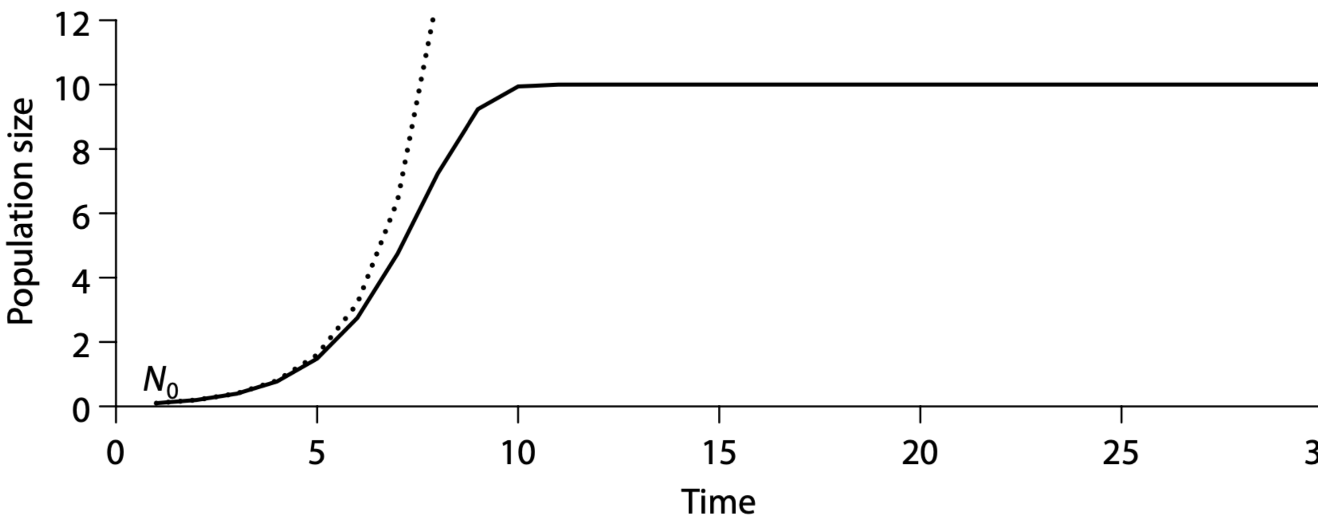
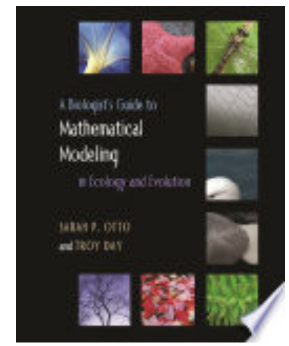
Why “ecological forecasting”?

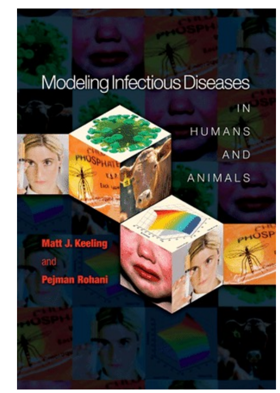
Amy Hurford
Memorial University

Population biology, deterministic dynamical systems, mechanistic models



Dietz 2017. Ecological forecasting. Ch 2.





$$\frac{dN(t)}{dt} = rN(t)\left(1 - \frac{N(t)}{K}\right)$$

$$N_{t+1} = N_t + rN_t\left(1 - \frac{N_t}{K}\right)$$

Simple parameterization approach

$$N_{t+1} = N_t + rN_t\left(1 - \frac{N_t}{K}\right)$$

- r = b – d
- b: births per individual per time step
- d: fraction of the population that dies per time step

$$\frac{dN(t)}{dt} = rN(t)\left(1 - \frac{N(t)}{K}\right)$$

Simple parameterization approach

The information below is taken from the following source:

Newcomb, HR. 1940. Ring-necked pheasant studies on Protection Island in the Strait of Juan de Fuca, Washington. MS thesis. Oregon State University.

a. Pheasant chicks are born during the summer.
b. In May 1937, 10 pheasants were introduced to the island. Before the next breeding season there were 35.
c. November 10, 1938 a census estimated 110 pheasants.
d. October 13, 1939 a census estimated 400 pheasants.
e. Between the 1938 and 1939 censuses, Newcomb observed that 17 adult birds died.
f. During the 1938 nesting season: 5.86 eggs/nest. 83.57% of eggs hatched.
g. During the 1939 nesting season: 8.73 eggs/nest. 64.58% hatched.
h. During the 1939 nesting season: Average number of chicks per clutch was 6.93.[1]
i. You can assume the sex ratio is 50:50 male to female. Pheasants are a sexually reproducing species.

