

# Visualizing Logistic Regression: Application of coloring book technique in a reproducible *ggplot2* system

Andriy Koval, Ph.D.

*Power of Population Data Science* webinar series

Population Data BC

2018-11-01

[github.com/andkov/ipdln-2018-hackathon](https://github.com/andkov/ipdln-2018-hackathon)

# About me

- Ph.D. in Quantitative Methods (2014)
- Reproducible research enthusiast since 2012
- Graph maker
- See work at [github.com/andkov](https://github.com/andkov)
- Follow @andkovpro

# A. Graphing Technique

- 0.0 **Data & Context** : Mortality factors of Canadian immigrants at [IPDLN-2018 hackathon](#)
- 0.1 **Modeling form**: univariate logistic regression with categorical predictors
- 0.2 **Graphical form**: faceted scatterplot in ggplot2
- 0.3 **Coloring book**: Mapping informed expectations from predictors onto color

# B. Workflow Highlights

- 1.0 “Let no one ignorant of geometry enter”: (my) [scripts were written to be read by humans](#)
- 1.1 [RAnalysisSkeleton](#) by Will Beasley: basic starting point for reproducible projects
- 1.2 **Autonomous phases**: data cleaning, statistical modelling, graph production
- 1.3 **Layers of Isolation**: analysis vs presentation using .R (+ .Rmd) => .html (+ .pdf )
- 1.4 Two essential **means of production**: [knitr:::stitch\(\)](#) vs [rmarkdown:::render\(\)](#)

# C. Live demonstration from [github.com/andkov/IPDLN-2018 hackathon](#)

# D. Conclusions

- 2.0 **Different than Notebooks**: sacrifices simplicity for agility via layers of isolation
- 2.1 **R (+ .Rmd) = .html (+ .pdf )** : moving away from *data playing* towards *data science*
- 2.2 **Reproducible projects**: moving away from notebooks towards software

# A. Graphing Technique

0.0 **Data & Context** : Mortality factors of Canadian immigrants at [IPDLN-2018 hackathon](#) by Statistics Canada in Banff

## **International Population Data Linkage Conference 2018 The LIDIC Hackathon: LInked Data Innovation Challenge**

### **Information for Participants**

**Date and Time:** September 11, 2018 afternoon

**Sponsors:** We are grateful for sponsorship of this workshop by Statistics Canada and IBM.

**Description:** Participants will engage in a team-based analysis of a complex, linked, synthesized dataset provided by Statistics Canada. This synthesized data base links socioeconomic and mortality data representing the Canadian population. The data based was derived from existing linked data available at Statistics Canada.

#### **Objectives:**

- To encourage innovative thinking about complex linked databases
- To stimulate interdisciplinary and inter-jurisdictional data collaborations
- To facilitate an environment for creative thinking about data
- To promote networking amongst participants



**Number of records:** 4,346,649

**Number of variables:** 34

## A. Graphing Technique

0.0 **Data & Context**: Mortality factors of Canadian immigrants at [IPDLN-2018 hackathon](#) by Statistics Canada in Banff

```
ls_model$predicted_values %>% glimpse(50) # predicted values
```

Observations: 3,883

Variables: 9

```
$ PR          <fct> Alberta, Alberta, Alberta...
$ age_group   <fct> 65, 60, 30, 80, 55, 40, 6...
$ female      <fct> FALSE, FALSE, TRUE, FALSE...
$ educ3       <fct> high school, more than hi...
$ marital     <fct> mar_cohab, mar_cohab, mar...
$ poor_health <fct> FALSE, FALSE, FALSE, TRUE...
$ FOL         <fct> English only, English onl...
$ dv_hat      <dbl> 1.8628432, 2.3139500, 6.1...
$ dv_hat_p    <dbl> 0.8656280, 0.9100258, 0.9...
```

Originally:

**Number of records:** 4,346,649

**Number of variables:** 34

Data recreated from  
model parameters

You can use this data to recreate the graphs from this talk  
with the script `./reports/graphing-phase-only/graphing-phase-only.R`

# A. Graphing Technique

## 0.1 Modeling form

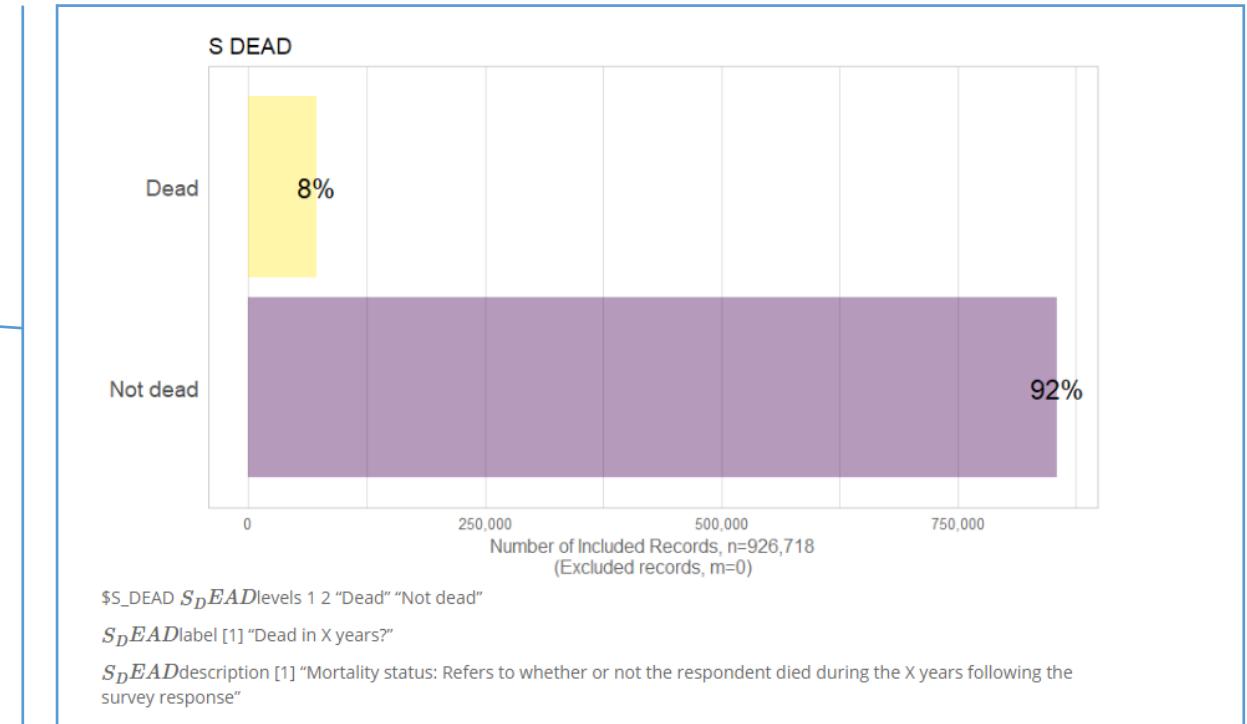
$$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$$

Dead in X years

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

Dependent Variable → Population Y intercept → Population Slope Coefficient → Independent Variable → Random Error term

Linear component → Random Error component



$$\ln\left(\frac{\hat{p}}{(1-\hat{p})}\right) = b_0 + b_1 X_1 + b_2 X_2 + \dots + b_p X_p$$

# A. Graphing Technique

## 0.1 Modeling form

$$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$$

Province of residence

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

Dependent Variable →

Population Y intercept →

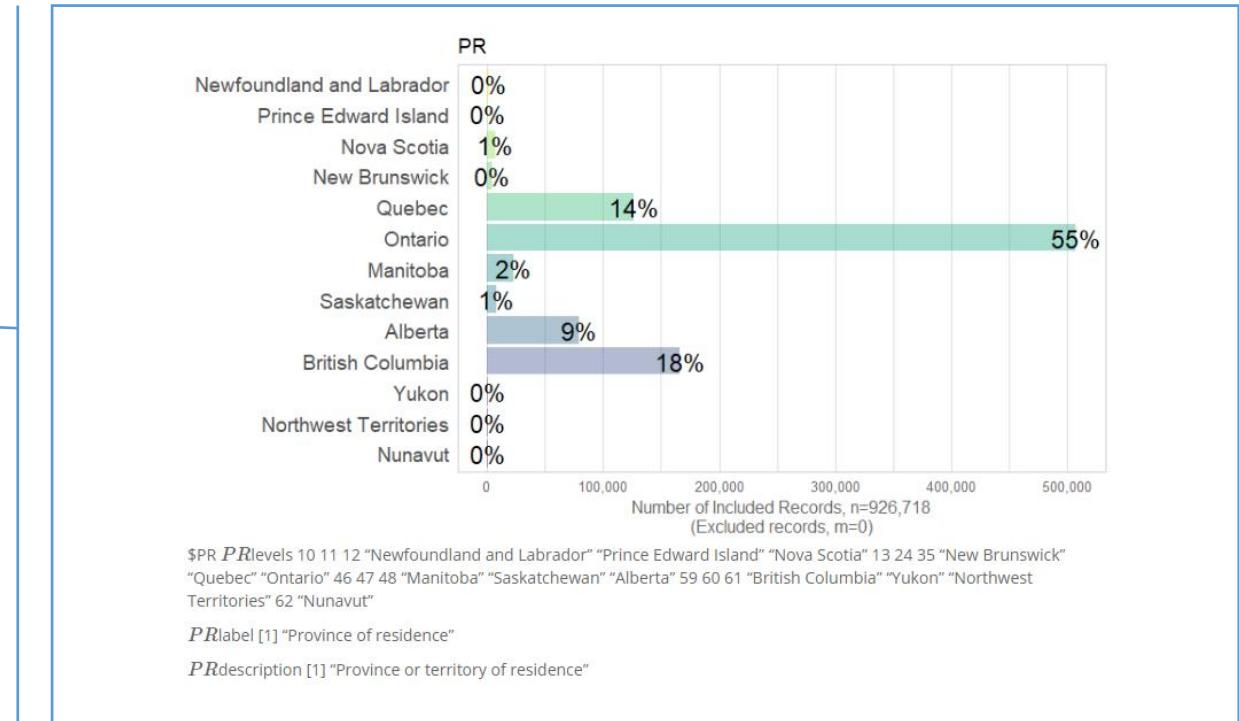
Population Slope Coefficient →

Independent Variable →

Random Error term →

Linear component →

Random Error component →



$$\ln\left(\frac{\hat{p}}{(1-\hat{p})}\right) = b_0 + b_1 X_1 + b_2 X_2 + \dots + b_p X_p$$

# A. Graphing Technique

## 0.1 Modeling form

$$dv \sim -1 + PR + \boxed{age\_group} + female + marital + educ3 + poor\_health + FOL$$

