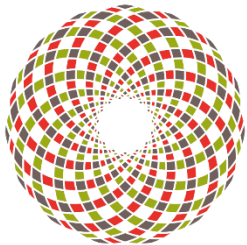


LINK ONLINE, 7 July 2020

# Mathematics, modelling and simulation supporting the COVID-19 response in New Zealand

Alex James   Michael Plank   Shaun Hendy  
Nic Steyn   Rachelle Binny   Audrey Lustig



**Te Pūnaha Matatini**  
Data ■ Knowledge ■ Insight



**Manaaki Whenua**  
Landcare Research

**Te Pūnaha Matatini** - *'the meeting place of many faces'*



# Te Pūnaha Matatini

- A national research centre in complex systems established in 2015 with 70 investigators
- Broad expertise in data and modelling, mostly social, economic, and ecological problems, and how these systems interact
- Have also worked on disease, e.g. *M. bovis*, seasonal flu and Havelock North gastroenteritis
- Strong track record in working with central government

Shaun Hendy



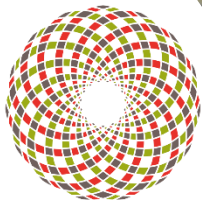
Alex James



Mike Plank



Nicholas Steyn

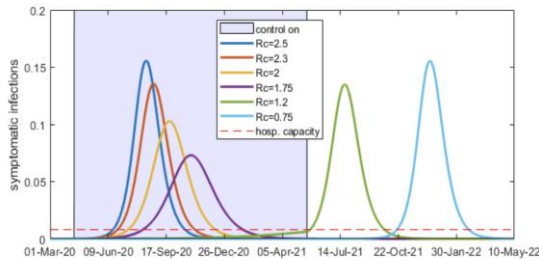


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# Modelling timeline

March

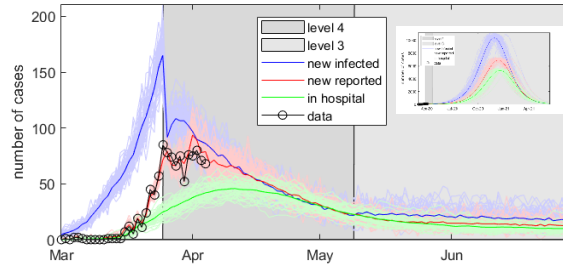
Deterministic  
SEIR model



- Long-term scenarios for an established outbreak

Early April

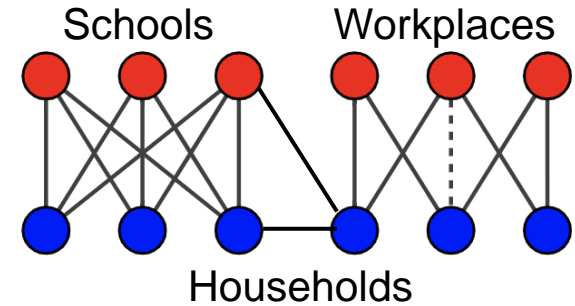
Stochastic SEIR  
model with case  
isolation



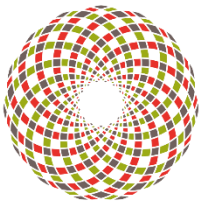
- + Short-term containment or elimination scenarios

Early May

Network/agent  
based model

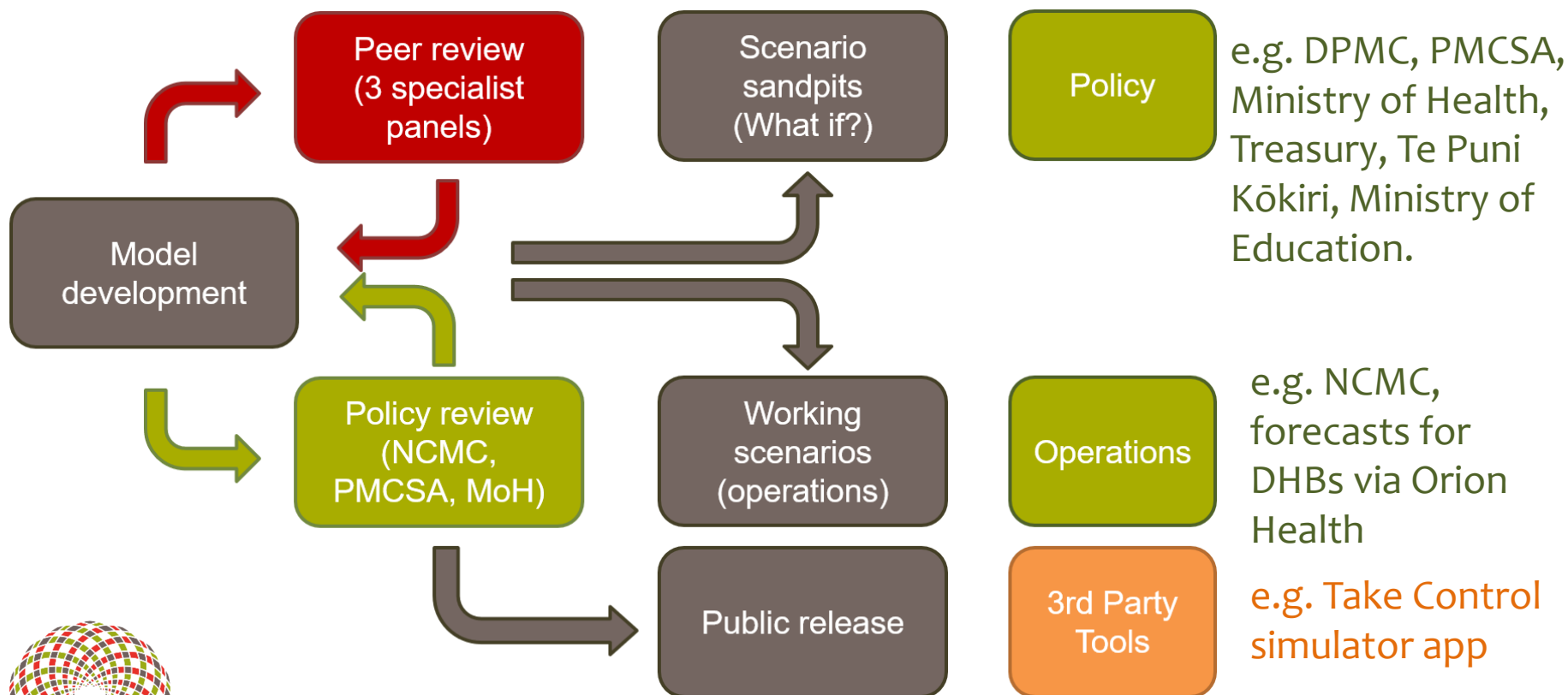


- + Ability to segment  
Alert Level restrictions



# Workflow

- Scenarios to inform policy and operations
- Regular model review and refinement



Policy

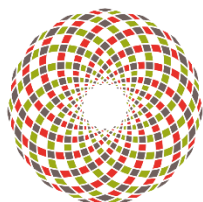
e.g. DPMC, PMCSA, Ministry of Health, Treasury, Te Puni Kōkiri, Ministry of Education.

Operations

e.g. NCCM, forecasts for DHBs via Orion Health

3rd Party Tools

e.g. Take Control simulator app



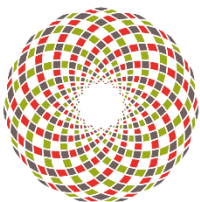
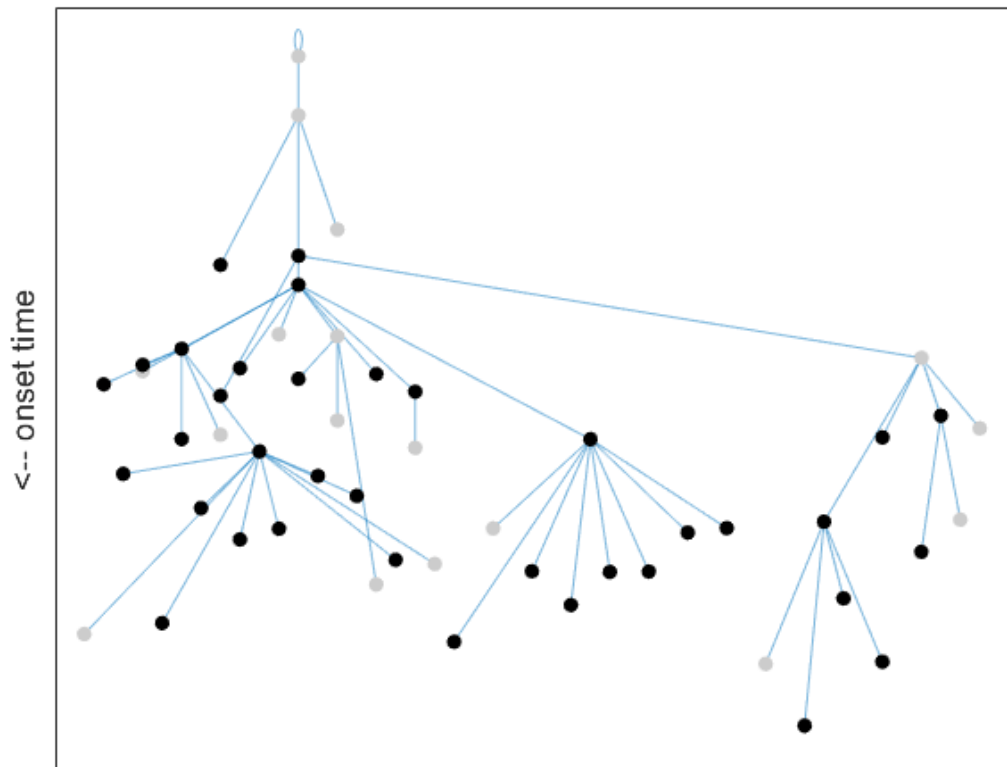
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E.g. Mainstream media

Papers available: [www.tepunahamatatini.ac.nz](http://www.tepunahamatatini.ac.nz)

# Stochastic model

For elimination/containment and compatibility with real case data need a stochastic model, e.g. branching process

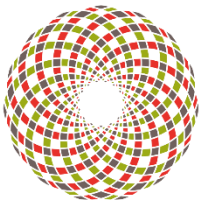
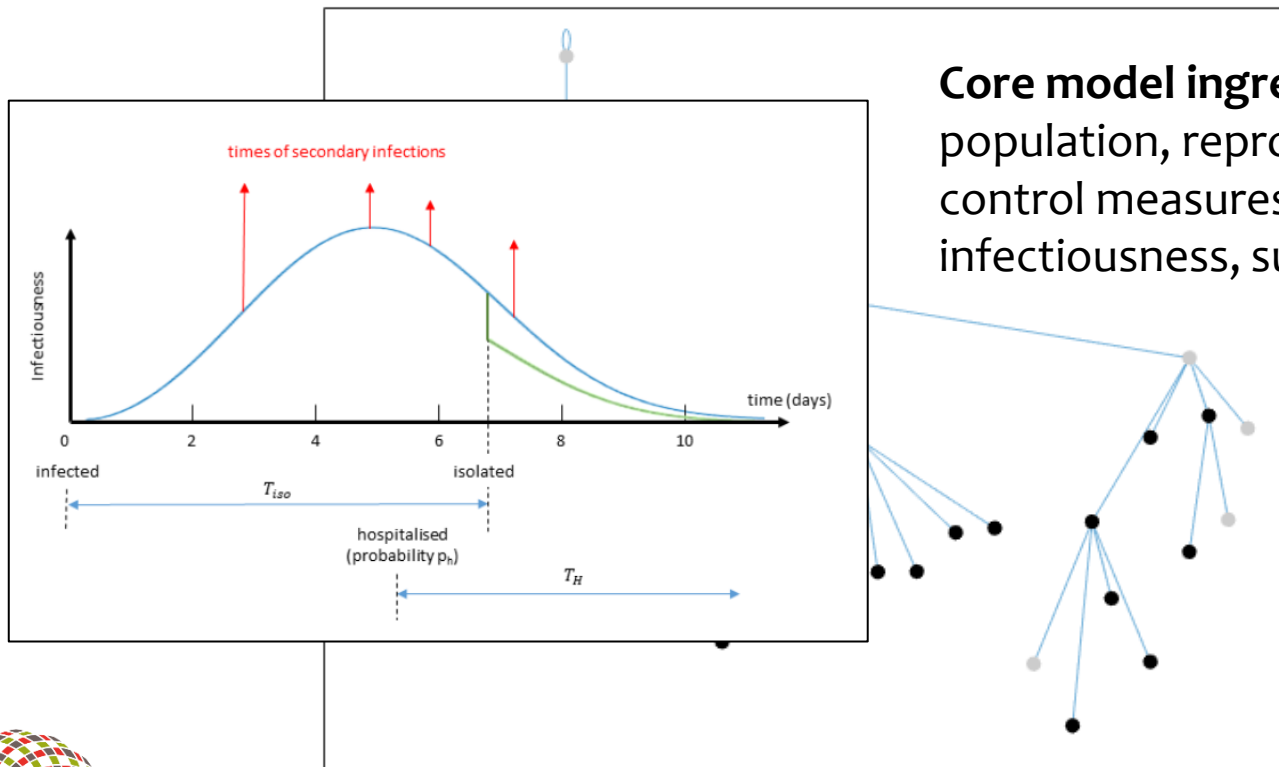