Simple parameterization approach

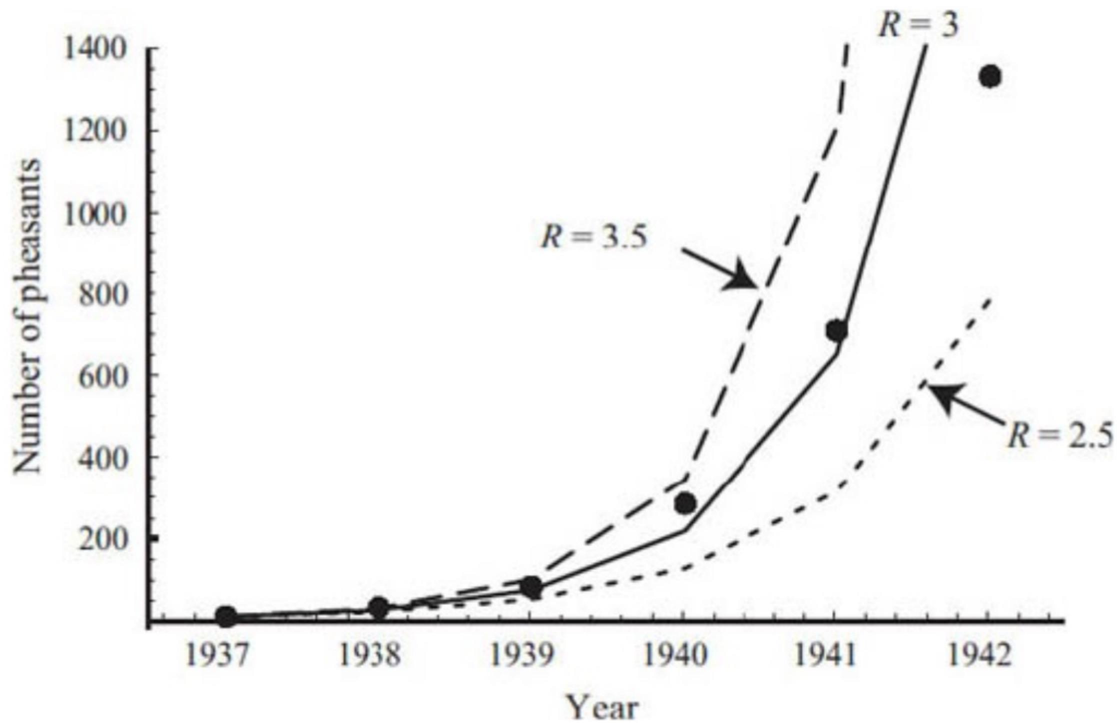


Figure 3.2: Example of exponential population growth in pheasants. The dots are based on spring census data (Lack 1954). The

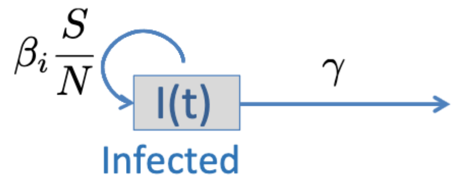
Otto & Day 2007. A biologists guide to mathematical modelling.

Simple parameterization approach

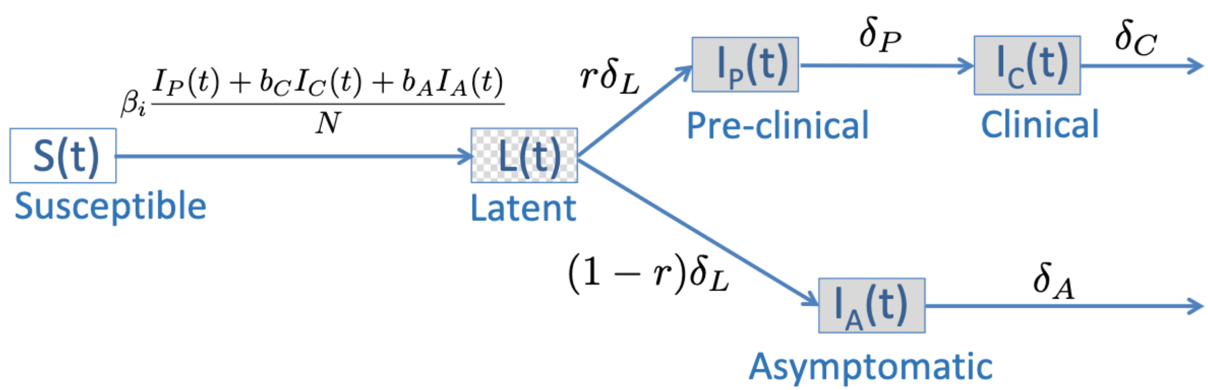
$$\frac{dI(t)}{dt} = ac_i S \frac{I(t)}{N} - \gamma I(t) + m_i$$

$$\frac{dC(t)}{dt} = ac_i S \frac{I(t)}{N},$$

Linear SIR model



COVID-19 model



Hurford & Watmough. 2021. Don't wait; re-escalate: delayed action results in longer duration of COVID-19 restrictions.

Simple parameterization approach

		Newfoundland and Labrador		New Brunswick	
	units	Fixed parameters			
Date corresponding to $t = 0$	date	March 23, 2020		March 18, 2020	
Recovery rate, γ	individuals per day	1/14		1/14	
Active cases when restrictions lifted, I_2	individuals	5		5	
Initial number of infected individuals, $I(0)$	individuals	10		10	
Day restrictions are enacted, t_1	day	14		18	
End time, t_2	day	65		50	
		Fitted parameters			
Exponential coefficient prior to restrictions, λ_1	per day	-0.104		0.027	
Exponential coefficient after restrictions, λ_2	per day	-0.086		-0.093	
Importation rate, m_1	individuals per day	25.9		2.70	
		Data	Predicted	Data	Predicted
Active infected individuals at peak, I_1	individuals	192	197	73	81
Duration of restrictions, τ	days	43	43	22	30
Total number of cases, $C(t_2)$	individuals	260	293	120	117

Hurford & Watmough. 2021. Don’t wait; re-escalate: delayed action results in longer duration of COVID-19 restrictions.