5-year age category

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

Dependent Variable →

Population Y intercept →

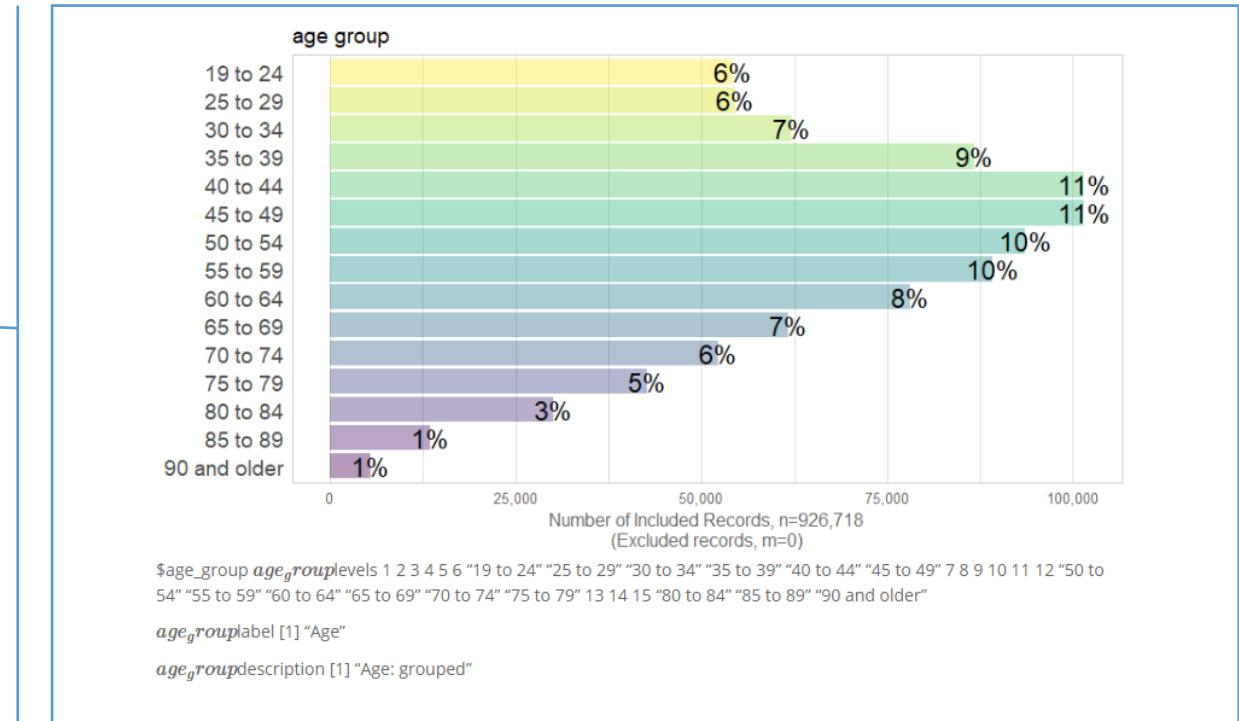
Population Slope Coefficient →

Independent Variable →

Random Error term →

Linear component →

Random Error component →



$$\ln\left(\frac{\hat{p}}{(1-\hat{p})}\right) = b_0 + b_1 X_1 + b_2 X_2 + \dots + b_p X_p$$

# A. Graphing Technique

## 0.1 Modeling form

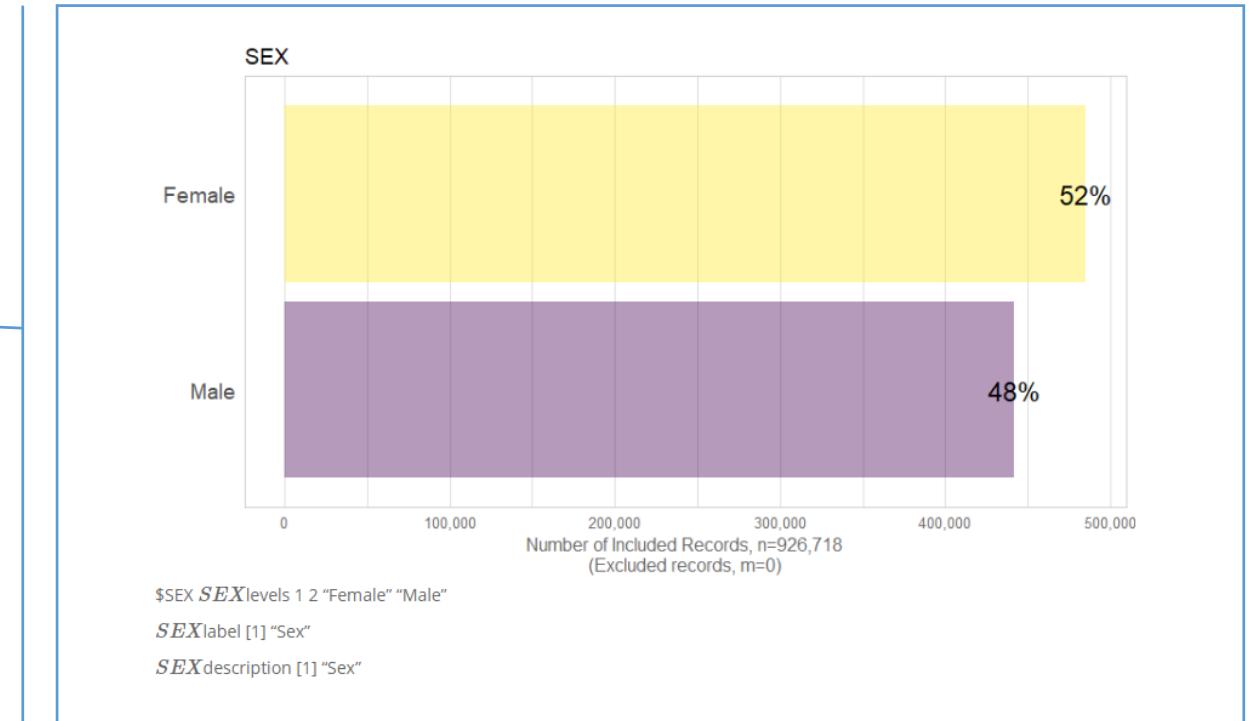
$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

Annotations:

- Dependent Variable →  $Y_i$
- Population Y intercept →  $\beta_0$
- Population Slope Coefficient →  $\beta_1$
- Independent Variable →  $X_i$
- Random Error term →  $\varepsilon_i$

Brackets indicate components:  
Linear component:  $\beta_0 + \beta_1 X_i$   
Random Error component:  $\varepsilon_i$



$$\ln\left(\frac{\hat{p}}{(1-\hat{p})}\right) = b_0 + b_1 X_1 + b_2 X_2 + \dots + b_p X_p$$

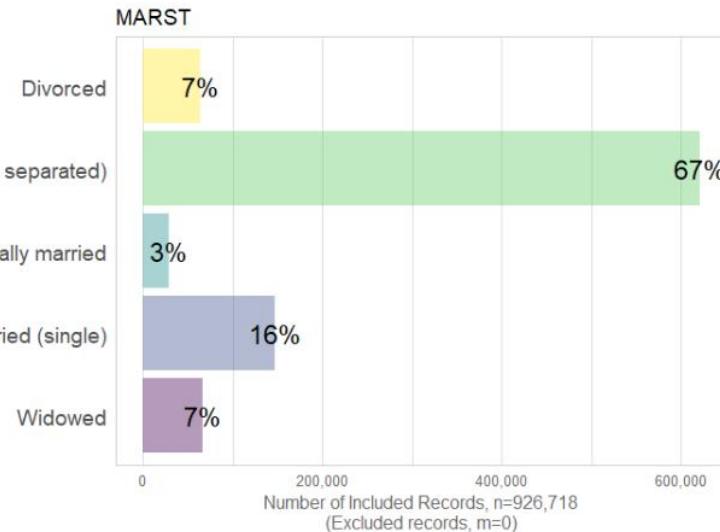
# A. Graphing Technique

## 0.1 Modeling form

$$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$$

### Marital Status

```
# because `still legally married` is more legal than human
,marital = car::recode(
  MARST,
  "Divorced" = 'sep_divorced'
  ;'Legally married (and not separated)" = 'mar_cohab'
  ;'Separated, but still legally married' = 'sep_divorced'
  ;'Never legally married (single)" = 'single'
  ;'Widowed'" = 'widowed'
  ")
,marital = factor(marital, levels = c(
  "sep_divorced", "widowed", "single", "mar_cohab"))
```



$$Y_i = \underbrace{\beta_0 + \beta_1 X_i}_{\text{Linear component}} + \underbrace{\varepsilon_i}_{\text{Random Error component}}$$

Dependent Variable →

Population Y intercept →

Population Slope Coefficient →

Independent Variable →

Random Error term →

$$\ln\left(\frac{\hat{p}}{(1-\hat{p})}\right) = b_0 + b_1 X_1 + b_2 X_2 + \dots + b_p X_p$$

# A. Graphing Technique

## 0.1 Modeling form

$dv \sim -1 + PR + age\_group + female + marital + \boxed{educ3} + poor\_health + FOL$

### Highest Degree

```
# because even only 5 may be too granular for our purposes
, educ3 = car::recode(
  HCD3,
  'None' = 'less than high school',
  'High school graduation certificate or equivalency certificate' = 'high school',
  'Other trades certificate or diploma' = 'high school',
  'Registered apprenticeship certificate' = 'more than high school',
  'College, CEGEP or other non-university certificate or diploma from a program of 3 months to less than 1 year' = 'more than high school',
  'College, CEGEP or other non-university certificate or diploma from a program of 1 year to 2 years' = 'more than high school',
  'College, CEGEP or other non-university certificate or diploma from a program of more than 2 years' = 'more than high school',
  'University certificate or diploma below bachelor level' = 'more than high school',
  'Bachelor's degree' = 'more than high school',
  'University certificate or diploma above bachelor level' = 'more than high school',
  'Degree in medicine, dentistry, veterinary medicine or optometry' = 'more than high school',
  'Masters degree' = 'more than high school',
  'Earned doctorate degree' = 'more than high school'
)
, educ3 = factor(educ3, levels = c(
  "less than high school",
  "high school",
  "more than high school"
))
```

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

Annotations:

- Dependent Variable →  $Y_i$
- Population Y intercept →  $\beta_0$
- Population Slope Coefficient →  $\beta_1$
- Independent Variable →  $X_i$
- Random Error term →  $\varepsilon_i$

Brackets at the bottom:

- $\underbrace{\beta_0 + \beta_1 X_i}_{\text{Linear component}}$
- $\underbrace{\varepsilon_i}_{\text{Random Error component}}$

```
# # because we want/need to inspect newly created variables
ds1 %>% group_by(educ3) %>% summarize(n = n())
```

```
# A tibble: 3 x 2
  educ3          n
  <fct>     <int>
1 less than high school 902326
2 high school        1403807
3 more than high school 2040516
```

$$\ln\left(\frac{\hat{p}}{(1-\hat{p})}\right) = b_0 + b_1 X_1 + b_2 X_2 + \dots + b_p X_p$$

# A. Graphing Technique

## 0.1 Modeling form

$$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$$

### Activities of Daily Living

```
# ADIFCLTY      "Problems with ADL" (physical & cognitive)
# DISABFL      "Problems with ADL" (physical & social)
# because this is what counts practically
,poor_health = ifelse(ADIFCLTY %in% c("Yes, often","Yes, sometimes")
&
DISABFL %in% c("Yes, often","Yes, sometimes"),
TRUE, FALSE
)
,poor_health = factor(poor_health, levels = c("TRUE","FALSE"))
```

$$Y_i = \beta_0 + \beta_1 X_i + \varepsilon_i$$

Dependent Variable →

Population Y intercept →

Population Slope Coefficient →

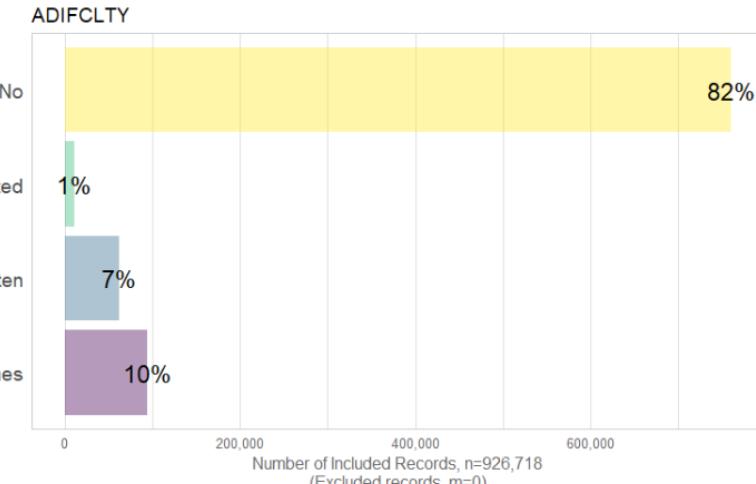
Independent Variable →

Random Error term →

Linear component →

Random Error component →

ADIFCLTY



\$ADIFCLTY ADIFCLTYlevels 1 2 3 4 "No" "Not stated" "Yes, often" "Yes, sometimes"

ADIFCLTYlabel [1] "Problems with ADL"

ADIFCLTYdescription [1] "Difficulties with activities of daily living: Difficulty with activities of daily living such as hearing, seeing, communicating, walking, climbing stairs, bending, learning or doing any similar activities."

$$\ln\left(\frac{\hat{p}}{(1-\hat{p})}\right) = b_0 + b_1 X_1 + b_2 X_2 + \dots + b_p X_p$$