**Te Pūnaha Matatini**  
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Plank MJ, Binny RN, Hendy SC, Lustig A, James A, Steyn N (9 April 2020). A stochastic model for COVID-19 spread and the effects of Alert Level 4 in Aotearoa New Zealand. MedRxiv preprint, doi: <https://doi.org/10.1101/2020.04.08.20058743>

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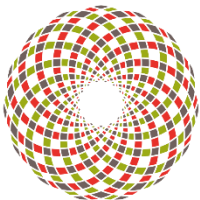
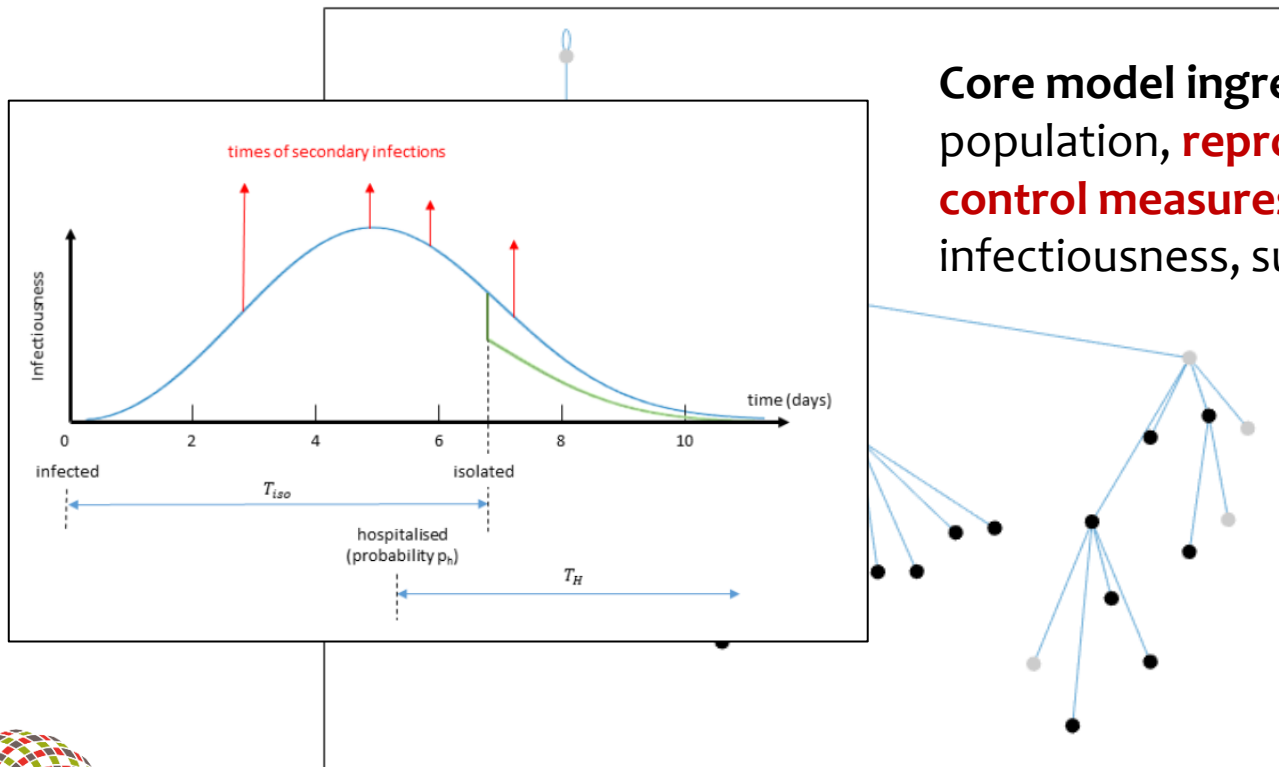


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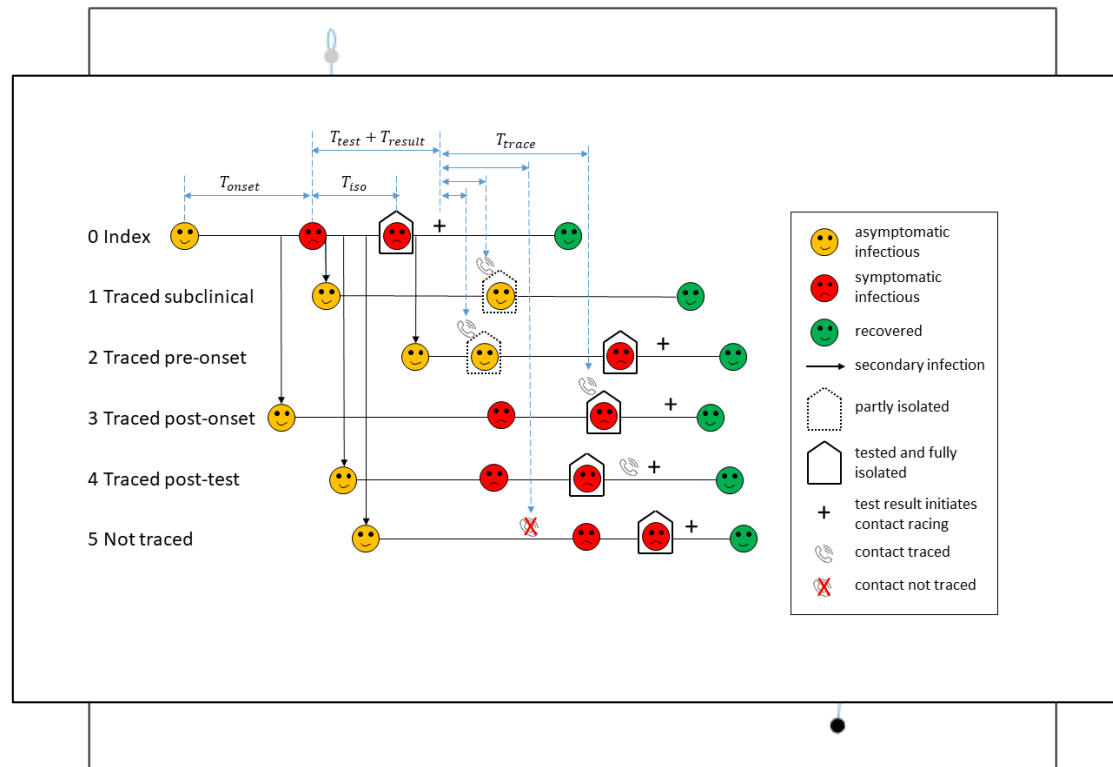


**Te Pūnaha Matatini**  
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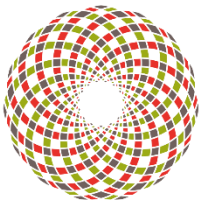
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Contact tracing



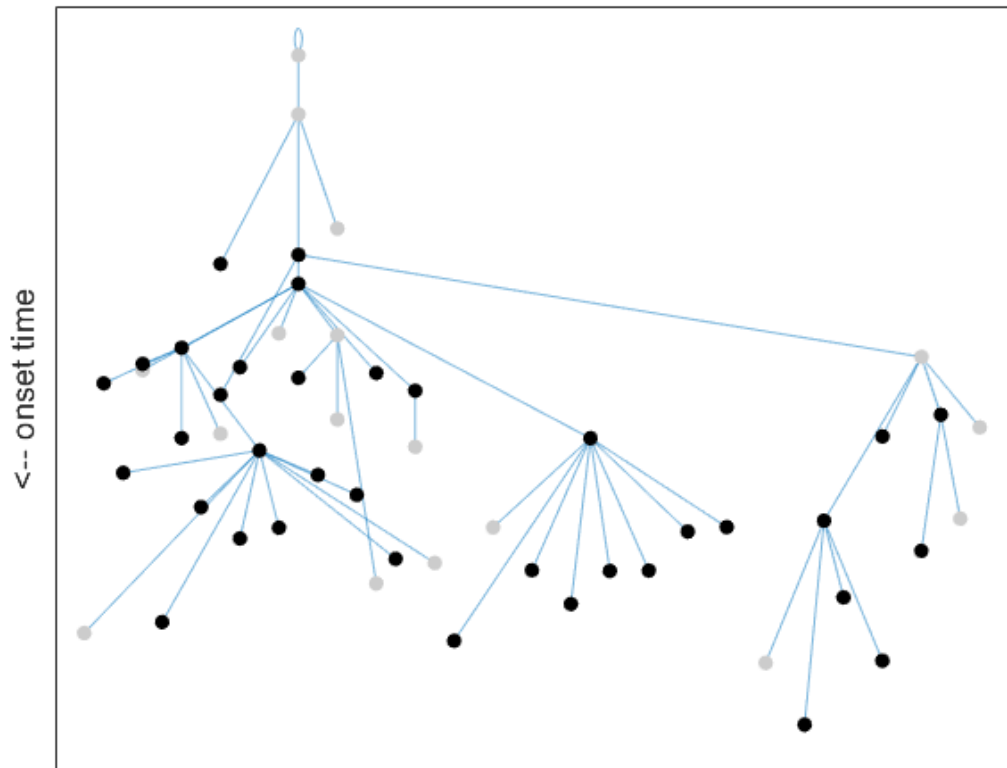
**Te Pūnaha Matatini**  
Data ■ Knowledge ■ Insight

James A, Plank MJ, Binny RN, Lustig A, Steyn N, Hendy S, Nesdale A, Verrall A (2020). Successful contact tracing systems for COVID-19 rely on effective quarantine and isolation. medRxiv preprint, doi: <https://doi.org/10.1101/2020.06.10.20125013>



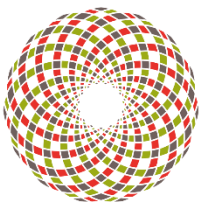
# Stochastic model

For elimination/containment and compatibility with real case data need a stochastic model, e.g. branching process



Contact tracing

Age structure & inequitable access to healthcare



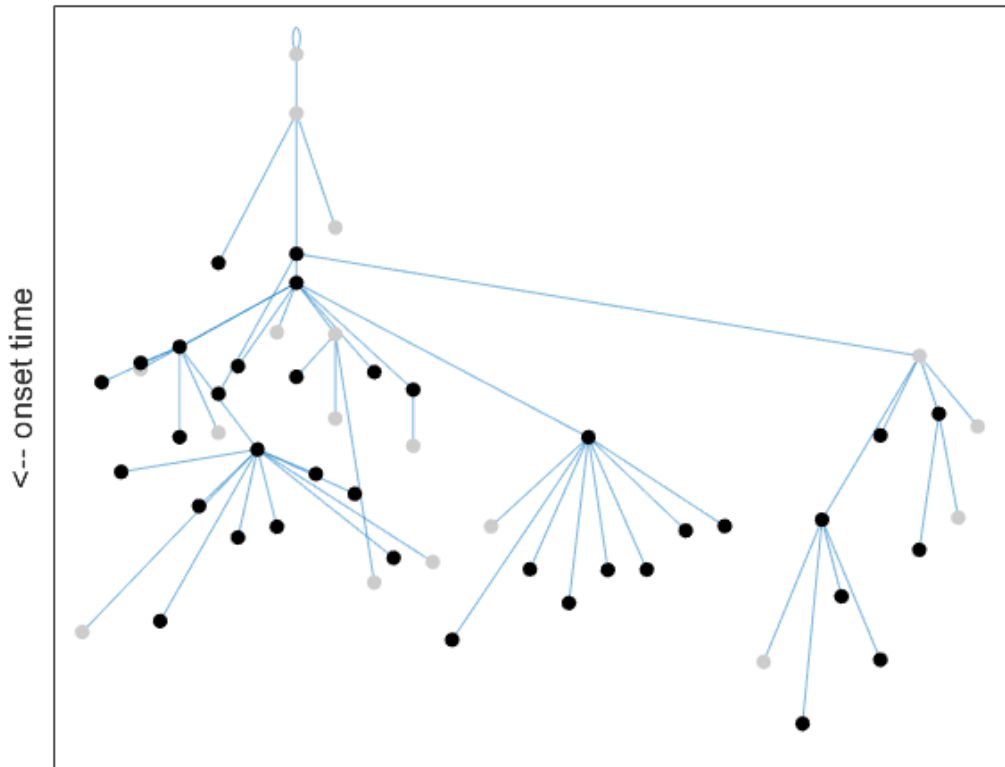
**Te Pūnaha Matatini**  
Data ■ Knowledge ■ Insight