Simple parameterization approach

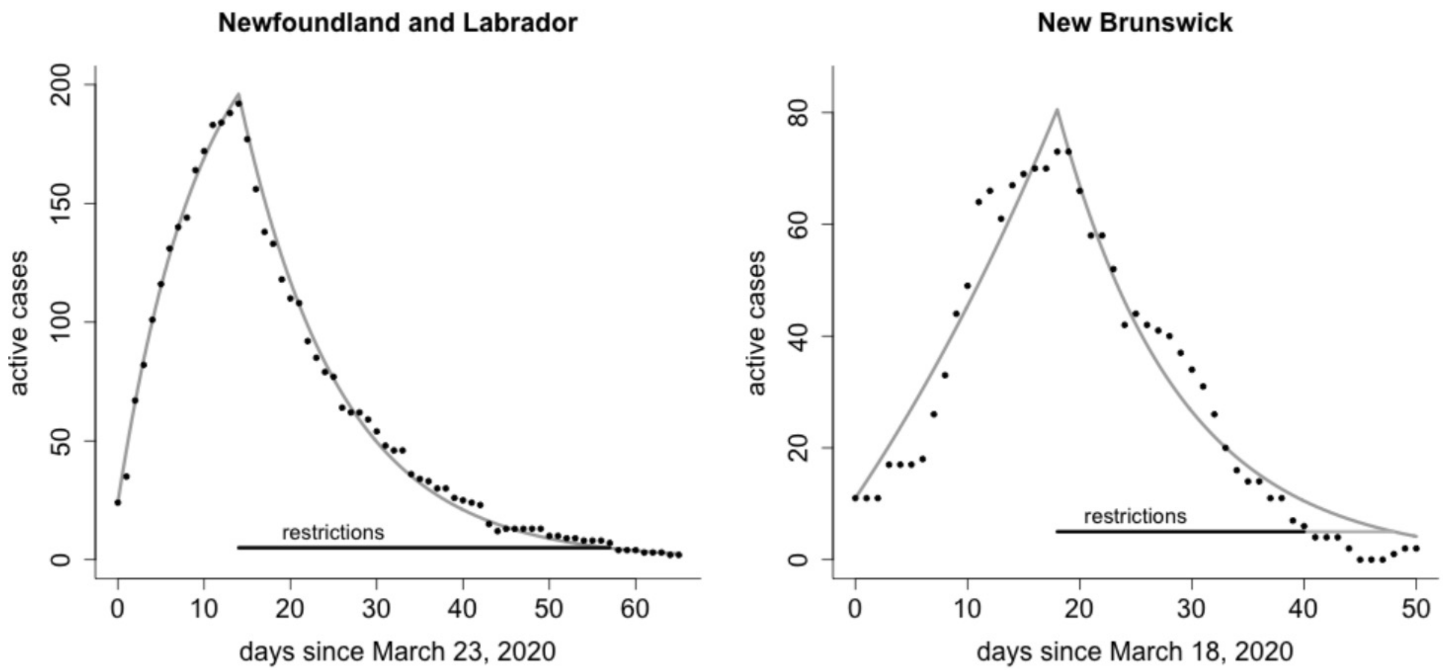
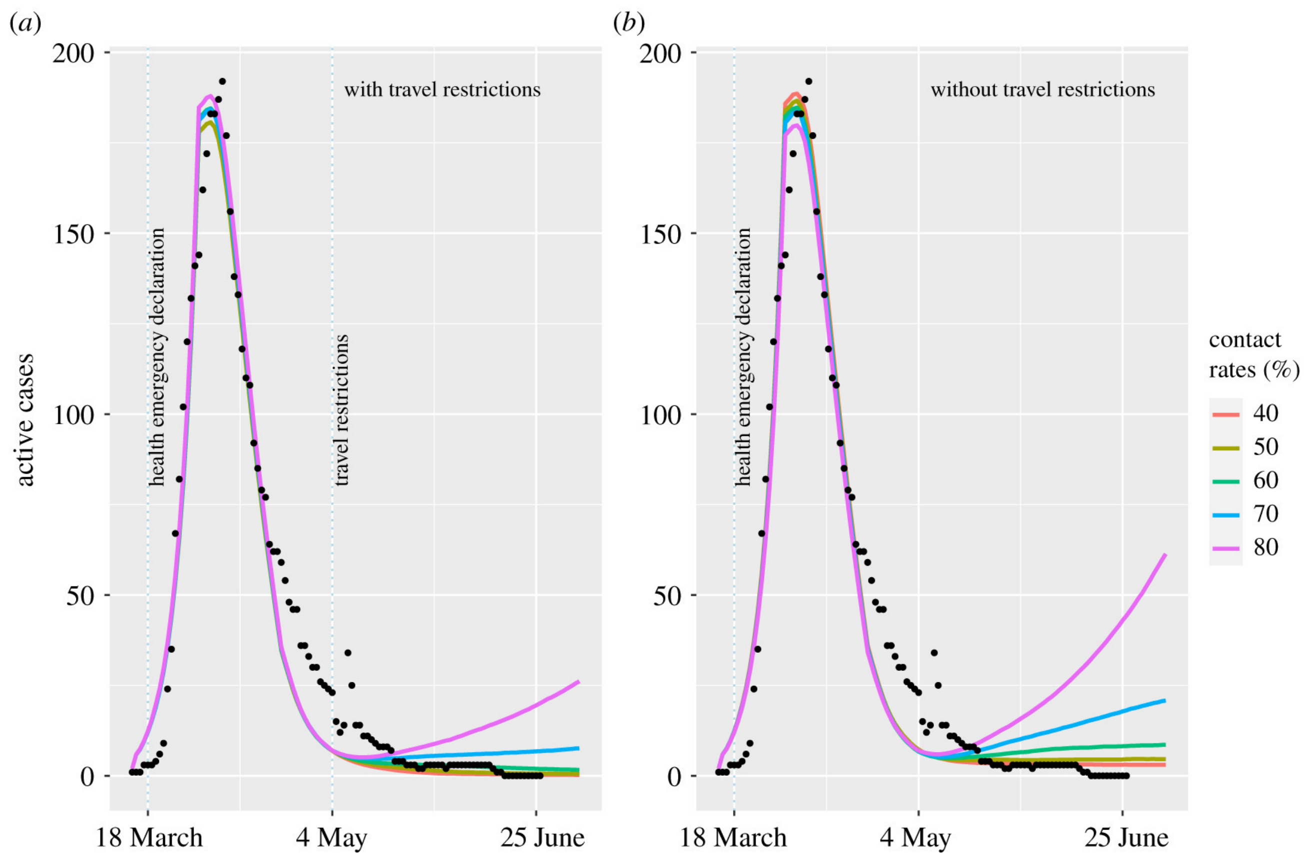