# A. Graphing Technique

## 0.1 Modeling form

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DISABFL %in% c("Yes, often","Yes, sometimes"),
TRUE, FALSE
)
,poor_health = factor(poor_health, levels = c("TRUE","FALSE"))
```

$$Y_i = \beta_0 + \beta_1 X_i + \epsilon_i$$

Dependent Variable →

Population Y intercept →

Population Slope Coefficient →

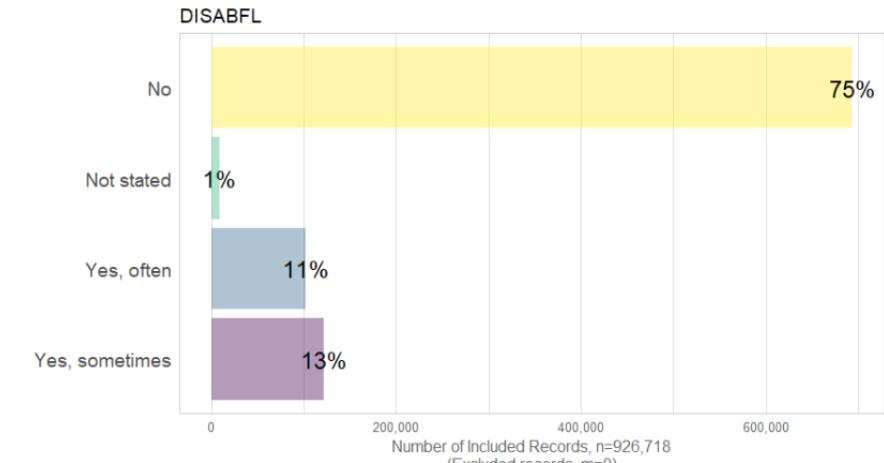
Independent Variable →

Random Error term →

Linear component →

Random Error component →

DISABFL



\$DISABFL \$DISABFLlevels 1 2 3 4 "No" "Not stated" "Yes, often" "Yes, sometimes"

DISABFLlabel [1] "Problems with ADL"

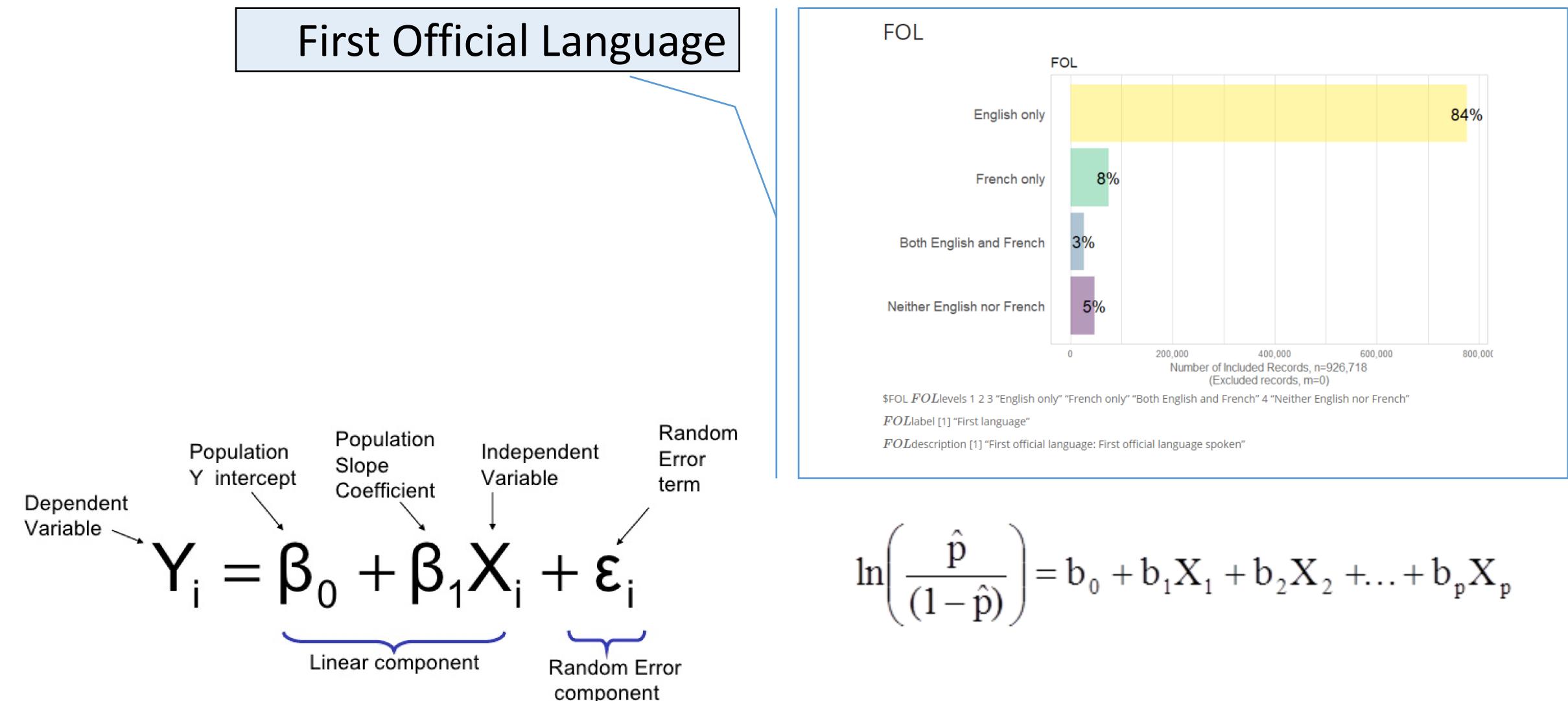
DISABFLdescription [1] "Difficulties with activities of daily living: Refers to difficulty with daily activities and/or a physical condition or mental condition or health problem that reduces the amount or kind of activity that a person can do at home, at work or school or in other activities (e.g., transportation, leisure)."

$$\ln\left(\frac{\hat{p}}{(1-\hat{p})}\right) = b_0 + b_1 X_1 + b_2 X_2 + \dots + b_p X_p$$

# A. Graphing Technique

## 0.1 Modeling form

$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$



# A. Graphing Technique

$$dv \sim -1 + PR + \text{age\_group} + \text{female} + \text{marital} + \text{educ3} + \text{poor\_health} + \text{FOL}$$

0.2 Graphical form

## LEGEND

point = person

Y-axis = probability R is dead in X years

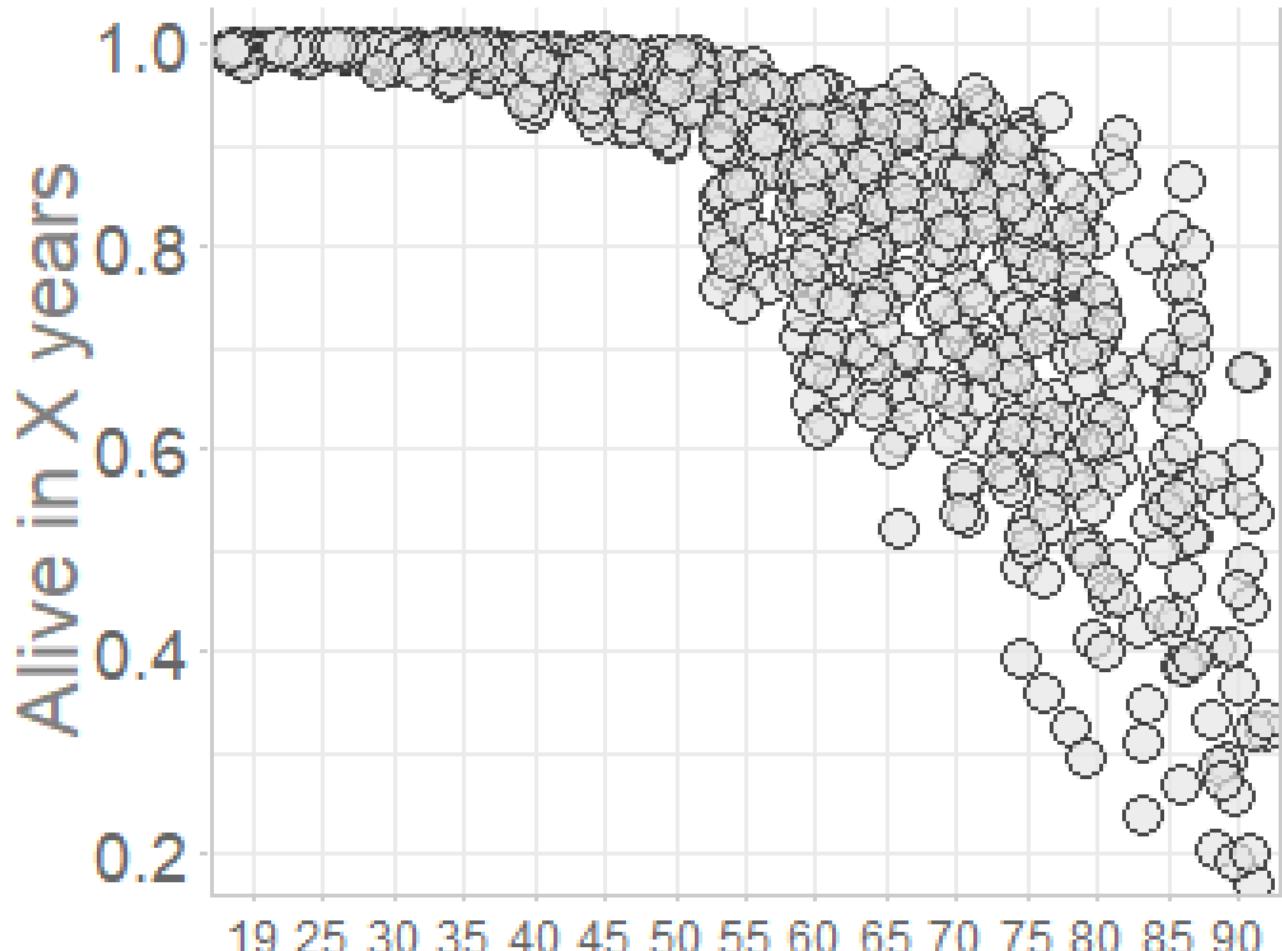
X-axis = age group (floor of 5-year category)

The higher the dot = the higher the chance to be alive in X years

Visualizing probability instead of log-odds because it is more intuitive

$$Y_i = \underbrace{\beta_0 + \beta_1 X_i}_{\text{Linear component}} + \underbrace{\varepsilon_i}_{\text{Random Error component}}$$

Dependent Variable →  $Y_i$   
Population Y intercept →  $\beta_0$   
Population Slope Coefficient →  $\beta_1$   
Independent Variable →  $X_i$   
Random Error term →  $\varepsilon_i$

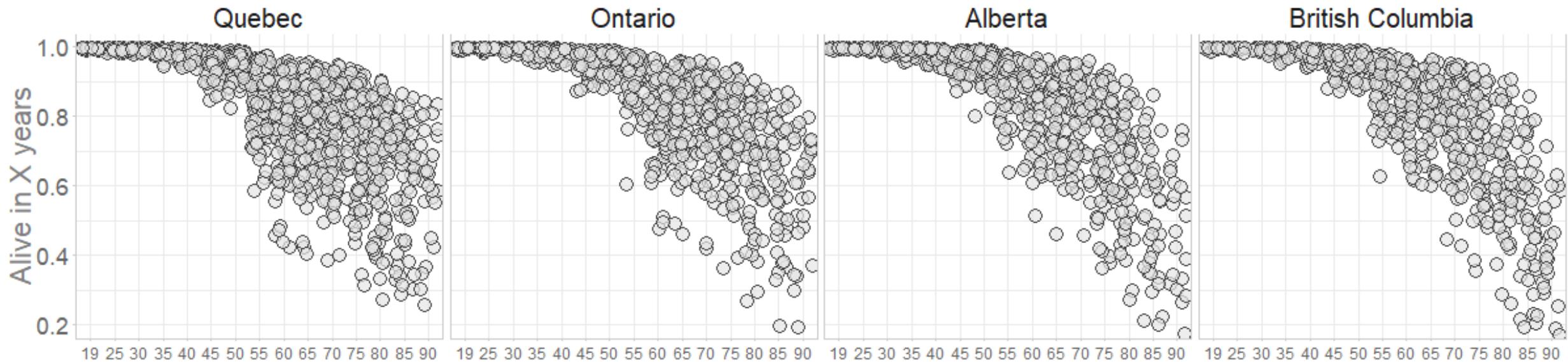


$$\ln\left(\frac{\hat{p}}{(1-\hat{p})}\right) = b_0 + b_1 X_1 + b_2 X_2 + \dots + b_p X_p$$