James A, Plank MJ, Binny RN, Hannah K, Hendy SC, Lustig A, Steyn N (2020). A structured model for COVID-19 spread: modelling age and healthcare inequities. medRxiv preprint, doi: <https://doi.org/10.1101/2020.05.17.20104976>

# Stochastic model

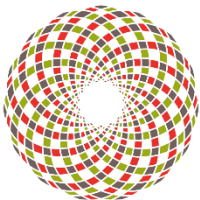
For elimination/containment and compatibility with real case data need a stochastic model, e.g. branching process

Age, ethnicity  
and regional  
variation in  
IFRs



Contact  
tracing

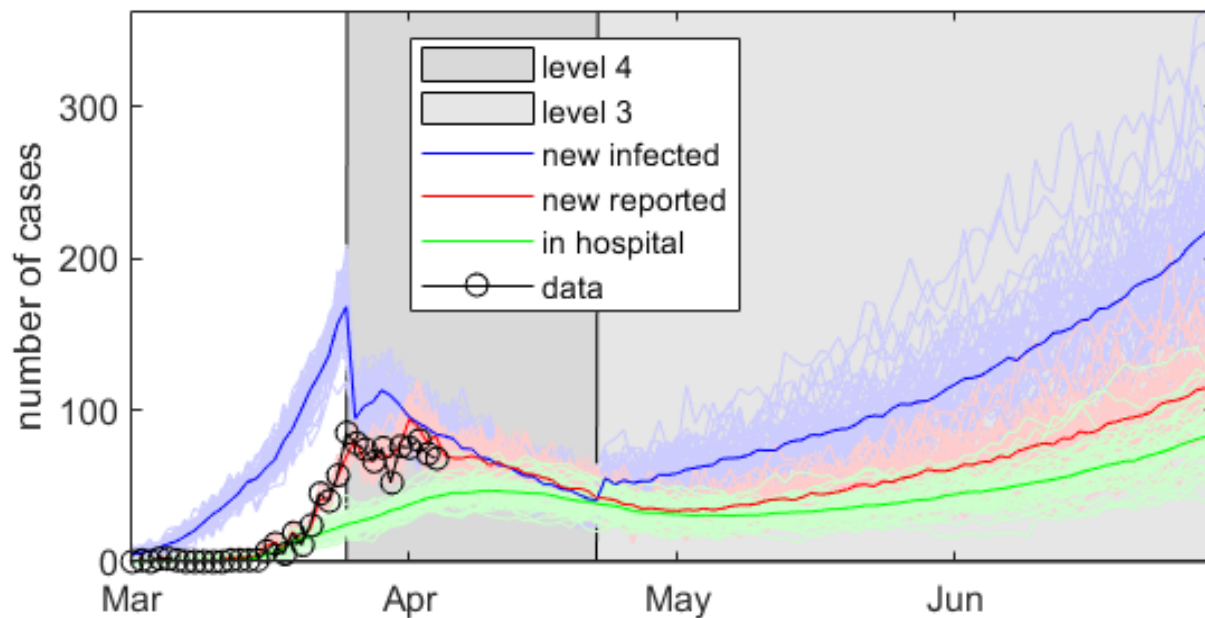
Age structure  
& inequitable  
access to  
healthcare



**Te Pūnaha Matatini**  
Data ■ Knowledge ■ Insight

Steyn N, Binny, RN, Hannah K, Hendy SC, James A, Kukutai T, Lustig A, McLeod M, Plank MJ, Ridings K, Sporle (2020). Estimated inequities in COVID-19 infection fatality rates by ethnicity for Aotearoa New Zealand. medrxiv preprint, doi: <https://doi.org/10.1101/2020.04.20.20073437>

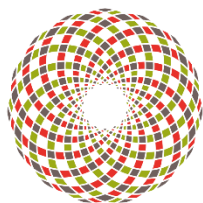
# Stochastic model scenarios



## Assumptions

- Model Structure
- Clinical and Public Health parameters (e.g. under-reporting)
- Alert Level Policy
- Alert Level Effectiveness

- Can compare:
  - Fast vs. slow case isolation
  - Different durations at each Alert level
  - Different effectiveness of Alert Levels



# Reproduction number

- Basic reproduction number,  $R_0$ : average no. of people infected by a single contagious individual in fully susceptible population
- $R_0$  between 2 and 4 for COVID-19
- Effective reproduction number,  $R_{eff}$ : actual transmission at any given time, accounting for control measures
- $R_{eff} > 1$ , virus outbreaks
- $R_{eff} < 1$ , virus dies out

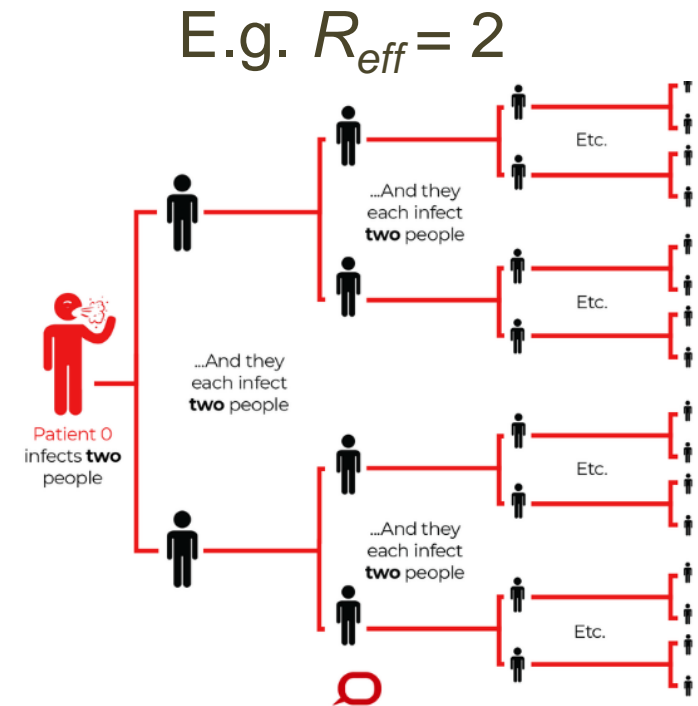
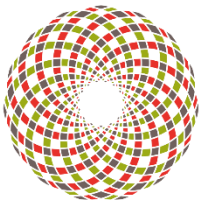
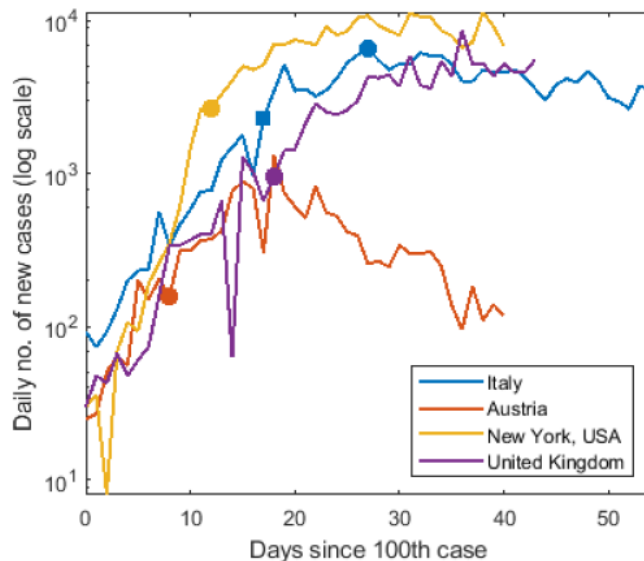


Image: The Conversation



# International review of $R_{eff}$ after interventions

- 25 countries (or provinces/states) with high total cases or different intervention approach
- Data:
  - Daily numbers of new cases and deaths from 22 January 2020 (source: Johns Hopkins University)
  - Types and dates of intervention measures (multiple sources)



## Effect of Alert Level 4 measures on COVID-19 transmission

Science Policy

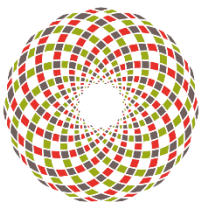
### COVID-19: New Research

Effect of Alert Level 4 on  $R_{eff}$ :  
review of international  
COVID-19 cases

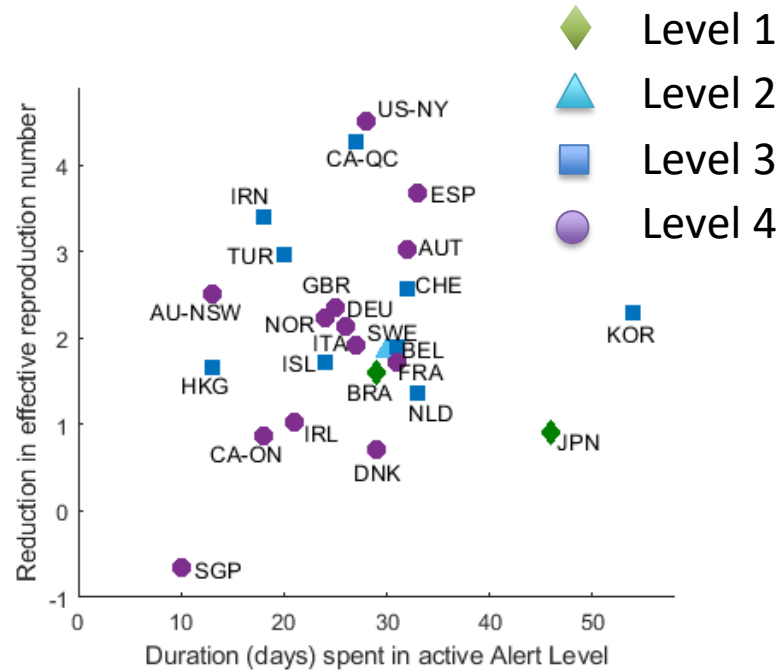


NEW RESEARCH — LINK TO FULL PDF HERE

22 April 2020

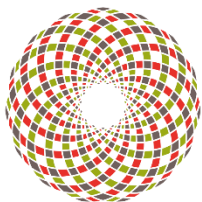


# International review of $R_{eff}$ after interventions



## Effective reproduction number

Alert	Effectiveness		
	Low	Med	High
Level 4	2.1 (e.g. GBR)	1.3-1.6 (e.g. DEU)	0.9 (e.g. NOR)
Level 3	1.8 (e.g. USA)	1.3 (e.g. NLD)	1.0-1.1 (e.g. NSW)
Level 2		1.6-1.8 (e.g. SWE)	1.1 (e.g. HKG)



Binny RN, Hendy SC, James A, Lustig A, Plank MJ, Steyn N (6 May 2020). Effect of Alert Level 4 on  $R_{eff}$ : review of international COVID-19 cases. MedRxiv preprint, doi:: <https://medrxiv.org/cgi/content/short/2020.04.30.20086934v1>