Fig. 1 The linear SIR model fitted to data describing the active number of COVID-19 cases in Newfoundland and Labrador and New Brunswick from March-May, 2020. Equation 1a,

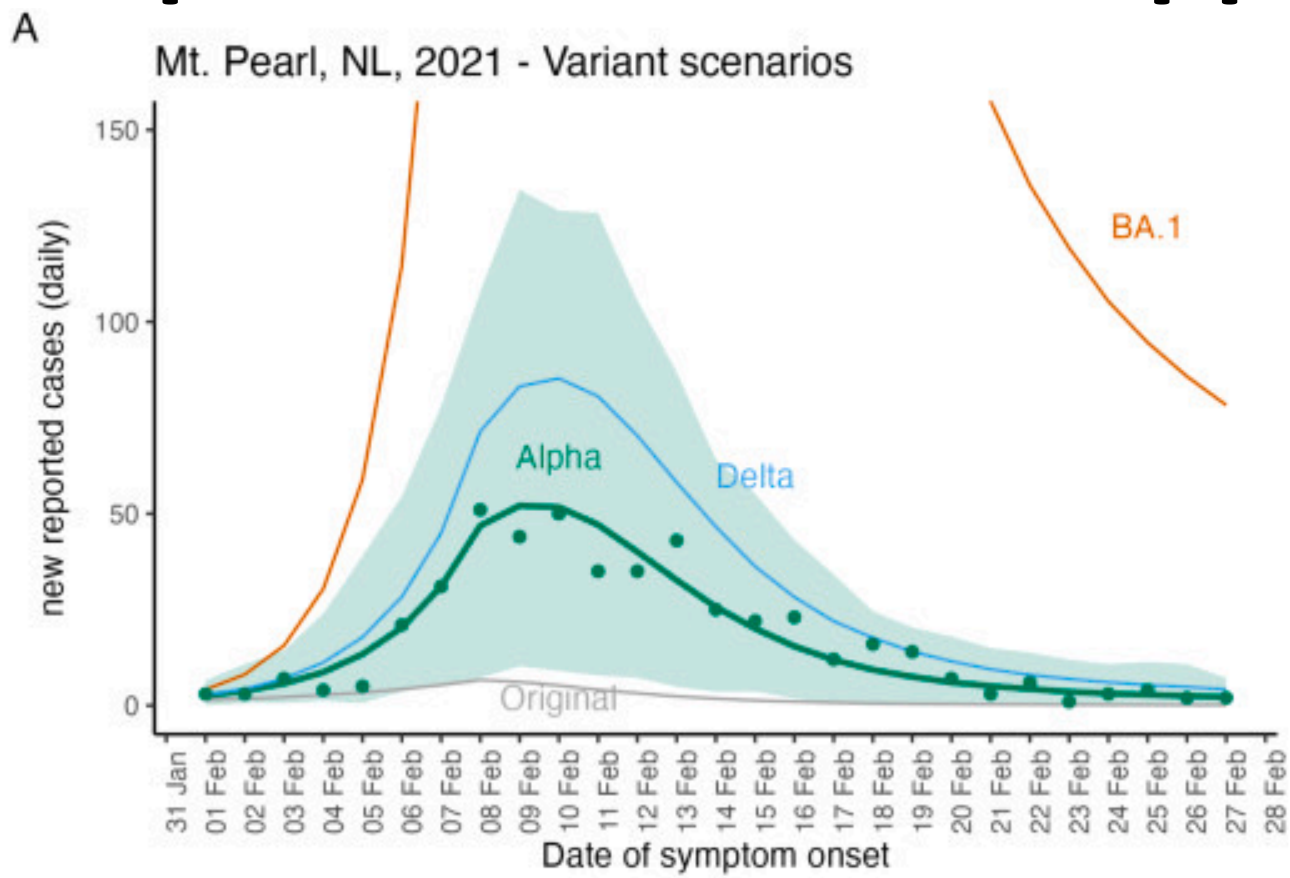
Hurford & Watmough. 2021. Don't wait; re-escalate: delayed action results in longer duration of COVID-19 restrictions.