# A. Graphing Technique

`dv ~ -1 + PR + age_group + female + marital + educ3 + poor_health + FOL`

0.2 Graphical form



## LEGEND

Facet = Province of residence

# A. Graphing Technique

## 0.2 Graphical form

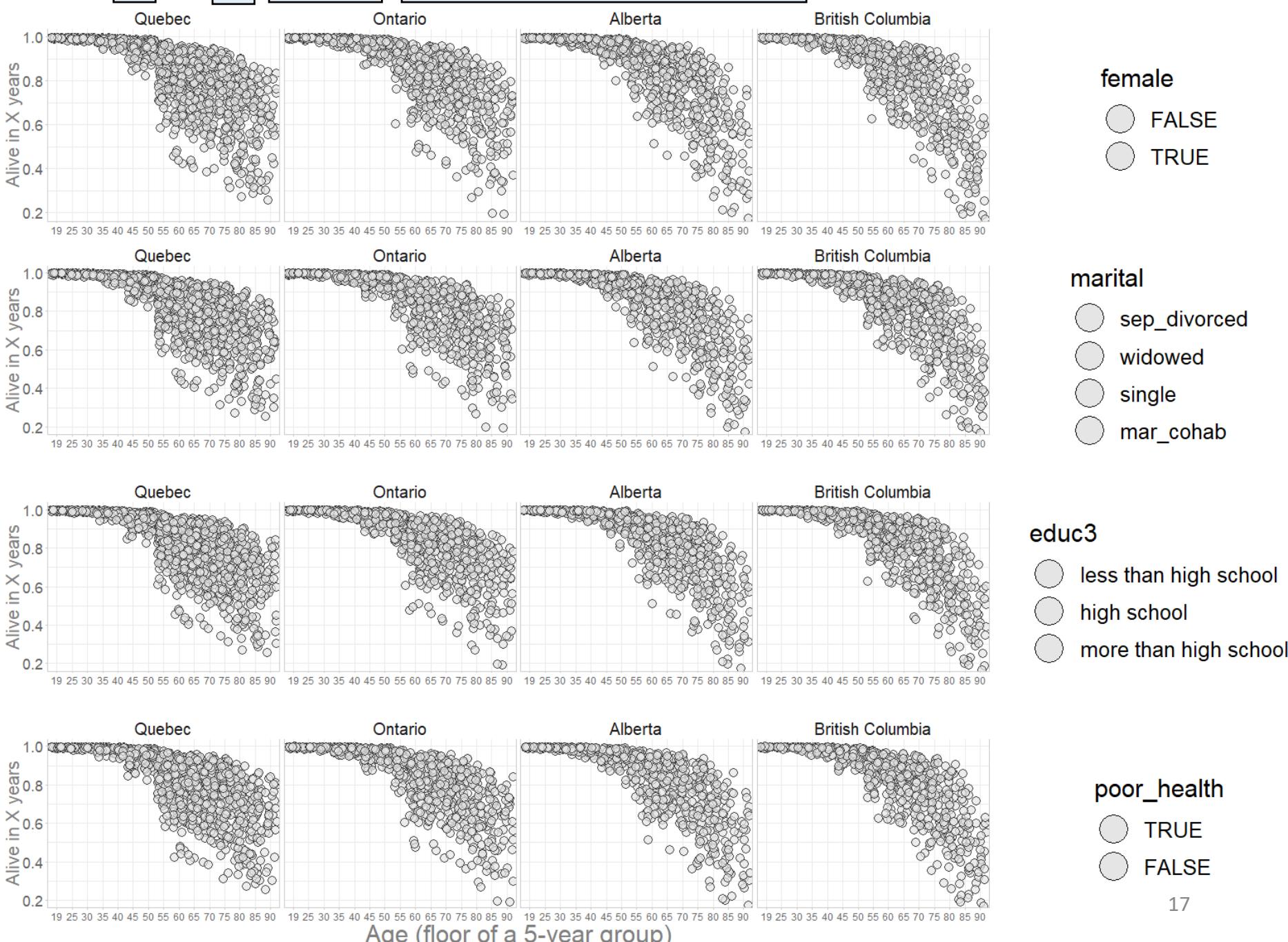
### LEGEND

Rows = duplicate of each other (for now).

Notice that FOL is not displayed

The book is ready for coloring

$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$



# A. Graphing Technique

0.3 Coloring book

## QUESTION

What should the “reference group” be for each predictor?

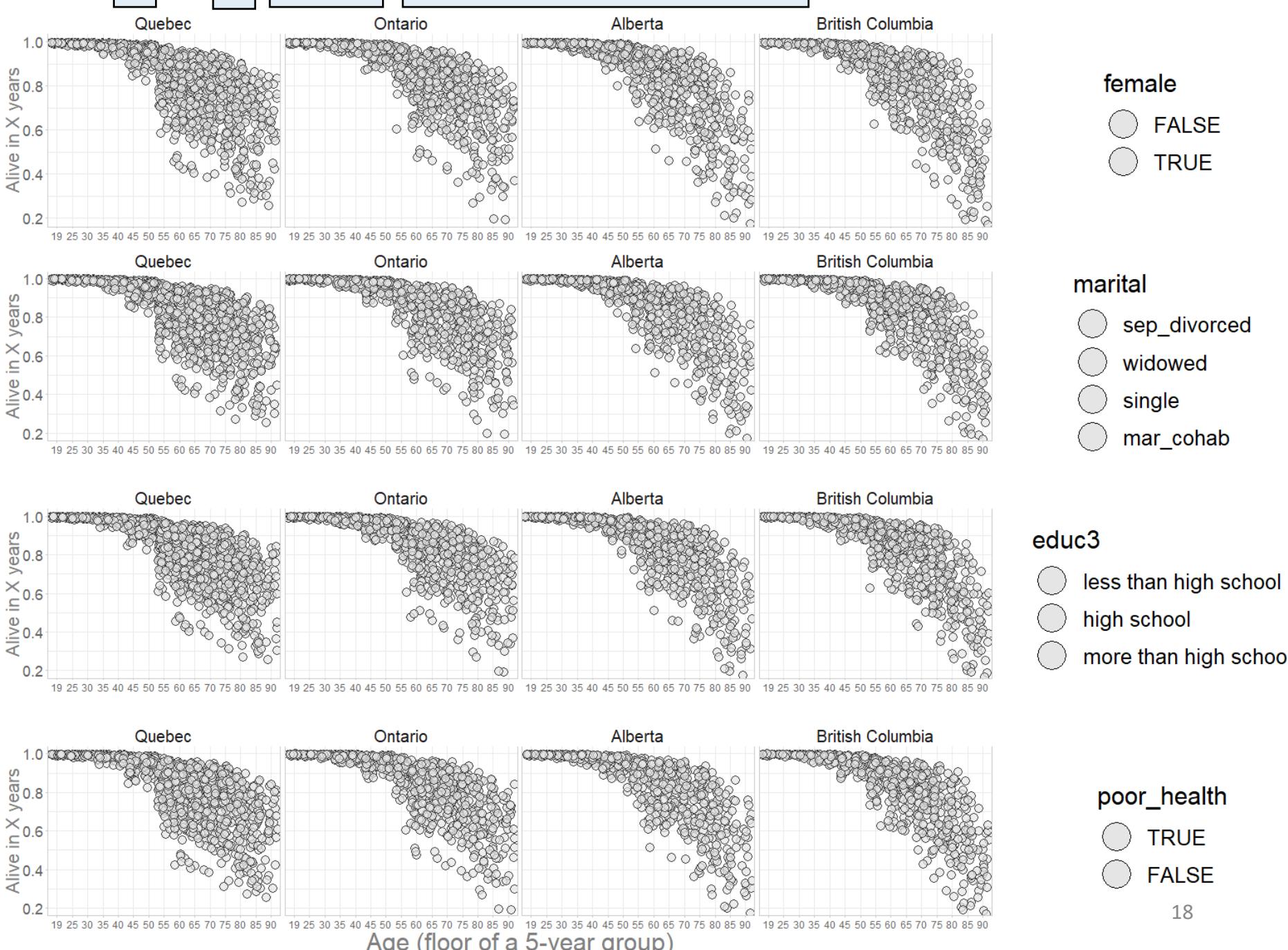
What do we expect based on existing research?

Informed expectation

Reference group



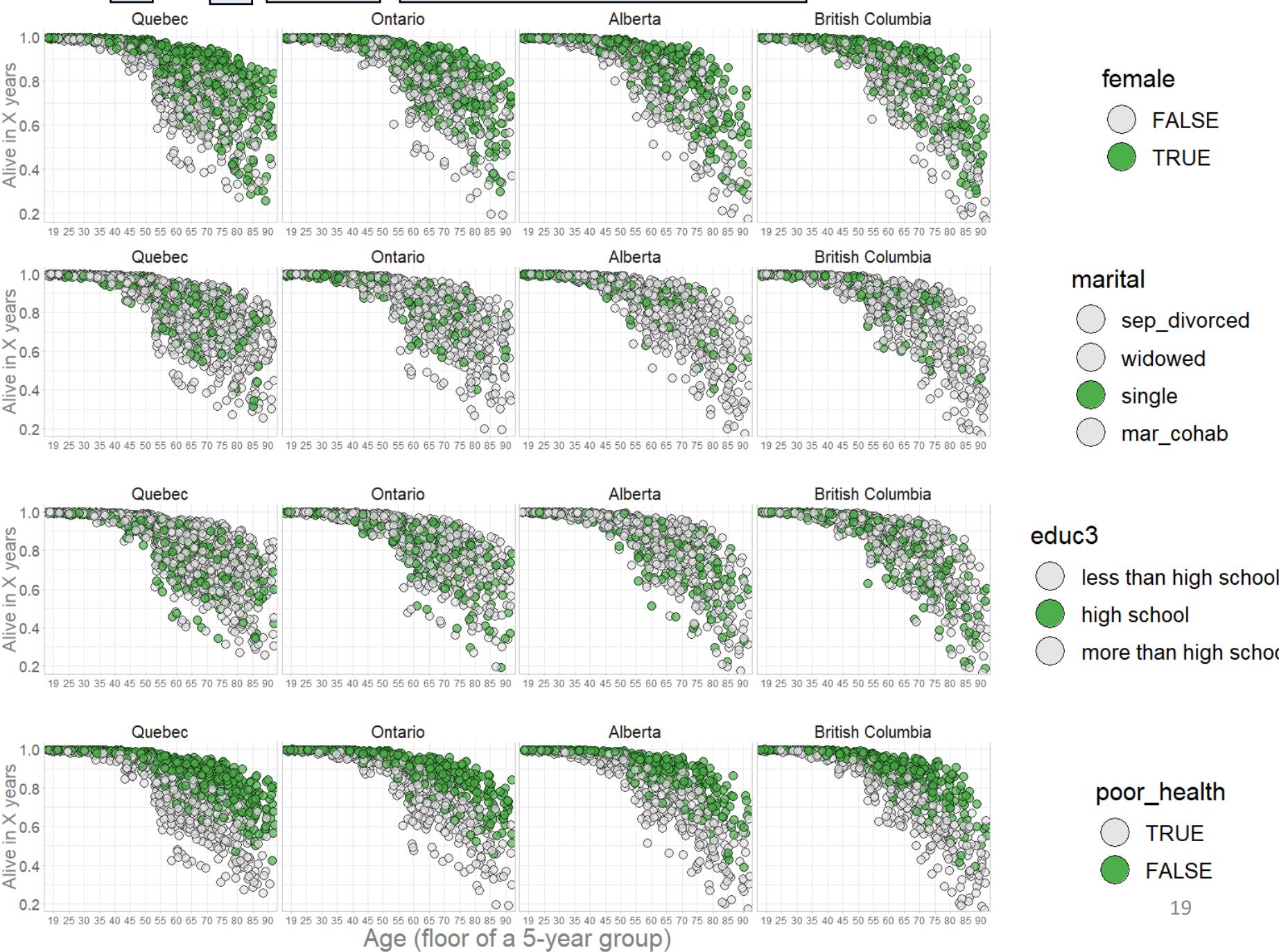
$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$



# A. Graphing Technique

0.3 Coloring book

$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$



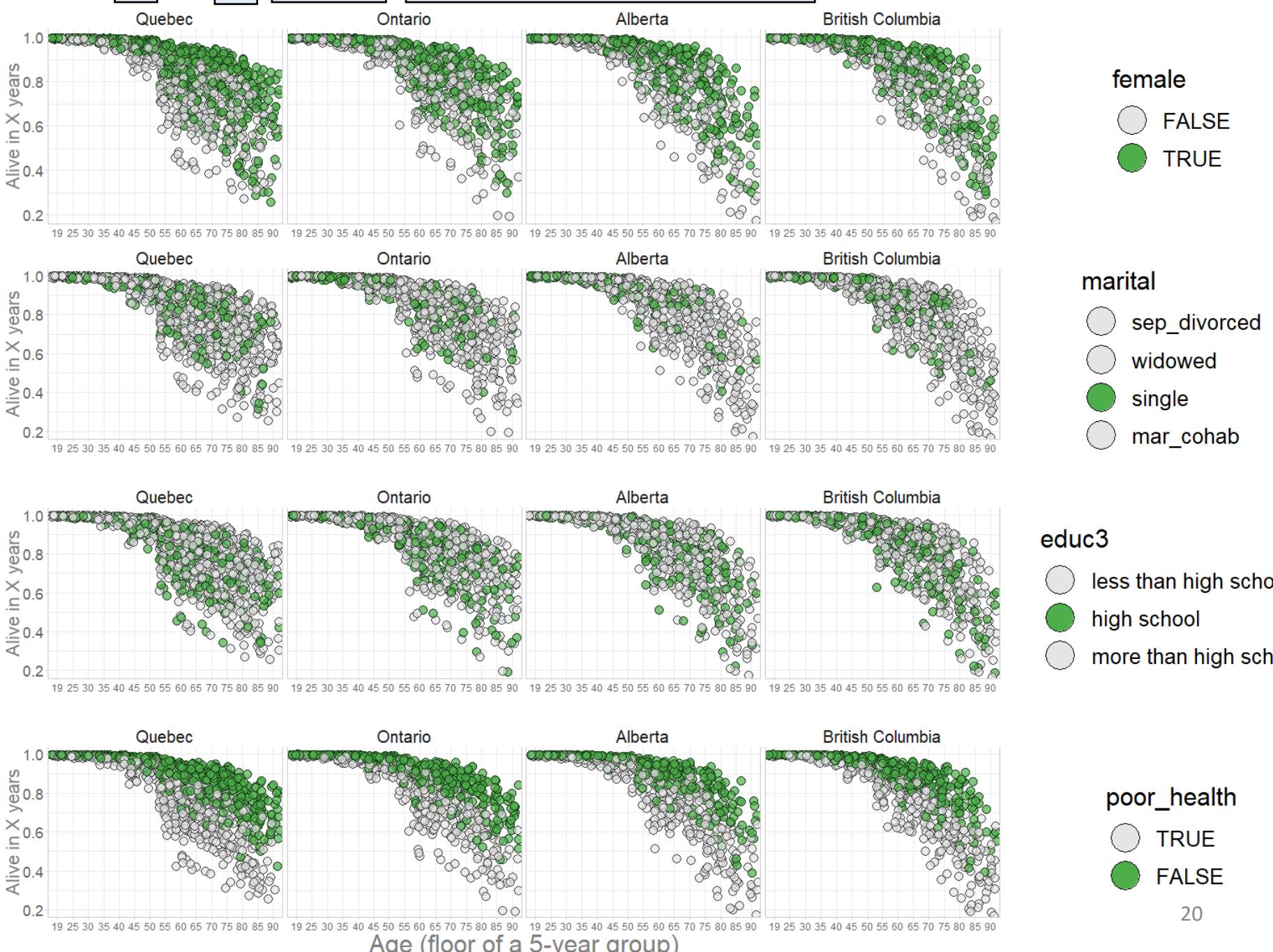
# A. Graphing Technique

0.3 Coloring book

## QUESTION

Compared to reference group, what levels of predictors are expected to **increase** the mortality risk?

$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$



## Informed expectation

Moderately increased risk

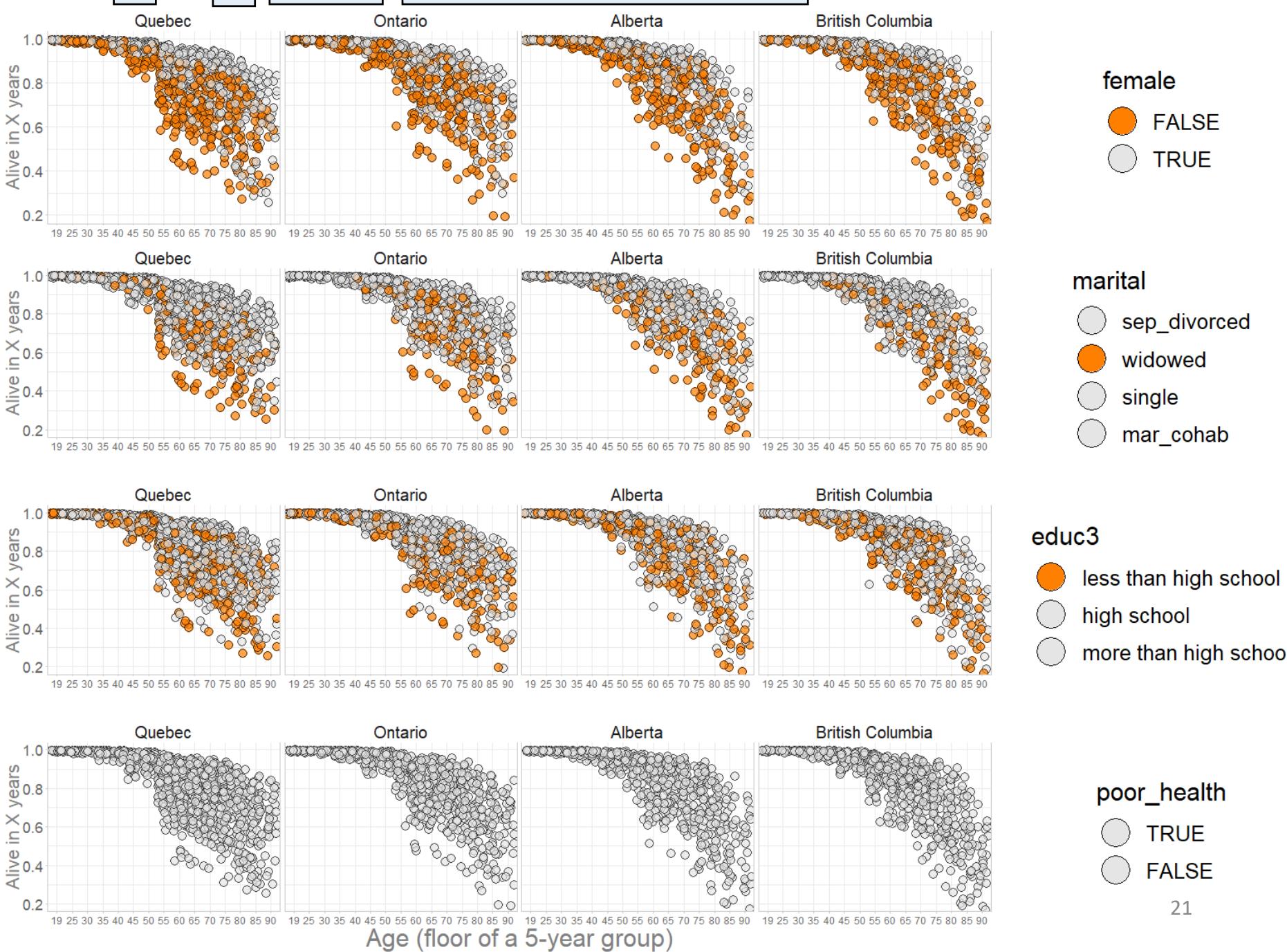


Reference group

# A. Graphing Technique

0.3 Coloring book

$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$



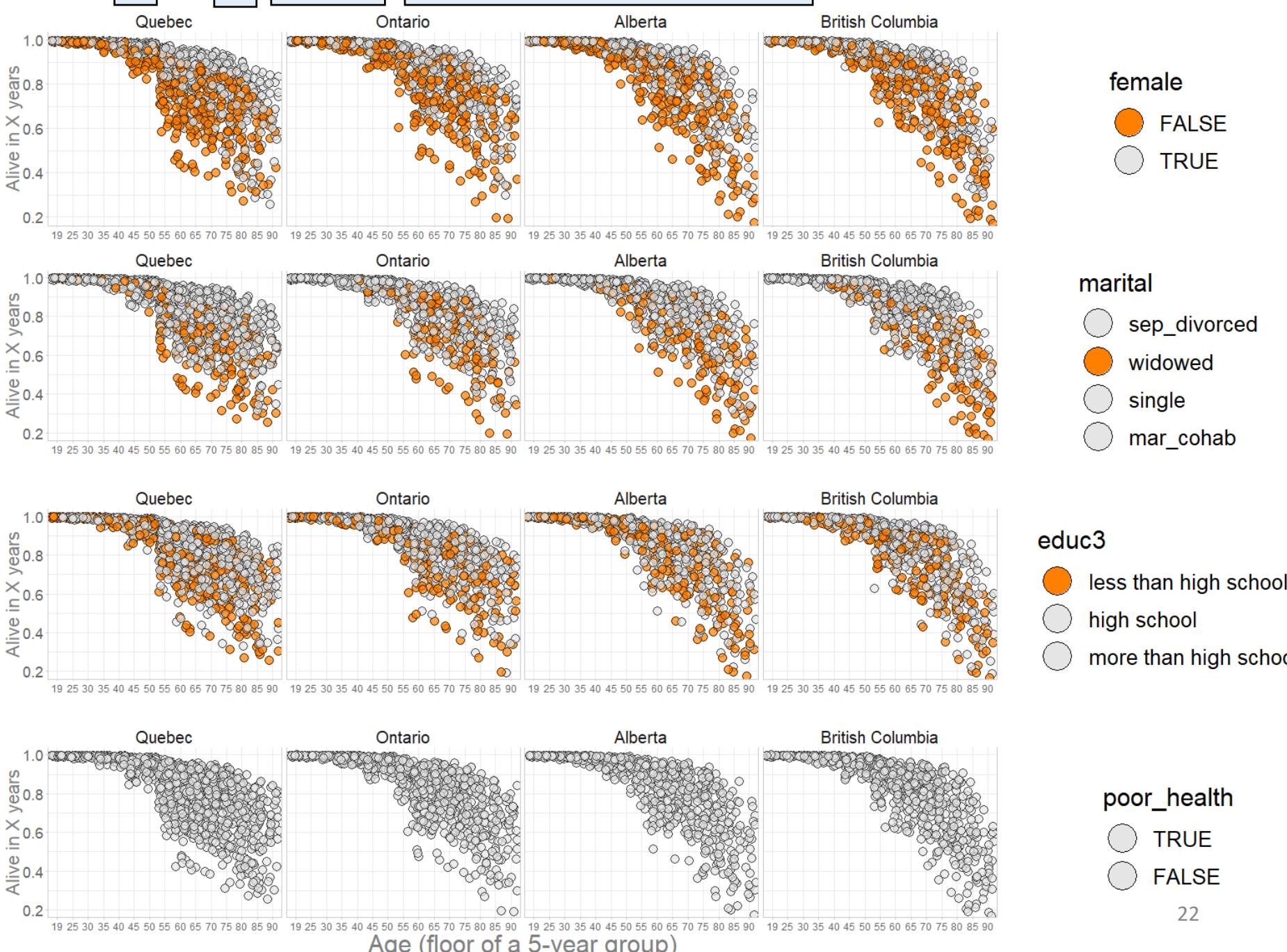
# A. Graphing Technique

0.3 Coloring book

## QUESTION

Compared to reference group, what levels of predictors are expected to **decrease** the mortality risk?

$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$



## Informed expectation

Moderately increased risk

Reference group

Moderately decreased risk

?

female

FALSE

TRUE

marital

sep\_divorced

widowed

single

mar\_cohab

educ3

less than high school

high school

more than high school

poor\_health

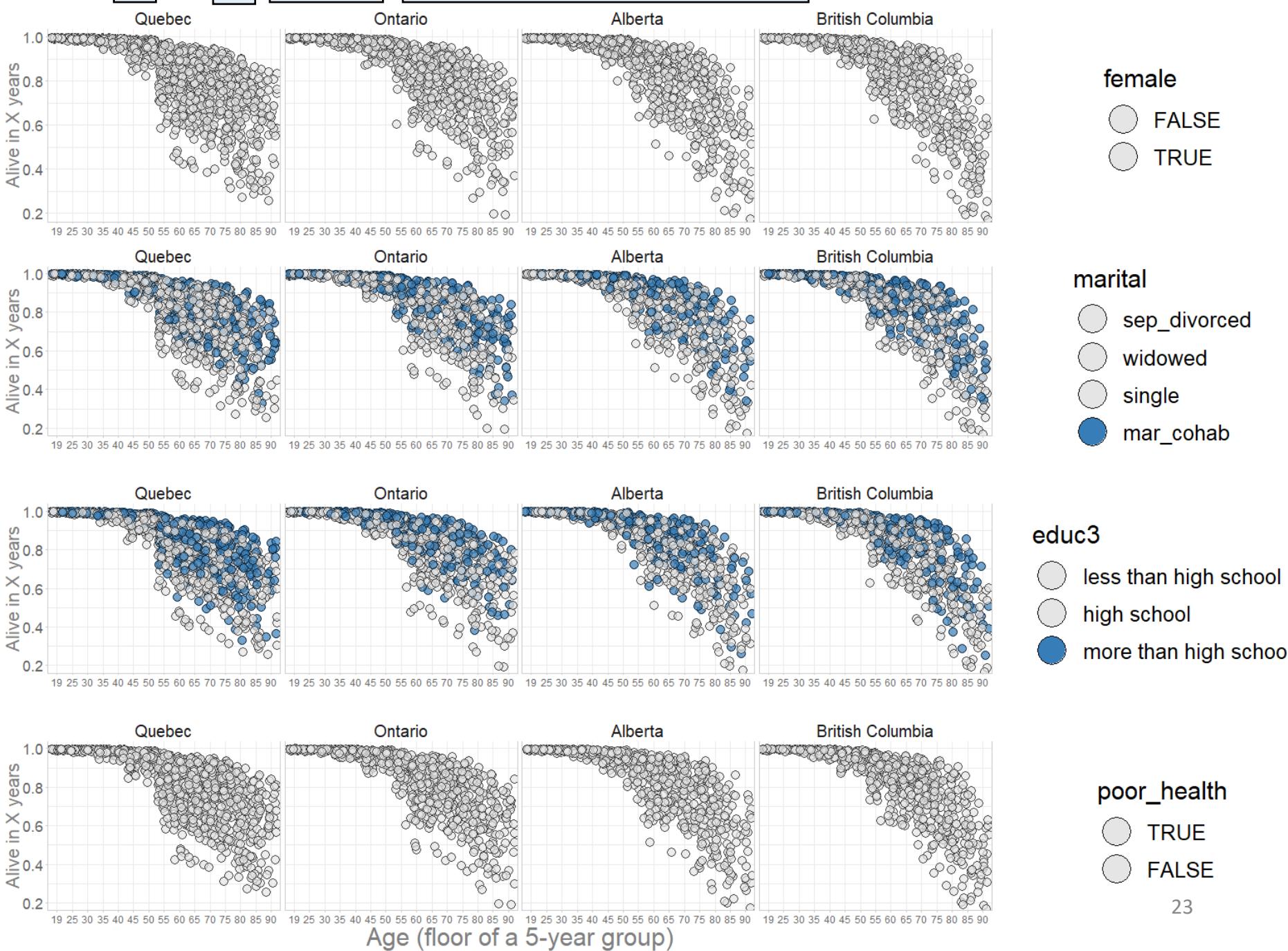
TRUE

FALSE

# A. Graphing Technique

0.3 Coloring book

$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$