# Italy

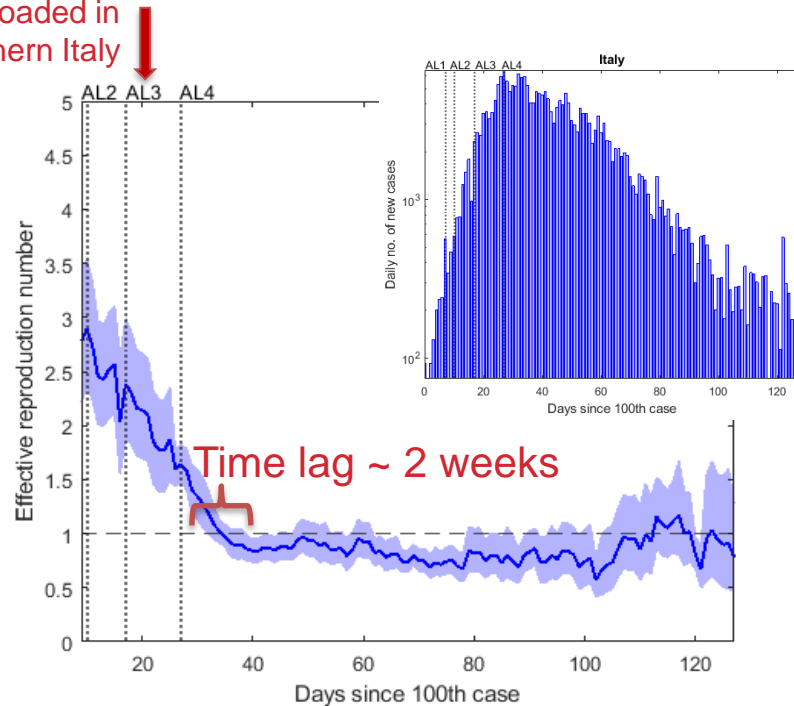
Alert Level 4



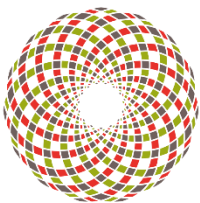
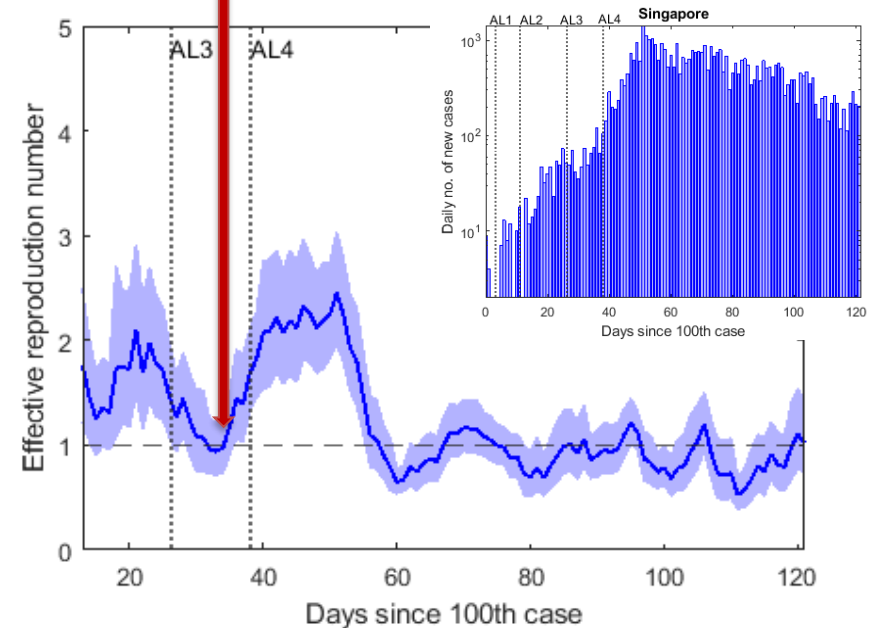
# Singapore

Alert Level 4

Healthcare system overloaded in Northern Italy



Second wave begins, 30 Mar



# Sweden

Alert Level 2



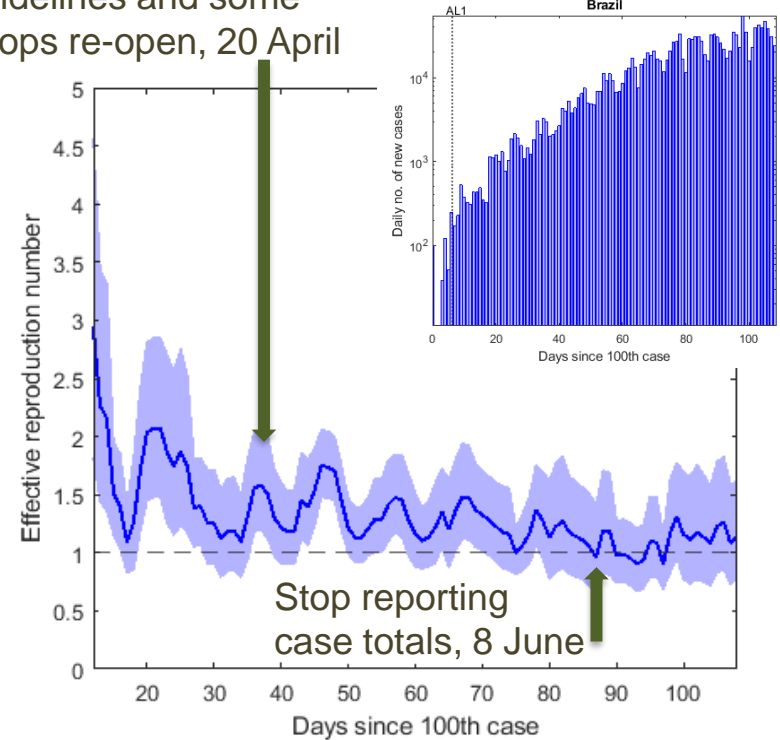
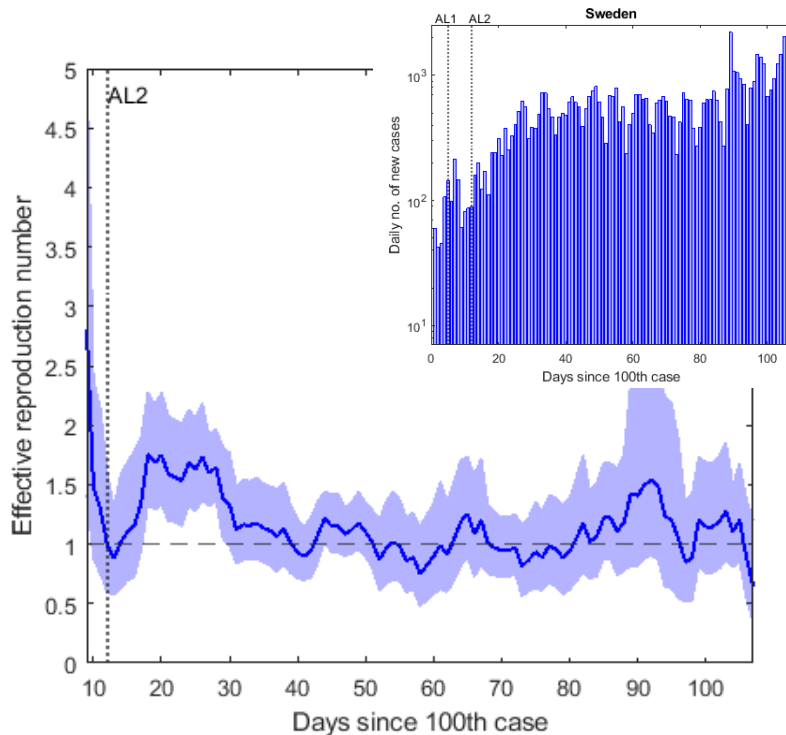
# Brazil

Alert Level 1

Country	Total cases (1 July)	Total deaths
Sweden (AL2)	68,451	5,333
Denmark (AL4)	12,768	605
Norway (AL4)	8,879	250

Total cases (1 July)	Total deaths
1,408,485	59,656

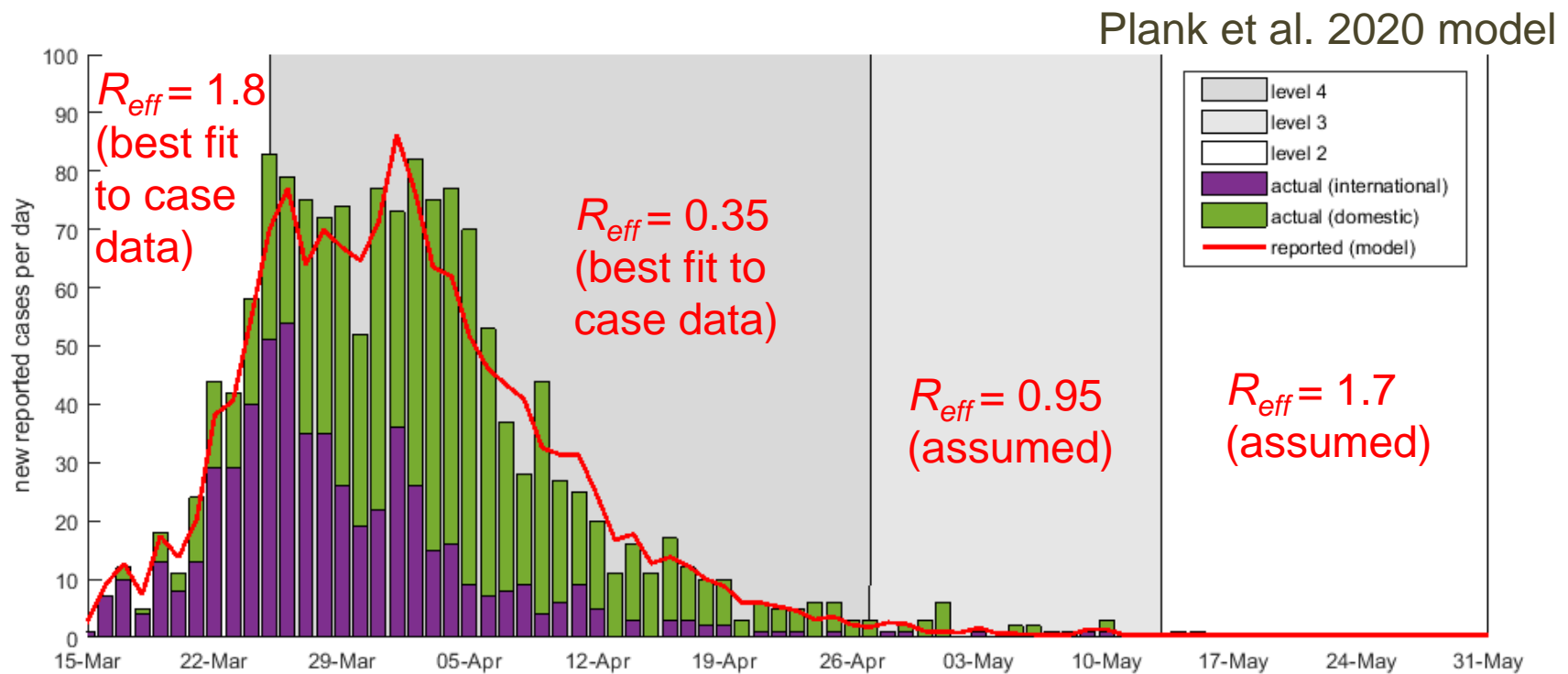
Several cities ease social isolation guidelines and some shops re-open, 20 April



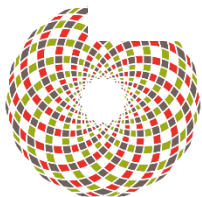


# New Zealand's effective reproduction number

- Simulated and actual daily numbers of new local (confirmed and probable) and imported cases
- Exceptionally early implementation of Alert Level 4



(Case data source: Ministry of Health)

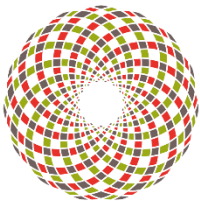
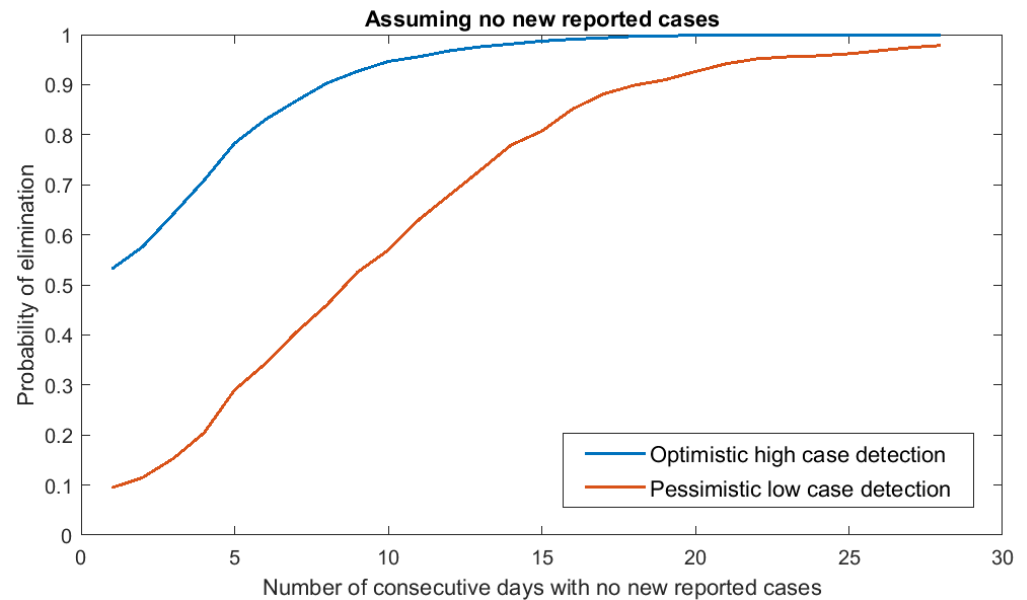