Simple parameterization approach



Hurford et al. 2021. Modelling the impact of travel restrictions on COVID-19 cases in Newfoundland and Labrador

Simple parameterization approach



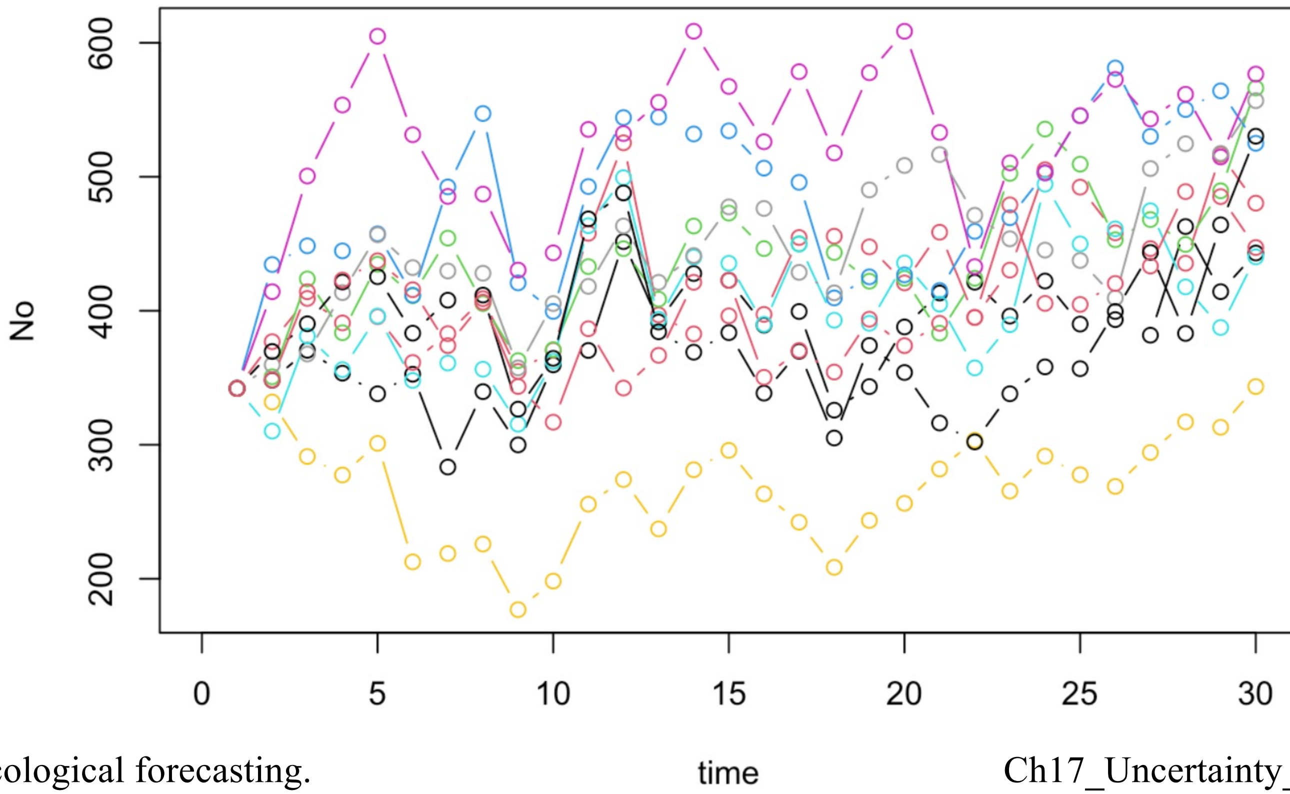
Hurford et al. 2023. Pandemic modelling for regions implementing an elimination strategy

Simple parameterization approach

- Search the literature for 1 value or average
  - Not rigorous
- No or limited treatment of uncertainty in forecasts
  - Some error sources overlooked, falsely confident predictions
- Does not fit data
- Disconnected from statistics

Ecological forecasting

Observed population size, No[s,t]