# A. Graphing Technique

0.3 Coloring book

## QUESTION

What levels of predictors are expected to affect mortality risk drastically?

## Informed expectation

Substantially increased risk



Moderately increased risk

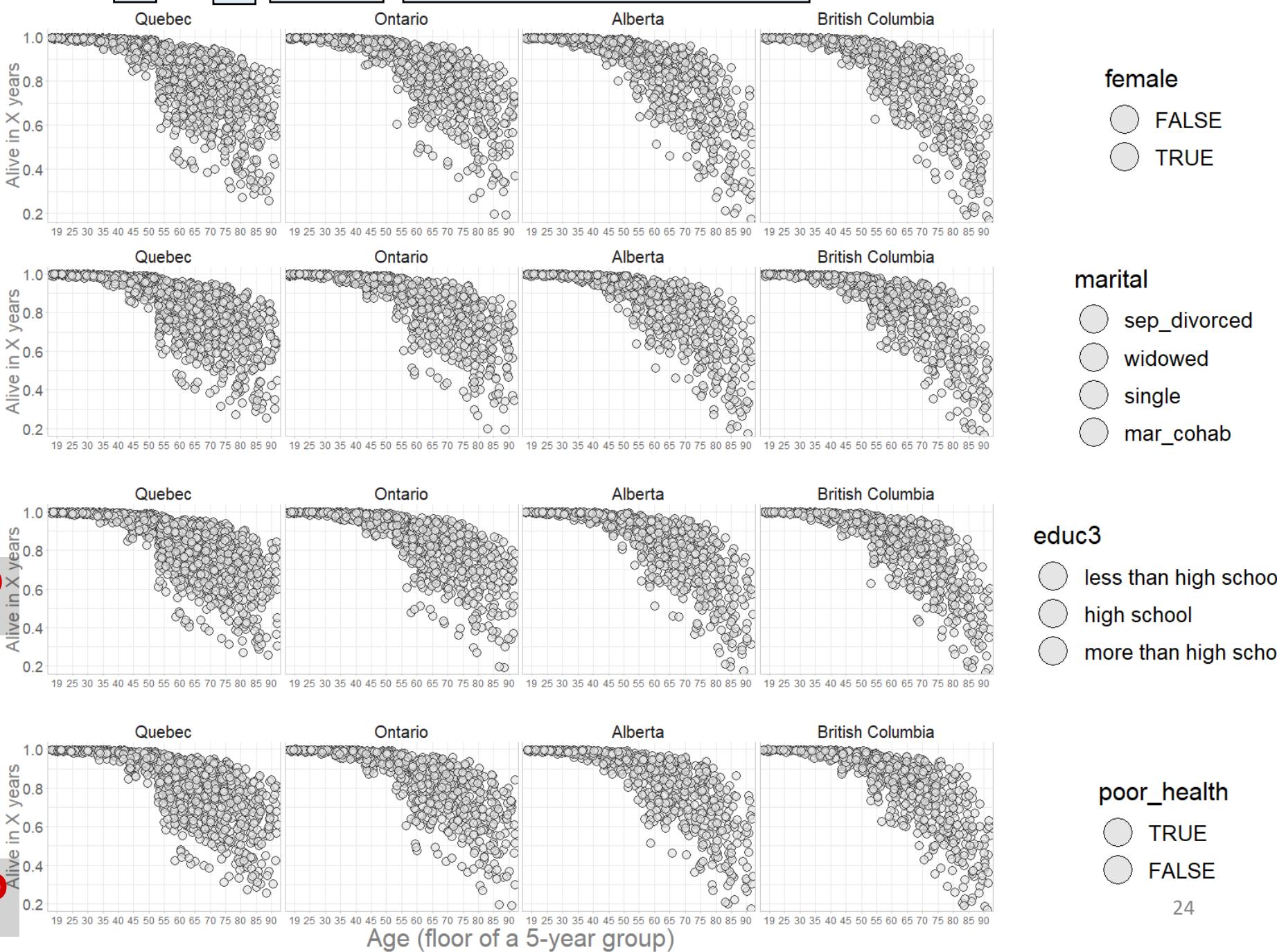
Reference group

Moderately decreased risk

Substantially decreased risk



$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$



# A. Graphing Technique

0.3 Coloring book

## QUESTION

What levels of predictors are expected to affect mortality risk drastically?

## Informed expectation

Substantially increased risk

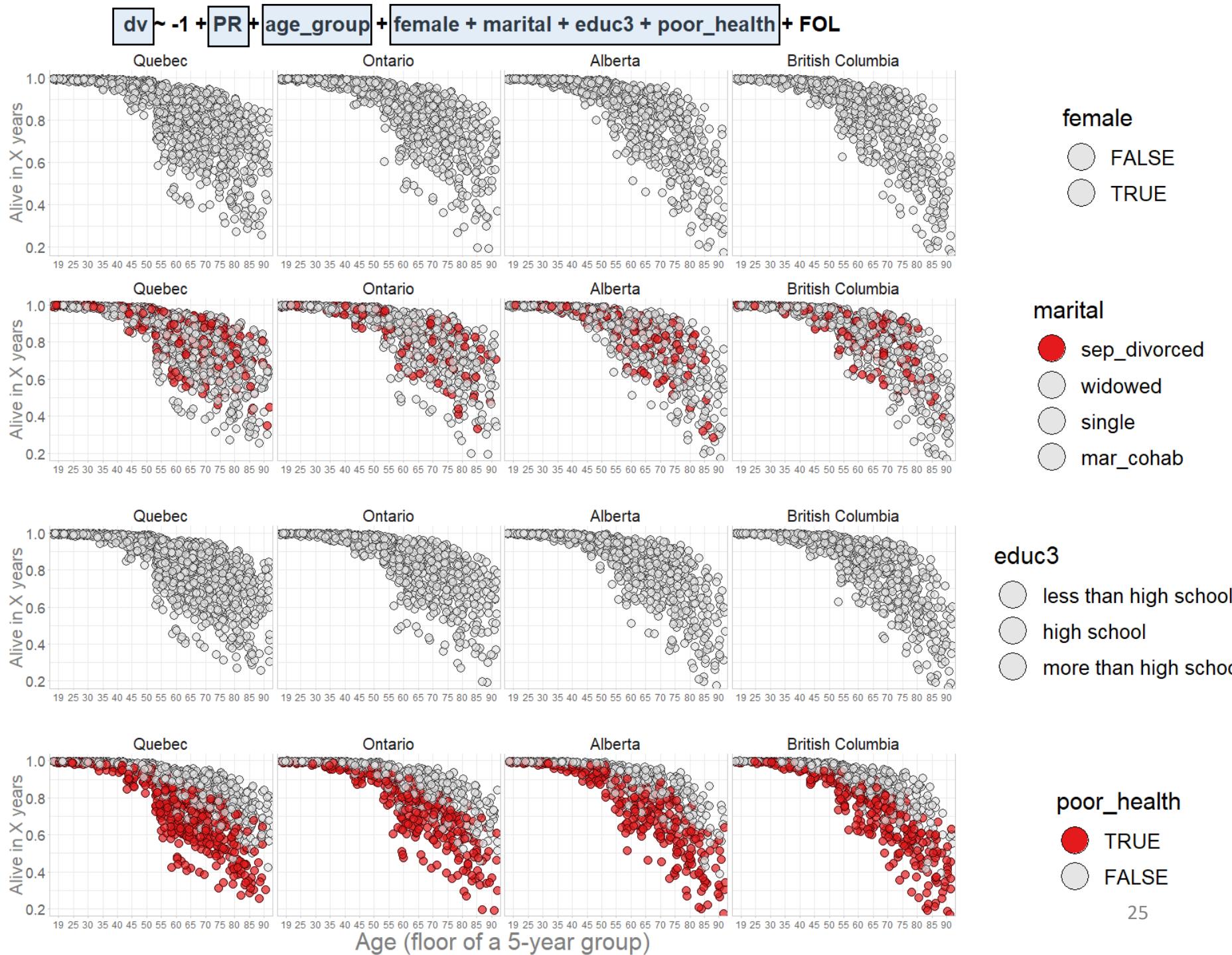
Moderately increased risk

Reference group

Moderately decreased risk

Substantially decreased risk

$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$



# A. Graphing Technique

0.3 Coloring book

## QUESTION

What levels of predictors are expected to affect mortality risk drastically?

No “very bad” and it’s ok.

## Informed expectation

Substantially increased risk

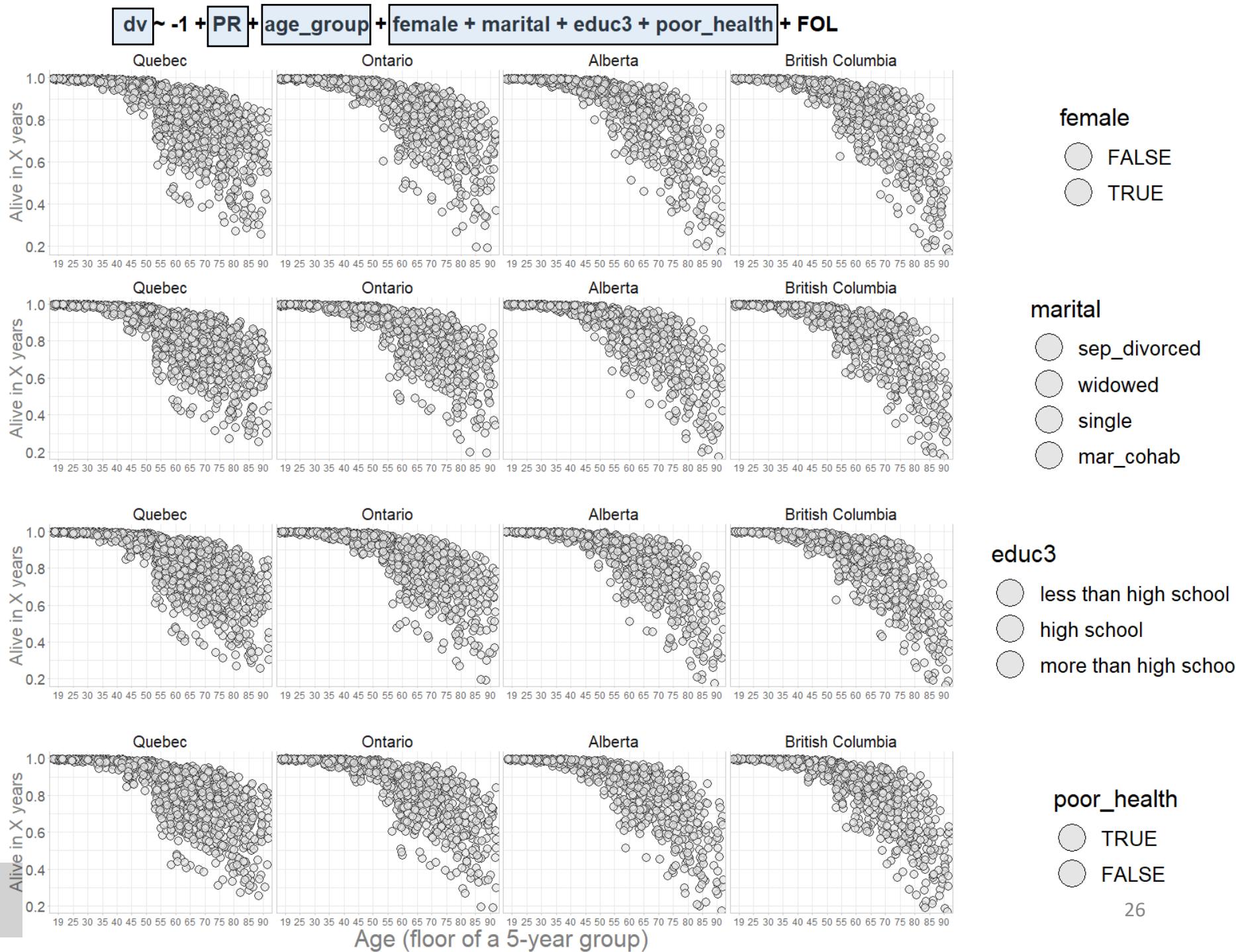
Moderately increased risk

Reference group

Moderately decreased risk

Substantially decreased risk

$$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$$



# A. Graphing Technique

0.3 Coloring book

## NOTICE

Plotting all colors at once  
may not be as informative  
as one would expect

May require too much  
tweaking to make useful

## Informed expectation

Substantially increased risk

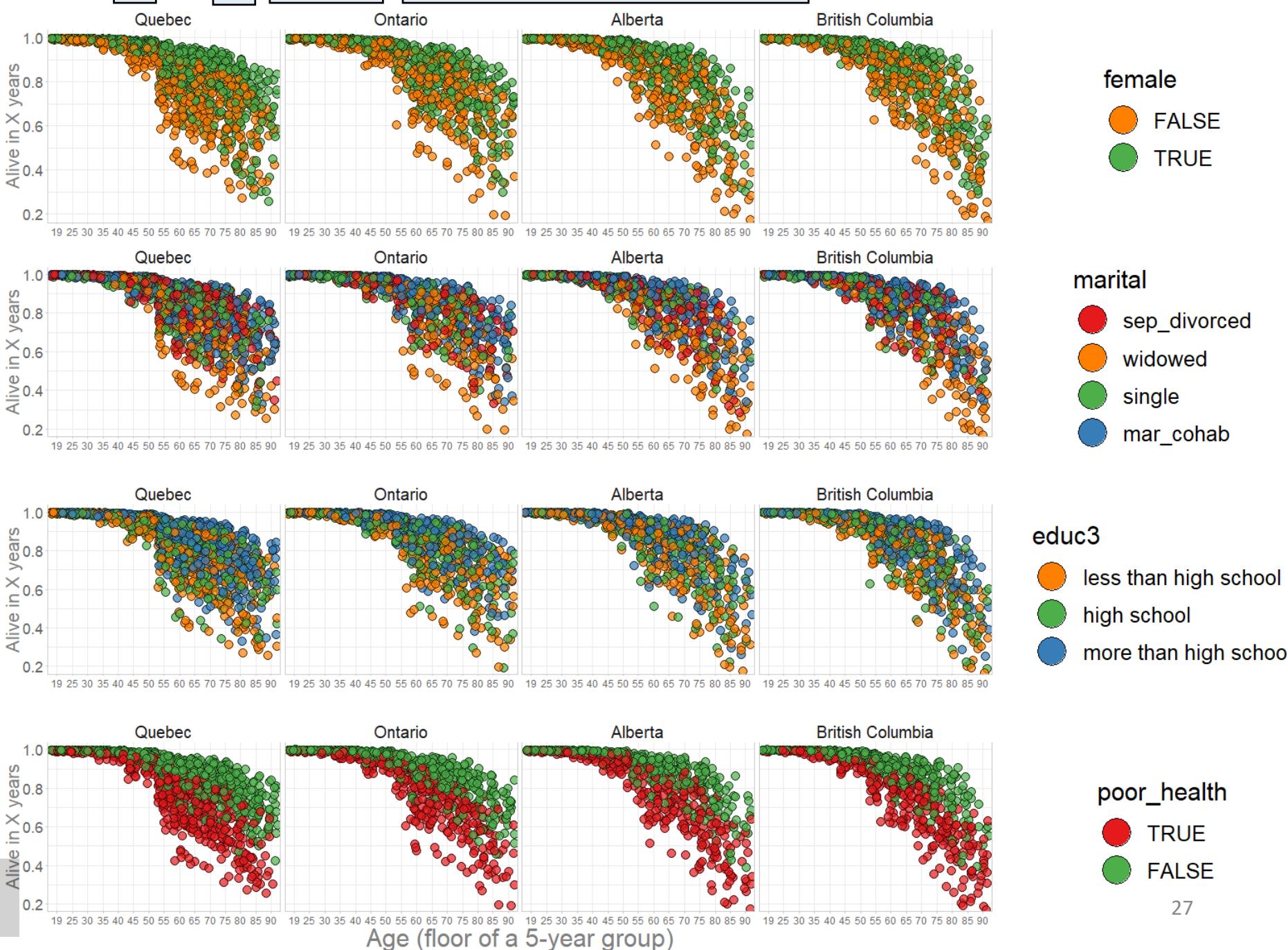
Moderately increased risk

Reference group

Moderately decreased risk

Substantially decreased risk

$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$



# A. Graphing Technique

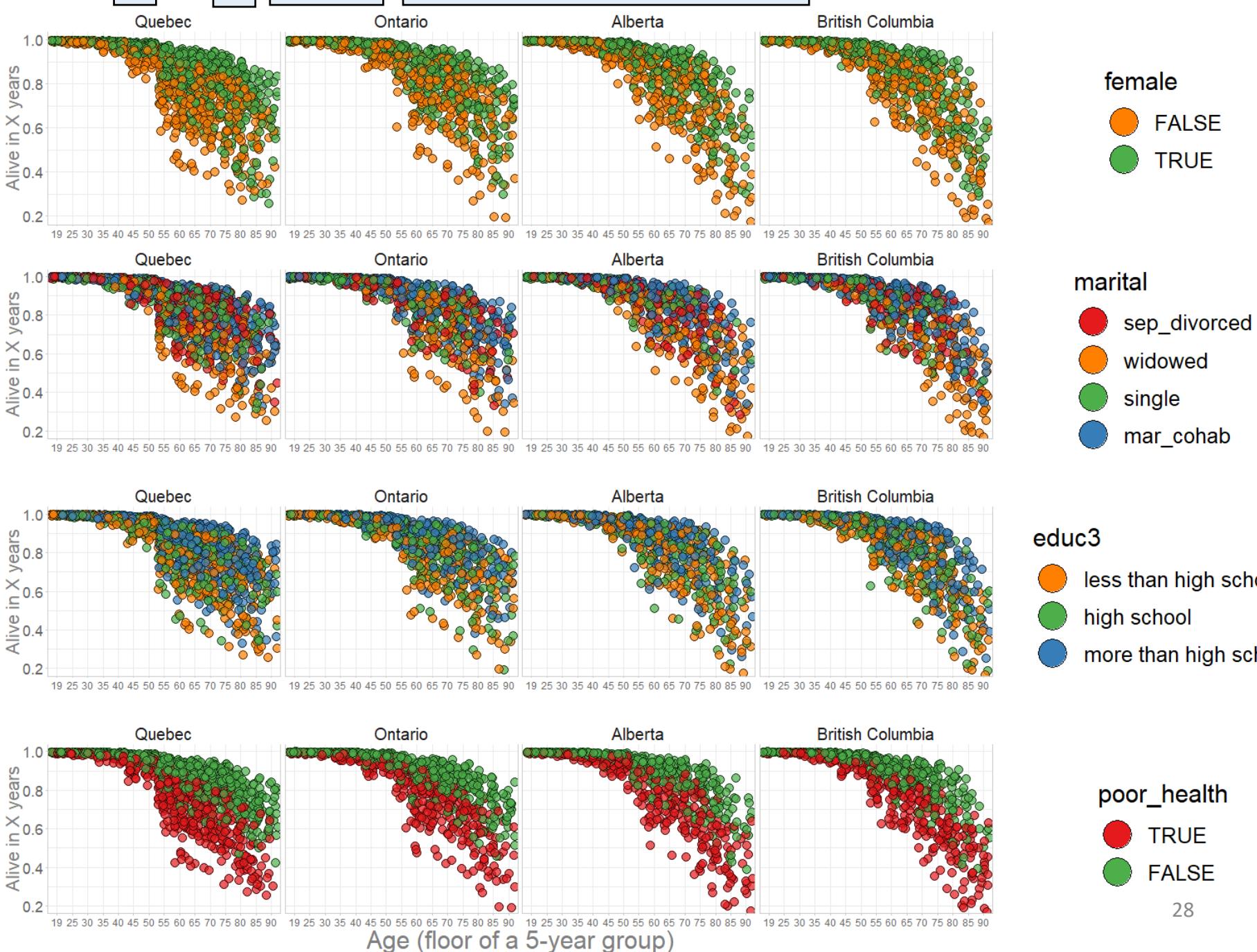
0.3 Coloring book

## NOTICE

Note all predictors are worth visualizing, some are there for control.

We can adjust what is being displayed

$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$



## Informed expectation

Substantially increased risk

Moderately increased risk

Reference group

Moderately decreased risk

Substantially decreased risk