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Total cases (1 July)	Total deaths
1528	22

# Declaring elimination in NZ

- After 2-3 weeks of no new reported cases, there is a 95% probability that COVID-19 has been eliminated in NZ
- NZ declares elimination 8<sup>th</sup> June and moves to Alert Level 1 (zero active cases and 17 days of no new reported cases)
- New cases arriving at the border

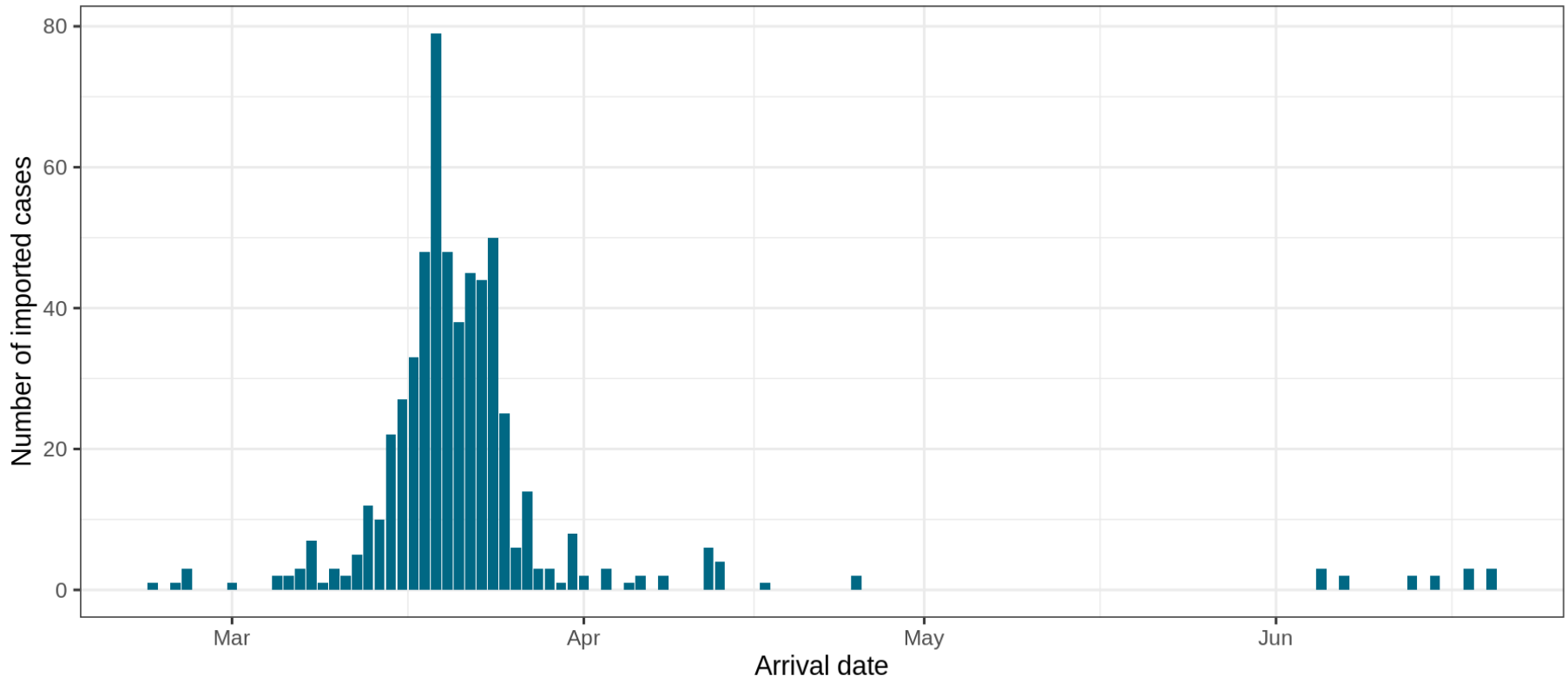


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<https://theconversation.com/new-zealand-hits-a-95-chance-of-eliminating-coronavirus-but-we-predict-new-cases-will-emerge-139973>

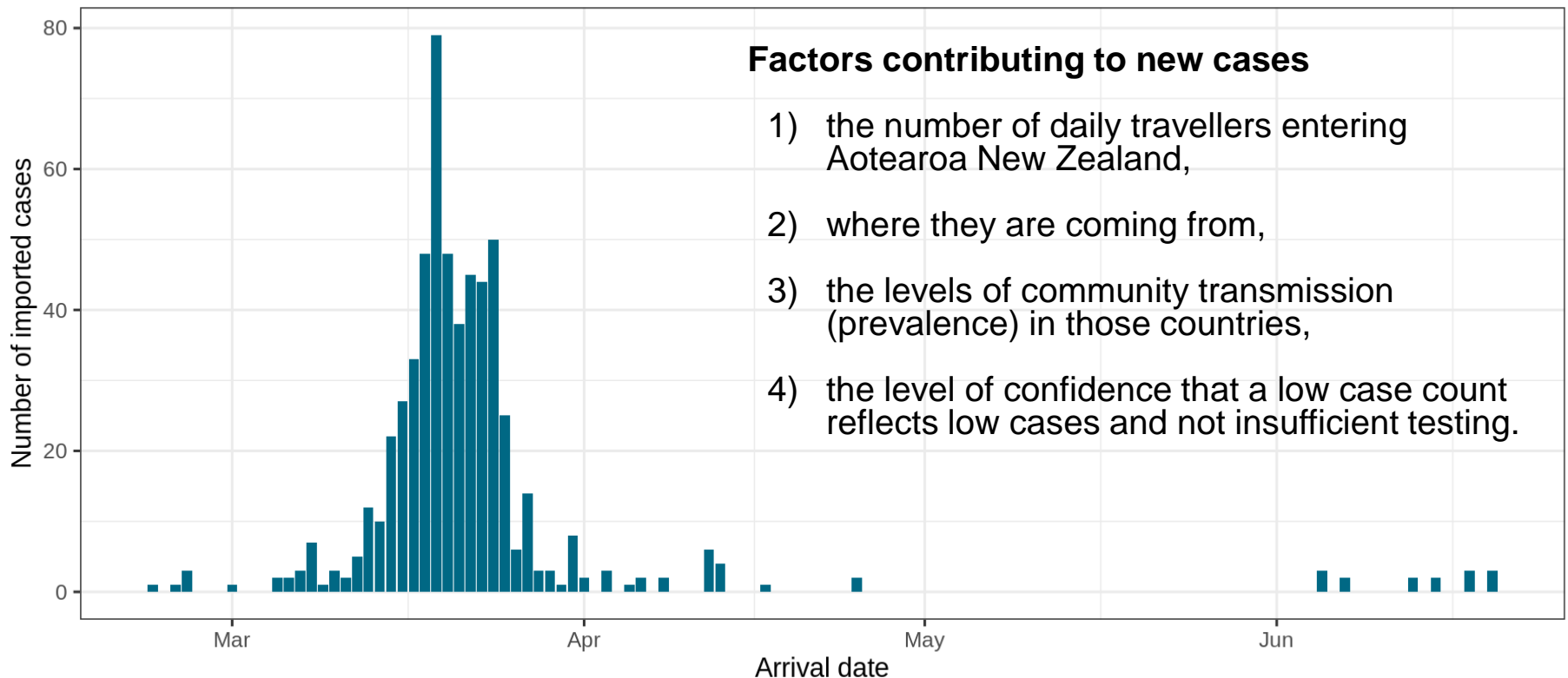
# Modelling border risk and controls

After weeks of no new cases of COVID-19, in the last week we've recorded more than twenty. That's sounds pretty scary, but "what we're seeing is no great surprise, and it's no time to panic" (Siouxie Wiles)!



# Modelling border risk and controls

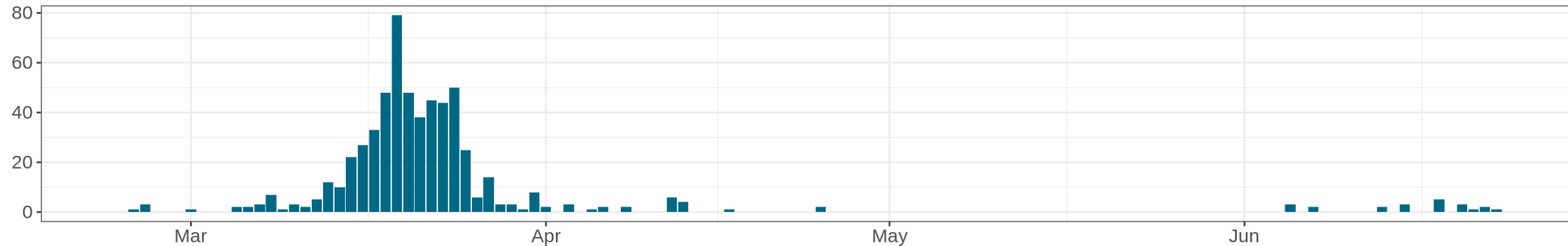
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# Volume of arriving travelers

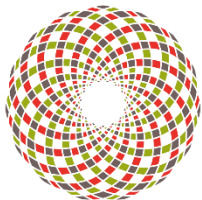
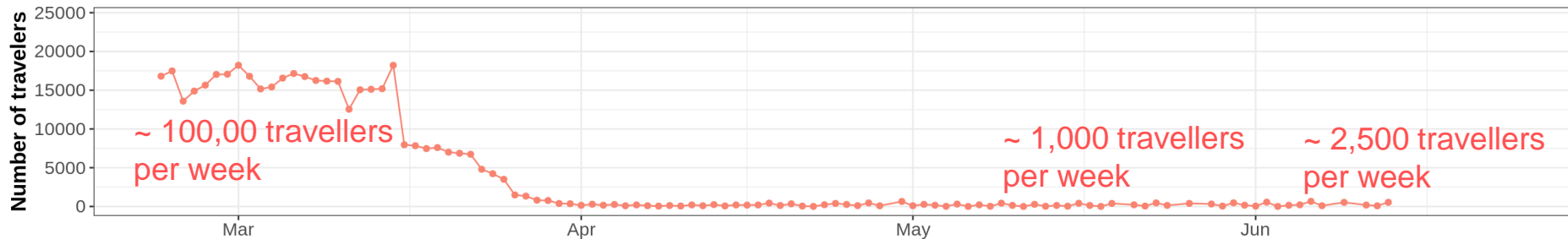
Number of imported cases

The daily number of imported cases has increased compared to mid-May (testing capacity at border)



Number of travellers

The volume of arriving travellers has more than doubled compared to mid-May



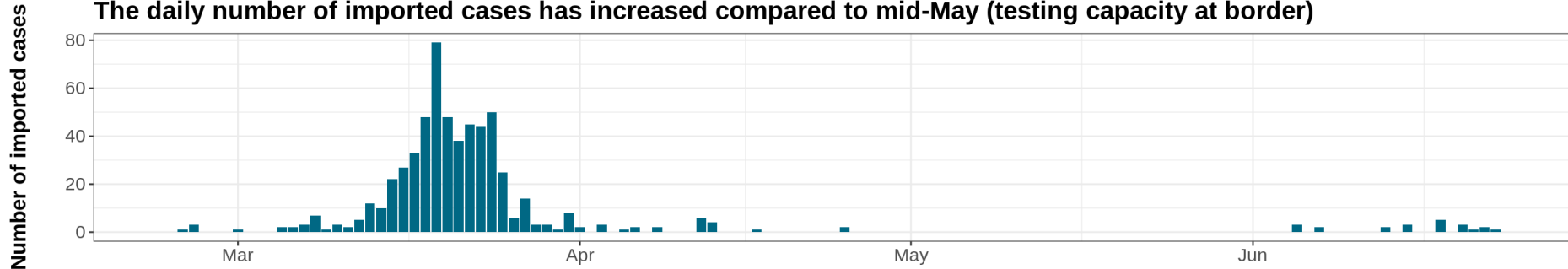
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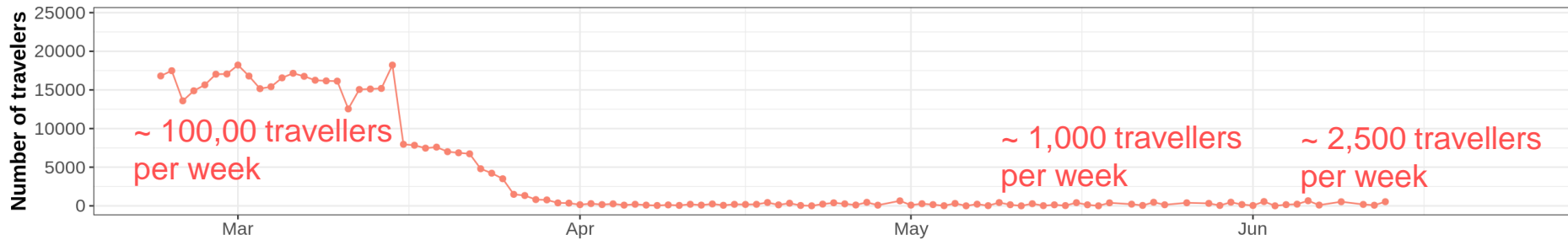
Source: The Spinoff