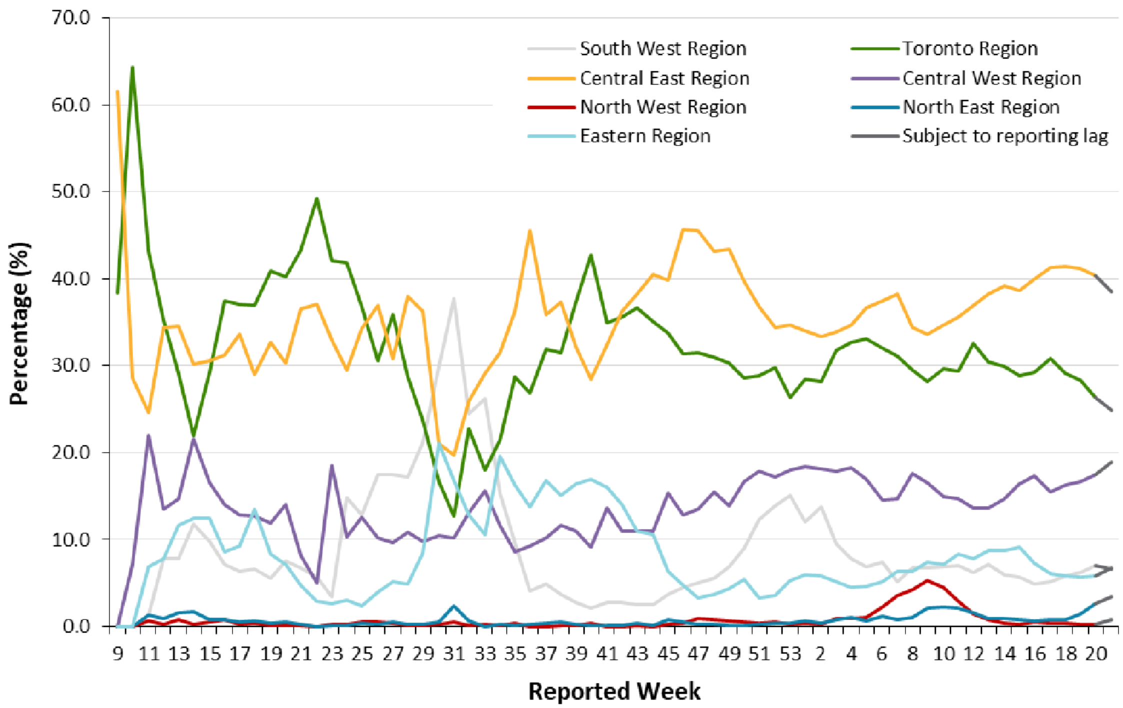
s: site
t: time

Dietz 2017. Ecological forecasting.

Ch17_Uncertainty_Analysis.Rmd

COVID-19 cases by geographic region

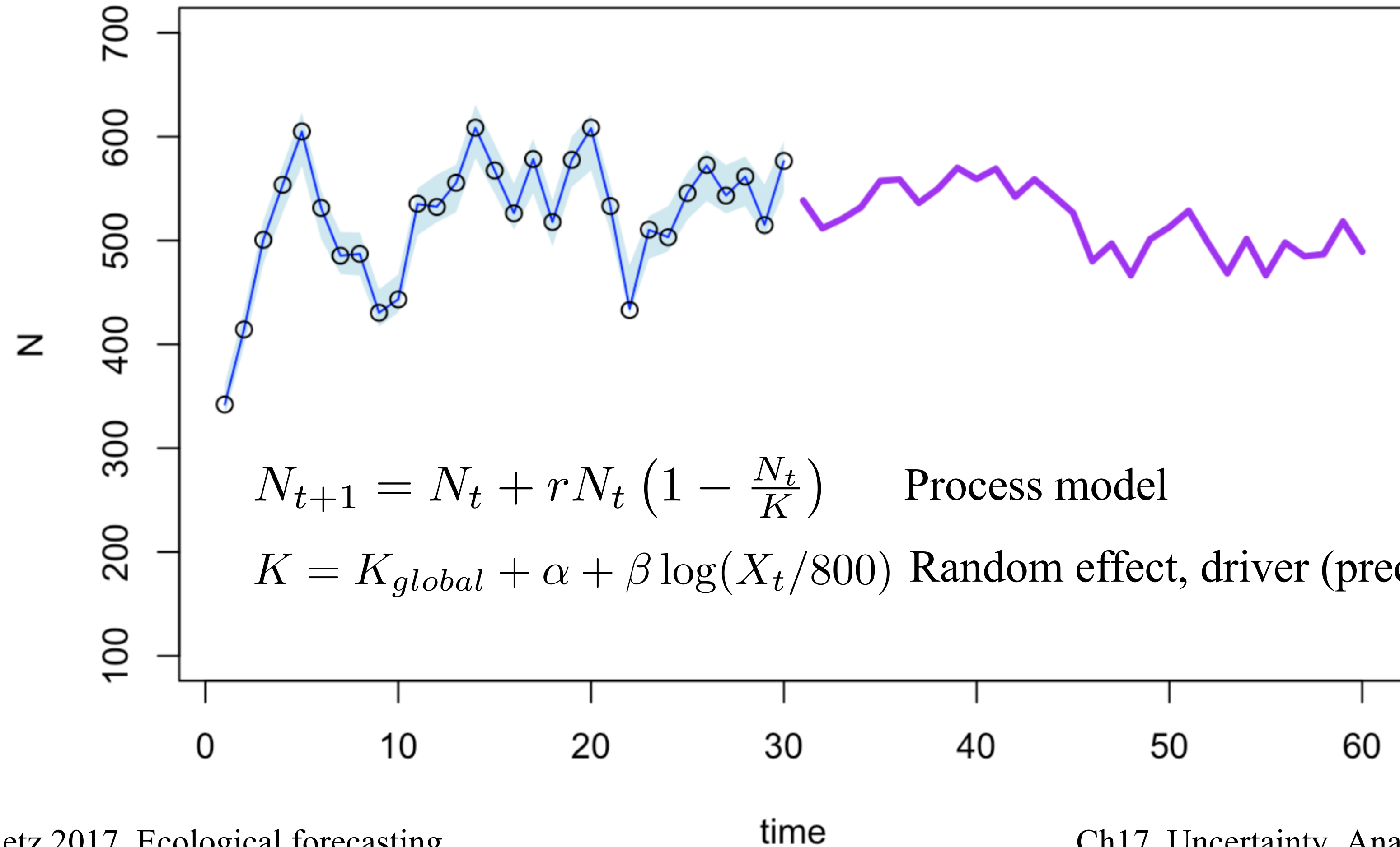
Figure 8. Percentage of COVID-19 cases by geographic region and public health unit reported week: Ontario