# A. Graphing Technique

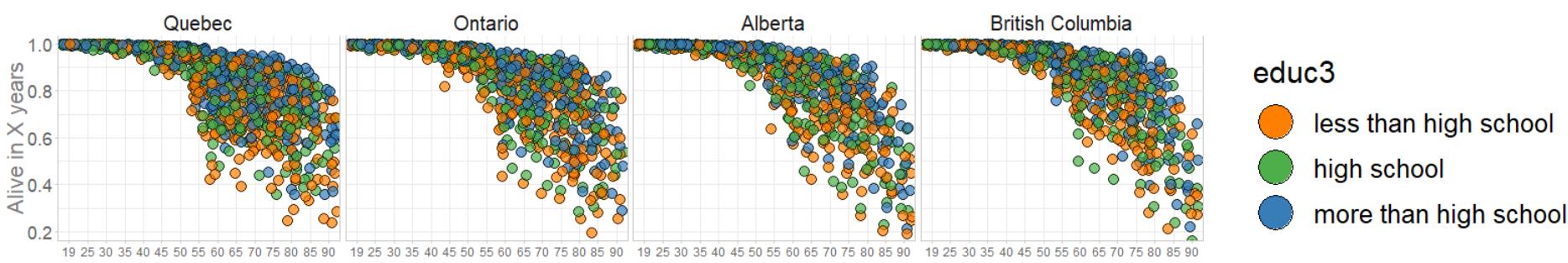
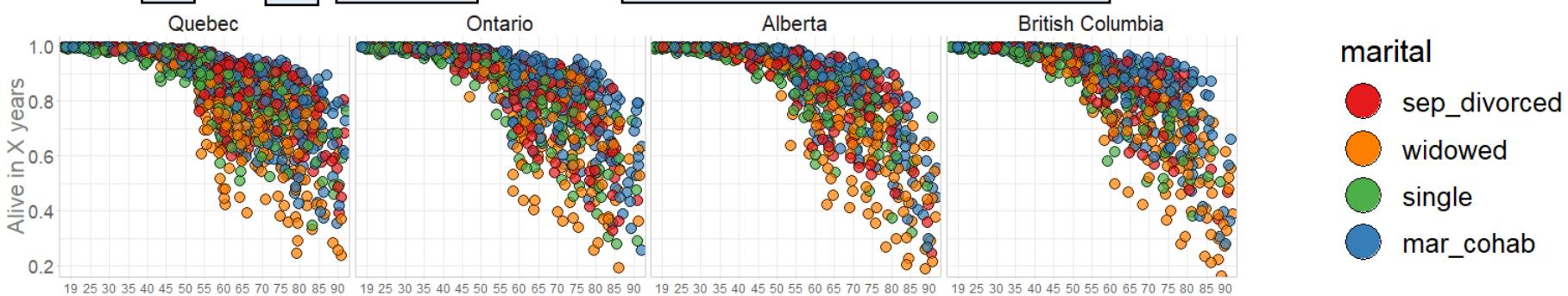
0.3 Coloring book

## NOTICE

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$dv \sim -1 + PR + age\_group + female + marital + educ3 + poor\_health + FOL$



## Informed expectation

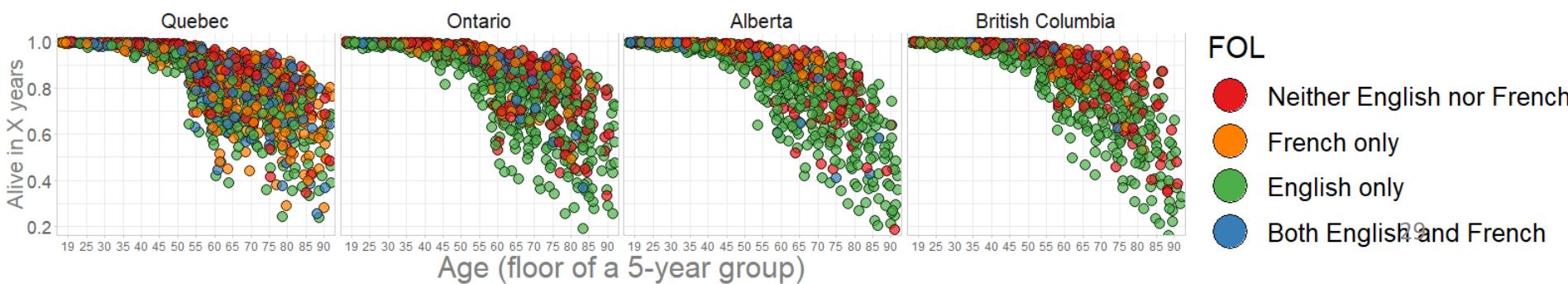
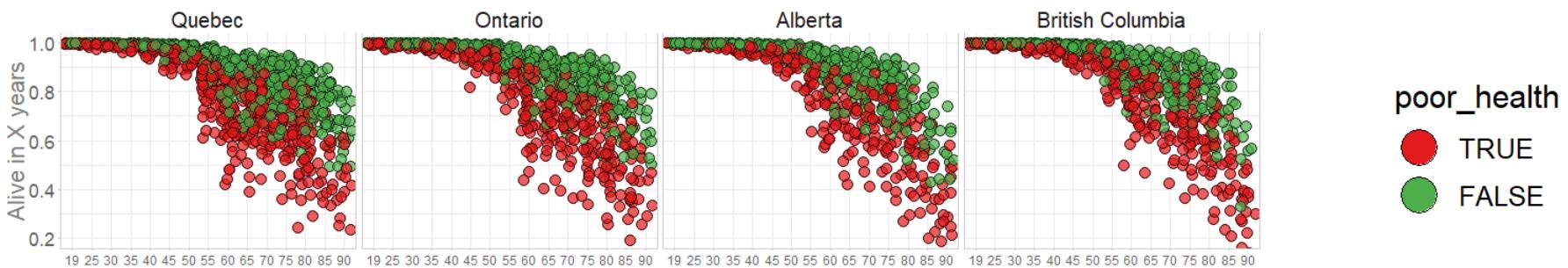
Substantially increased risk

Moderately increased risk

Reference group

Moderately decreased risk

Substantially decreased risk



Let us try to reproduce these graphs!

Ideas to keep in mind as we begin live demonstration

## B. Workflow Highlights

- 1.0 “Let no one ignorant of geometry enter”: (my) [scripts were written to be read by humans](#)
- 1.1 [RAnalysisSkeleton](#) by Will Beasley: basic starting point for reproducible projects
- 1.2 [Autonomous phases](#): data cleaning, statistical modelling, graph production
- 1.3 [Layers of Isolation](#): analysis vs presentation using .R (+ .Rmd) => .html (+ .pdf )
- 1.4 Two essential means of production: [knitr:::stitch\(\)](#) vs [rmarkdown:::render\(\)](#)

We will find these ideas implemented in this project

## B. Workflow Highlights

1.0 “Let no one ignorant of geometry enter”: (my) scripts were written to be read by humans

*Donald Knuth. "Literate Programming (1984)" in Literate Programming. CSLI, 1992, pg. 99.*

I believe that the time is ripe for significantly better documentation of programs, and that we can best achieve this by considering programs to be works of literature. Hence, my title: "Literate Programming."

Let us change our traditional attitude to the construction of programs: Instead of imagining that our main task is to instruct a computer what to do, let us concentrate rather on explaining to human beings what we want a computer to do.

Source: <http://www.literateprogramming.com/>

Let's open the main README and start the reproduction

## B. Workflow Highlights

### 1.3 **Layers of Isolation**: analysis vs presentation

.R

stores analysis  
(what really happens)

.Rmd