# Prevalence at source

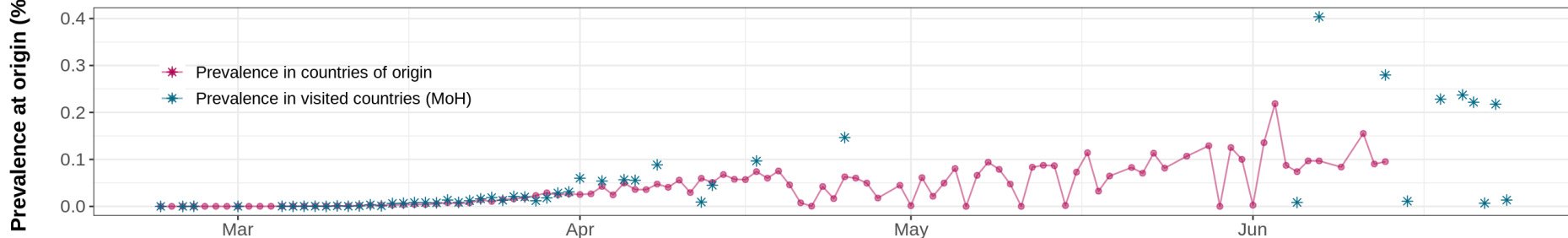
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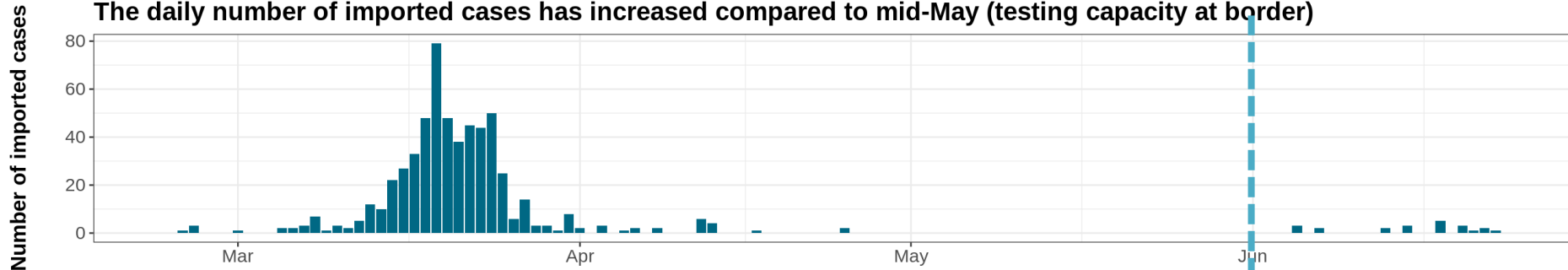


The prevalence has rapidly increased in countries people are traveling from

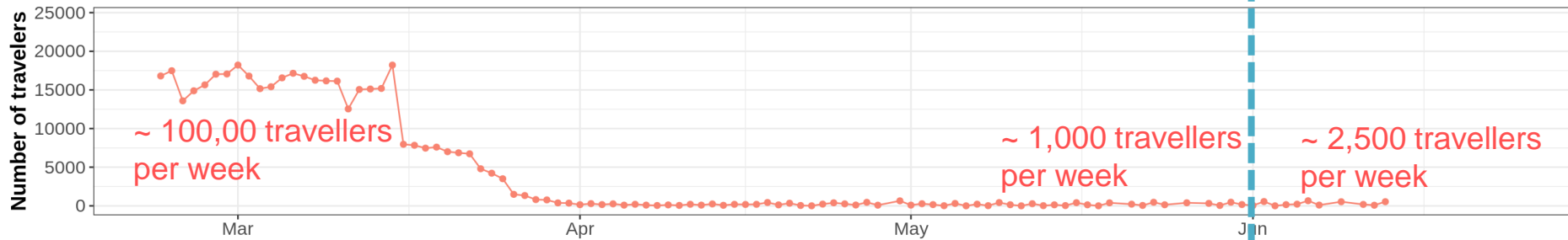


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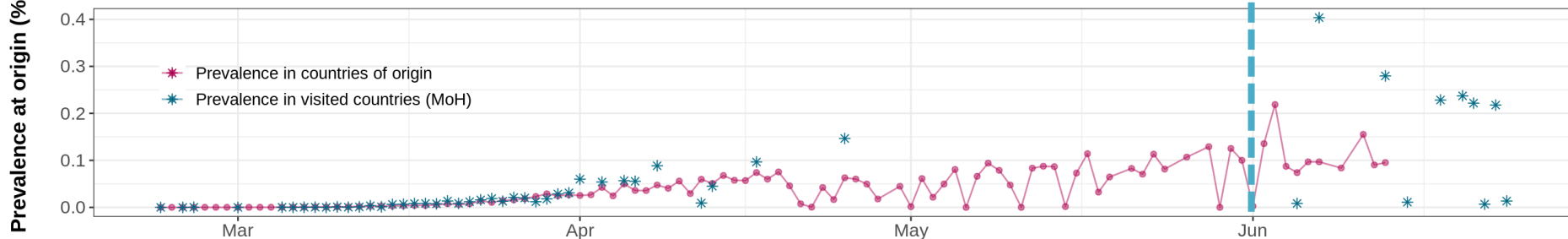
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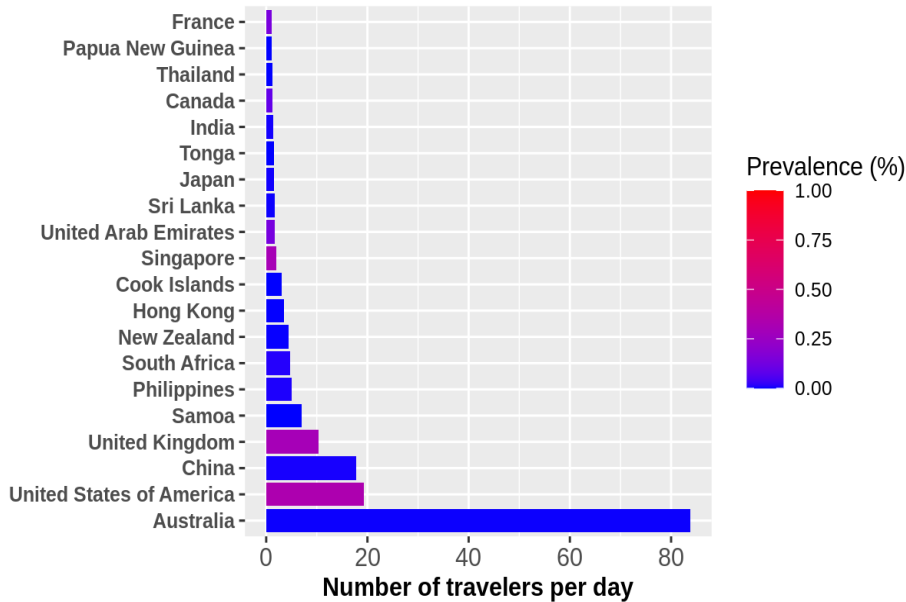


Increased testing

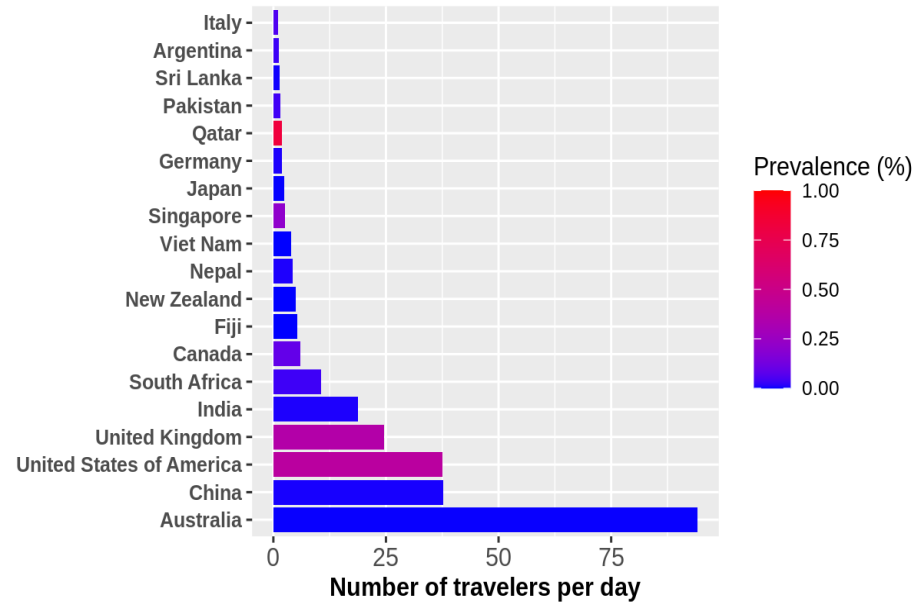
# Make up of countries people are traveling from

In the latest fortnight period, we have seen an increase in the number of people arriving from the USA, UK, South Africa and India, where Covid-19 is relatively widespread.