Note: Only weeks with more than 10 cases by public health unit reporting date are included (starting in week-9). Include cases with reported dates ranging from week-9 (February 23 and 29, 2020) to week 21 (May 23 and 29, 2021). Table 2A in Appendix A has a listing of public health units by region.
Data Source: CCM

Weekly epidemiological summary. COVID-19 in Ontario: Focus on May 23, 2021 to May 29, 2021. Public Health Ontario. link

Deterministic forecast for site, s=6



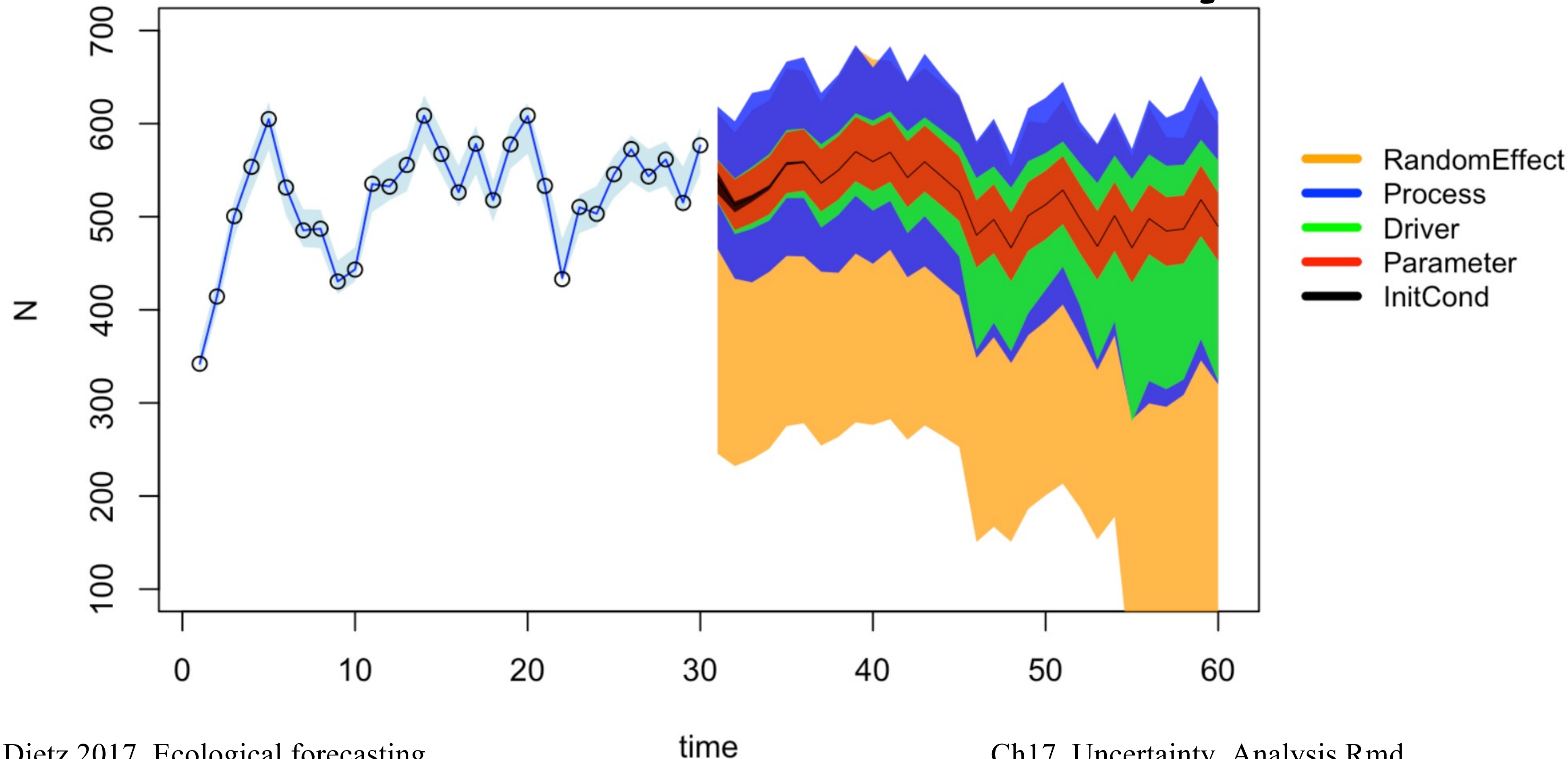
$$N_{t+1} = N_t + rN_t\left(1 - \frac{N_t}{K}\right)$$ Process model

$$K = K_{global} + \alpha + \beta \log(X_t/800)$$ Random effect, driver (precipitation)

Dietz 2017. Ecological forecasting.