stores presentation  
(how you tell about it)

$$\text{.R} + \text{.Rmd} = \text{.html}$$

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# B. Workflow Highlights

- 1.0 “Let no one ignorant of geometry enter”: (my) [scripts were written to be read by humans](#)
- 1.1 [RAnalysisSkeleton](#) by Will Beasley: basic starting point for reproducible projects
- 1.2 **Autonomous phases**: data cleaning, statistical modelling, graph production
- 1.3 **Layers of Isolation**: analysis vs presentation using .R (+ .Rmd) => .html (+ .pdf )
- 1.4 Two essential **means of production**: [knitr:::stitch\(\)](#) vs [rmarkdown:::render\(\)](#)

# C. Live demonstration from [github.com/andkov/IPDLN-2018 hackathon](#)

# D. Conclusions

- 2.0 **Different than Notebooks**: sacrifices simplicity for agility via layers of isolation
- 2.1 **R (+ .Rmd) = .html (+ .pdf )** : moving away from *data playing* towards *data science*
- 2.2 **Reproducible projects**: moving away from notebooks towards software

# Questions? Comments?



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@andkovpro

## B. Workflow Highlights

### 1.3 Layers of Isolation: analysis vs presentation

nents > GitHub > andkov > ipdln-2018-hackathon

<input type="checkbox"/> Name
data-public
data-unshared
libs
manipulation
<input checked="" type="checkbox"/> reports
sandbox
scripts
utility
.gitignore
R
.Rhistory
ipdln-2018-hackathon
LICENSE
NEWS
README.md

.R + .Rmd = .html

ib > andkov > ipdln-2018-hackathon > reports > graphing-phase-only

<input type="checkbox"/> Name	Type
figure-png	File folder
prints	File folder
stitched_output	File folder
graphing-phase-only.md	MD File
<input checked="" type="checkbox"/> graphing-phase-only	R File
<input checked="" type="checkbox"/> graphing-phase-only	RMD File
graphing-phase-only-1	Chrome HTML Document
graphing-phase-only-2	Chrome HTML Document

## B. Workflow Highlights

### 1.4 Two essential means of production

rmarkdown::render(.R + .Rmd) = .html  
knitr::stitch(.R ) = .html

nents > GitHub > andkov > ipdln-2018-hackathon	
<input type="checkbox"/> Name	