May

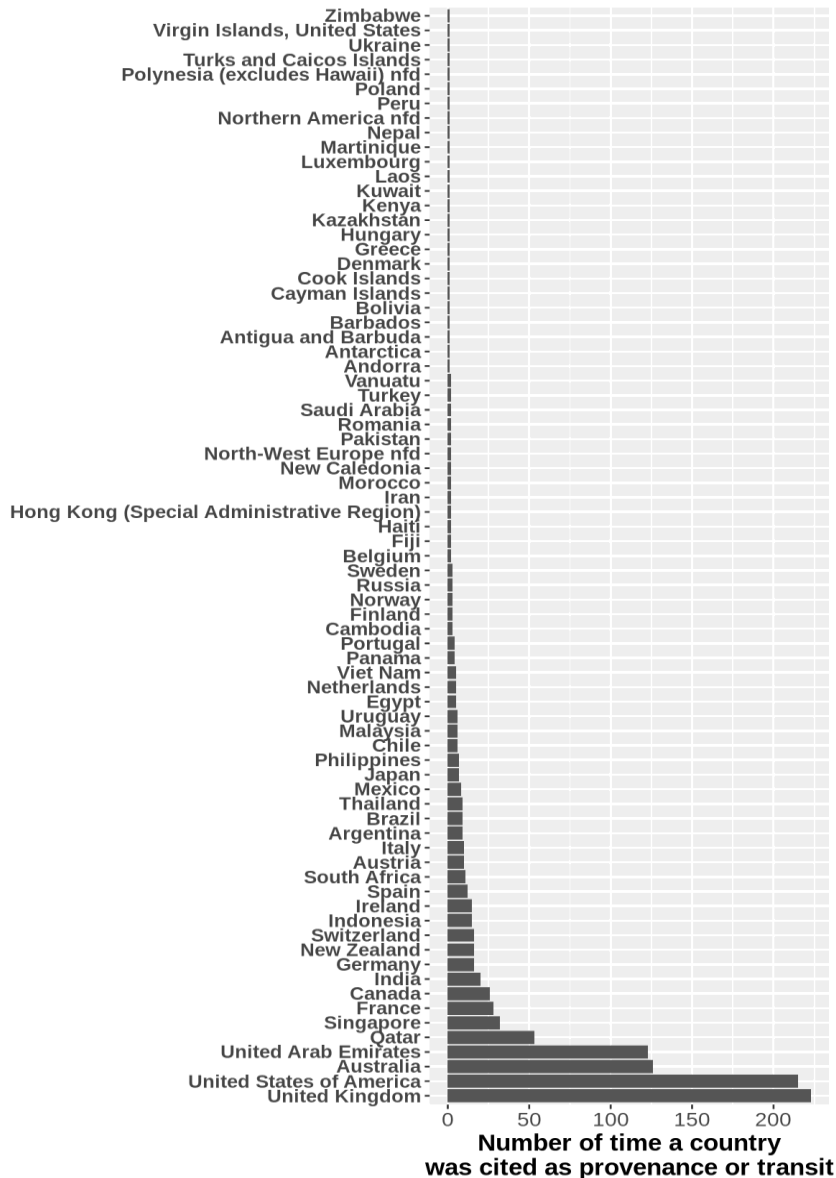


June





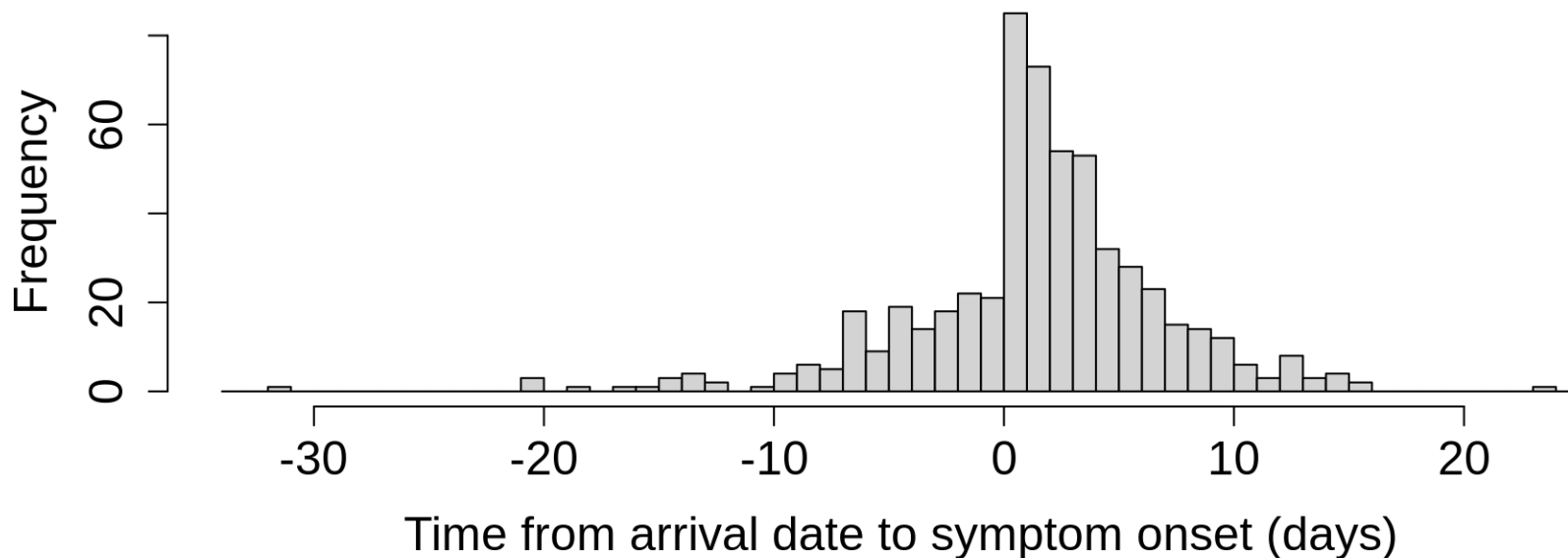
# Source of acquisition



- The data are a bit noisy because many of our imported cases visited or transited through multiple countries. It is sometimes difficult to associate a country of provenance/transit to a case.
- Most overseas-acquired cases have been from USA, UK and Australia.
- The source of acquisition has varied in the latest fortnight period. 14 out of the 24 last cases have been from India.

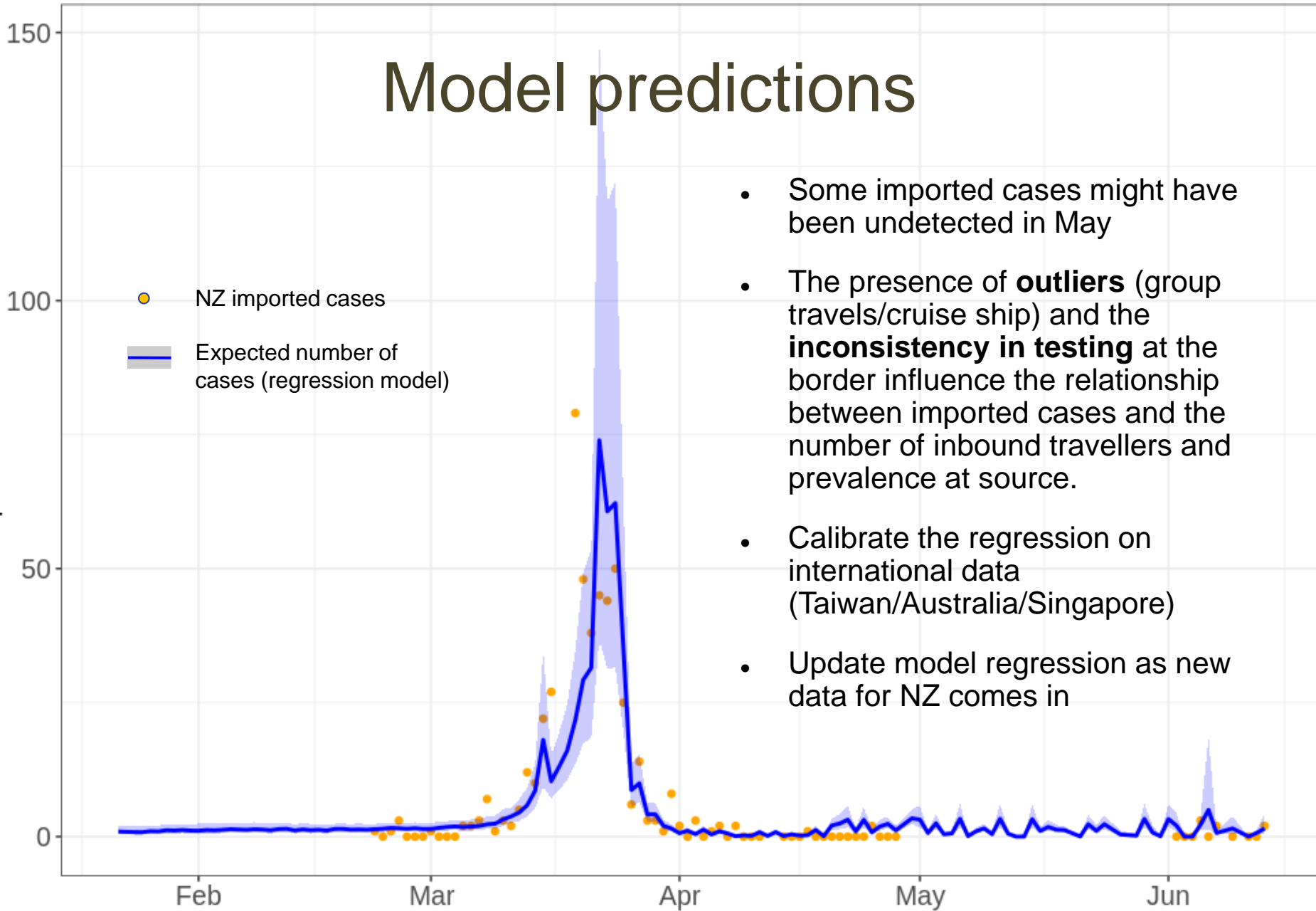
# Prevalence in inbound travelers

- Since June 9 (consistent testing in isolation), the average prevalence in inbound travelers is **3.85 cases per 1,000 travelers**.
- 7 cases (1.2%) developed their first symptoms two weeks or more after arriving; providing opportunity for onward transmission in the wider community.



# Model predictions

Number of imported cases of COVID-19



● NZ imported cases  
— Expected number of cases (regression model)

- Some imported cases might have been undetected in May
- The presence of **outliers** (group travels/cruise ship) and the **inconsistency in testing** at the border influence the relationship between imported cases and the number of inbound travellers and prevalence at source.
- Calibrate the regression on international data (Taiwan/Australia/Singapore)
- Update model regression as new data for NZ comes in

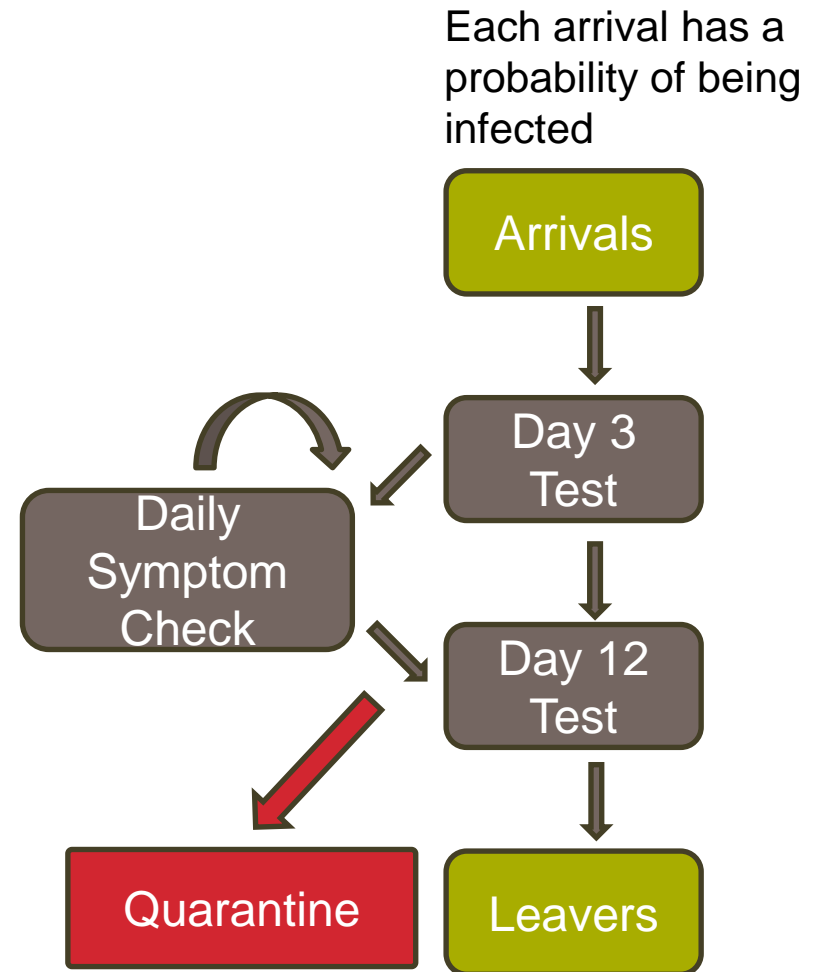
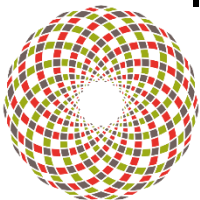
# Managed isolation facilities

We have a good idea of how many cases we expect at the borders.

The mandatory 14-days is pretty good, but not impenetrable.

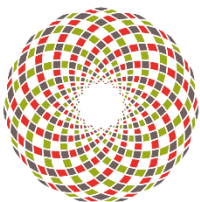
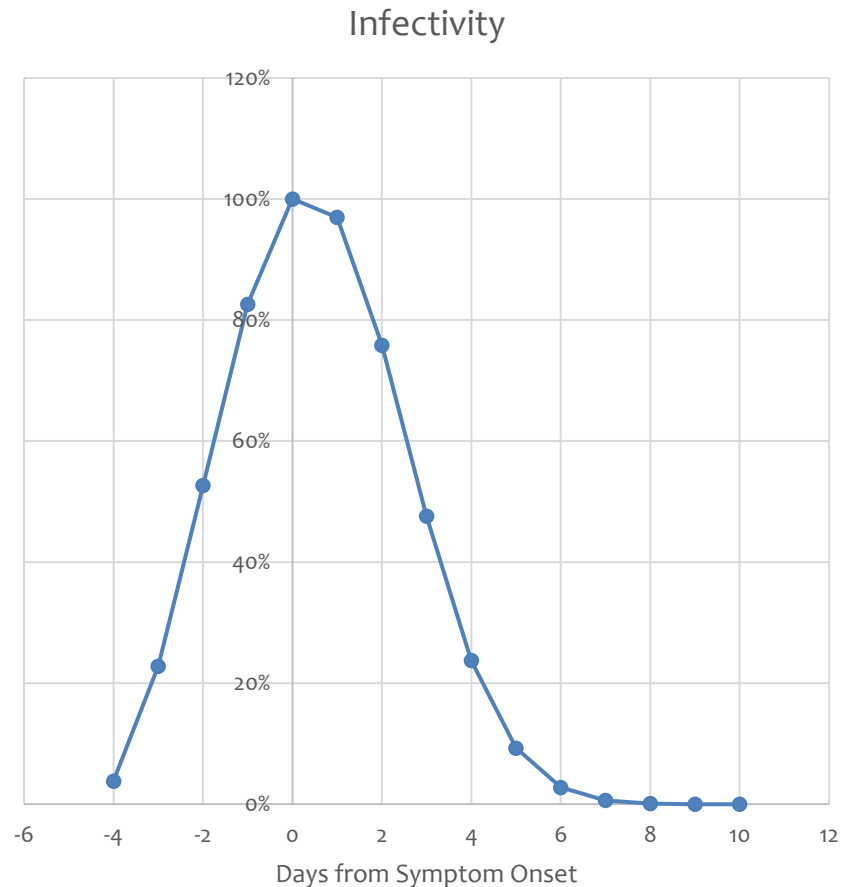
## How to measure the effectiveness of managed isolation?