Ch17_Uncertainty_Analysis.Rmd

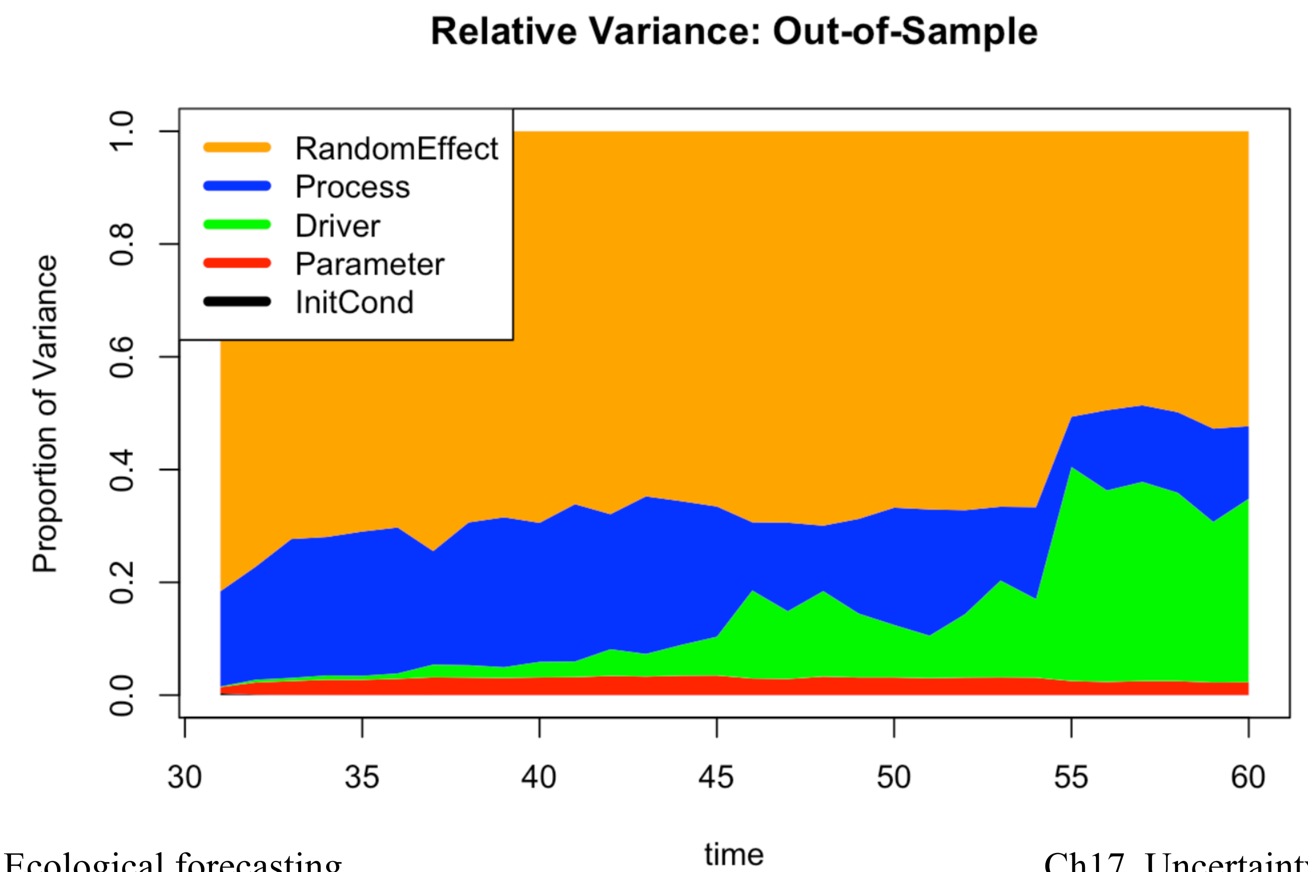
Sources of uncertainty



Dietz 2017. Ecological forecasting.

Ch17_Uncertainty_Analysis.Rmd

Sources of uncertainty



Dietz 2017. Ecological forecasting.

Ch17_Uncertainty_Analysis.Rmd

Process-based vs. fit data

Mechanistic
epidemiological

Phenomenological
Machine learning
Statistical

The argument for process-based:

- Decision-makers need a justification based on a process
- Parameters have a meaning, useful derived data products
- Out-of-sample prediction
- Counterfactual

Schedule

- Chapter 6: Characterizing uncertainty (Tuesday PM)
- Chapter 8: Latent and state-space models (Wednesday PM)
- Chapter 9: Fusing data sources (Wednesday PM)
- Chapter 11: Propagating uncertainty (Thursday PM)