<input type="checkbox"/> data-public	
<input type="checkbox"/> data-unshared	
<input type="checkbox"/> libs	
<input type="checkbox"/> manipulation	
<input checked="" type="checkbox"/> reports	
<input type="checkbox"/> sandbox	
<input type="checkbox"/> scripts	
<input type="checkbox"/> utility	
<input type="checkbox"/> .gitignore	
<input type="checkbox"/> .Rhistory	
ipdln-2018-hackathon	
<input type="checkbox"/> LICENSE	
<input type="checkbox"/> NEWS	
<input type="checkbox"/> README.md	

**coloring-book-mortality**

**eda-1**

**graphing-phase-only**

**technique-demonstration**

**README.md**

andkov > ipdln-2018-hackathon > reports > technique-demonstration	
Name	Type
figure-png	File folder
prints	File folder
stitched\_output	File folder
technique-demonstration.md	MD File
technique-demonstration	R File
technique-demonstration	RMD File
technique-demonstration-1	Chrome HTML Document
technique-demonstration-2	Chrome HTML Document
ipdln-2018-hackathon > reports > technique-demonstration > **stitched\_output**	
Name	Type
technique-demonstration	Chrome HTML Document
technique-demonstration.md	MD File

## B. Workflow Highlights

### 1.3 Layers of Isolation: analysis vs presentation

	nents > GitHub > andkov > ipdln-2018-hackathon
<input type="checkbox"/> Name	
data-public	coloring-book-mortality
data-unshared	<input checked="" type="checkbox"/> eda-1
libs	graphing-phase-only
manipulation	technique-demonstration
<input checked="" type="checkbox"/> reports	README.md
sandbox	
scripts	
utility	
.gitignore	
.Rhistory	
ipdln-2018-hackathon	
LICENSE	
NEWS	
README.md	

$$.R + .Rmd_1 = .html_1$$

$$.R + .Rmd_2 = .html_2$$

	nents > GitHub > andkov > ipdln-2018-hackathon > reports > eda-1
<input type="checkbox"/> Name	Type
figure-png	File folder
eda-1	Chrome HTML Document
eda-1.md	MD File
<input checked="" type="checkbox"/> eda-1	R File
<input checked="" type="checkbox"/> eda-1	RMD File
eda-1a-first-gen-immigrant	Chrome HTML Document
eda-1a-first-gen-immigrant.md	MD File
<input checked="" type="checkbox"/> eda-1a-first-gen-immigrant	RMD File