- 1.1 How many cases have we missed?
- 1.2 How infectious are those cases?
- 1.3 How much internal transmission is there?



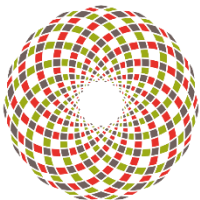
# Missed cases

- We almost certainly don't detect every case that arrives at the border
- However, the model suggests these 'missed cases' pose little risk
  - On average they have passed 99.9% of their infectious period



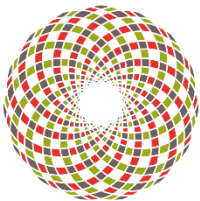
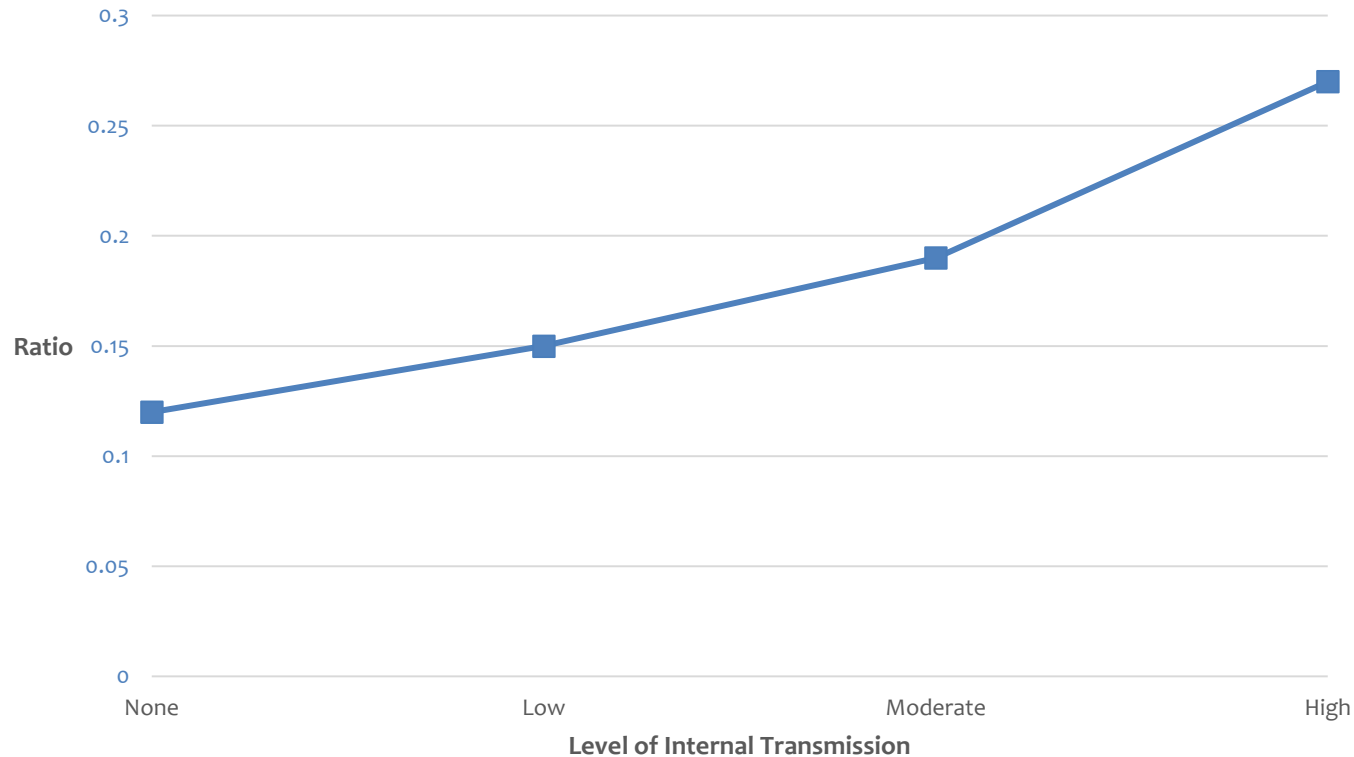
# Internal Transmission

- Typically still infectious when they leave (if undetected)
  - Likely only passed ~50% of their infectiousness
- Hard to know the level of internal transmission
  - Someone that develops symptoms on day 8 may have been exposed before arrival *or* in the facility
  - Someone that tests positive on day 12 may have just had a false negative on day 3
- What **observable** data may indicate the level of internal transmission?
  - Ratio of cases detected in the 2<sup>nd</sup> weeks to cases detected in the first week



# Internal Transmission

Modelled Results (too early to use current data):



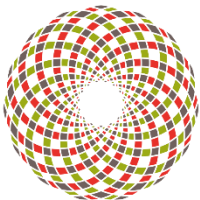
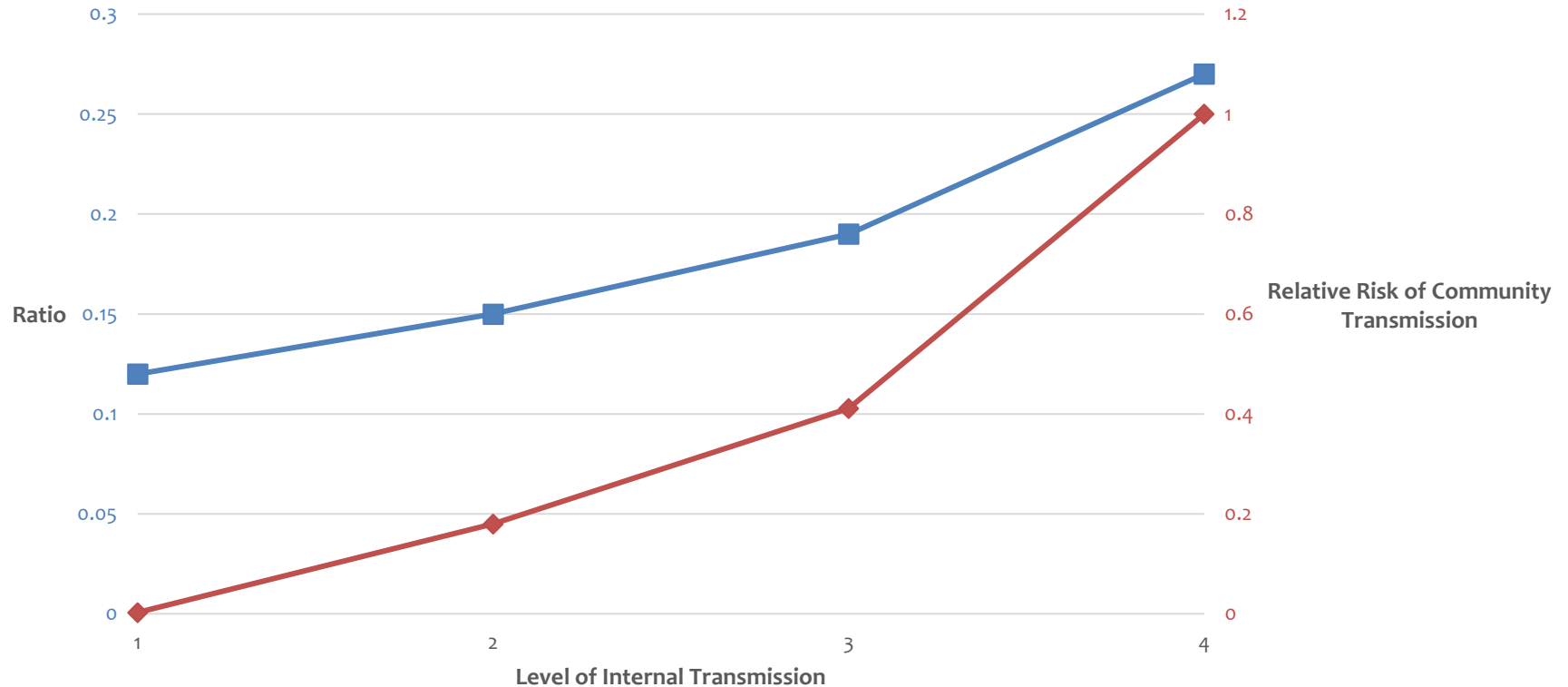
**Te Pūnaha Matatini**  
Data ■ Knowledge ■ Insight

—■ Ratio

\*Ratio approximate and depends on parameters

# Internal Transmission

Modelled Results (too early use real data):



**Te Pūnaha Matatini**  
Data ■ Knowledge ■ Insight

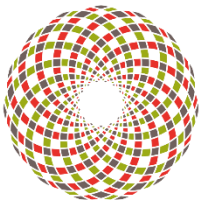
■ Ratio ■ Relative Risk

\*Ratio approximate and depends on parameters



# Other Scenarios

- Is it worth separating recent arrivals from those nearing the end of their stay?
- What additional risk do special exemptions pose? How can we make them safer?
- Can we have more relaxed rules for people coming from safer regions? (modeling the Australian – NZ bubbles)



# Thank you for listening

- Papers available from: [www.tepunahamatatini.ac.nz](http://www.tepunahamatatini.ac.nz)
- Take Control simulator: [http://covid19takecontrol.nectar.auckland.ac.nz/covid19\\_takeControl/](http://covid19takecontrol.nectar.auckland.ac.nz/covid19_takeControl/)

## COVID-19 Take Control simulator

Disclaimer: This simulator is intended for research and educational purposes only, not for decision-making. It simulates the natural course of a COVID-19 epidemic in Aotearoa, New Zealand. This work is licensed under the [GNU General Public License v3.0 \(GNU GPLv3\)](https://www.gnu.org/licenses/gpl-3.0.html)

Introduction Basics R calculator **Simulator** Tutorial About

### Reproduction number (R) under different social conditions

The Do Nothing Option  
 Break the chain of transmission

R during Level 4: observed between 0.3 and 0.6.

R during Level 3: use the R Calculator

R during Level 2: use the R Calculator

R during Level 1: use the R Calculator

How long would you maintain the Level 3 restrictions?  82 days

How long would you maintain the Level 2 restrictions?  82 days

How long would you maintain the Level 1 restrictions?  82 days

Advanced Options

### Simulated COVID-19 cases for Aotearoa, New Zealand

There is much we don't know about COVID-19 infection and transmission. And there is **great uncertainty** about what we think we know. We built that uncertainty into the simulator with 'stochasticity'. If you re-run the simulator multiple times for each collection of settings you choose, you'll notice different results. This is not a mistake. It just conveys uncertainty in a rapidly changing field of knowledge. For a more thorough tutorial, please see the Tutorial tab.

Select the number of replications to display (we recommend starting with 5 replicates)

0 simulation(s) out of 5 lead to an outbreak.

This epidemiological simulator graphs the natural course of a COVID-19 epidemic in Aotearoa, New Zealand. The **green lines** depict the expected number of new cases per day (both 'clinical' or 'silent'). The **yellow lines** depict the expected number of reported cases per day. There is a lag between infection and symptoms, and another between symptoms and a test result. We can see this lag between the peak of the green lines at the start of Level 4, and the peak of yellow lines of reported cases about a week later.

You can change the reproduction number under different alert levels, and set the duration of these levels. To change the virus' clinical parameters, click on Advanced Options at the bottom. To reset back to the simulator's default values, click on Reset parameters at the bottom. The graphs are interactive: hover over a curve to get values.



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