Oikos

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Appendix 1

Annotated R code for applying the latent indicator process model

Here, we provide R code to demonstrate an application of the latent indicator process model. Though empirical data for the proposed model in the manuscript featuring the red-backed salamander *Plethodon cinereus* are not available, we use this example to guide the demonstration. The 'GGally' package is required for reproducing figures.

```
library(GGally)
```

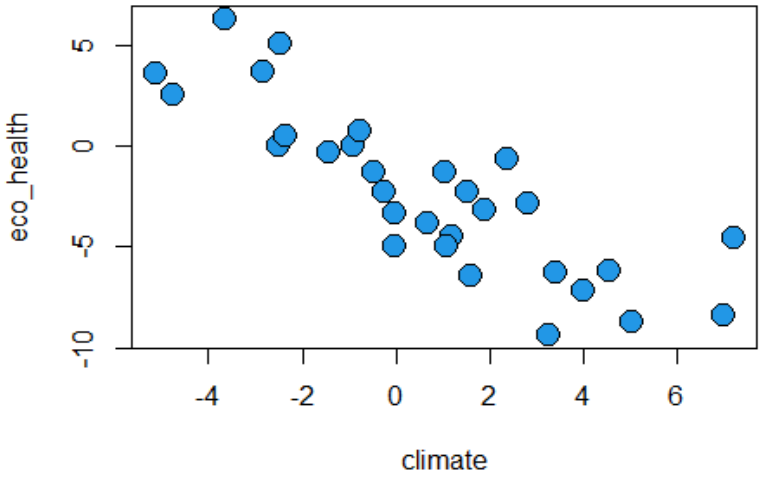
In this example, we observe the effects of the latent driver variable (*D*) climate over 30 years. Ecosystem health, the latent variable of interest (*U*), has a negative relationship with climate through an unobserved pathway.

```
years <- 30

climate <- rnorm(years, 0 + runif(years,-2,2)*1.5, 2)

eco_health <- rnorm(30, -2 - 1*climate, 2)

plot(eco_health ~ climate, bg=4, pch=21, cex=2)
```



There are four measurable environmental variables (M_1: temperature variability, M_2: soil moisture, M_3: soil chemistry, M_4: soil freeze depth) that are all influenced by climate.

```
temp_var <- rnorm(years, 0.5*climate, 1)
soil_mois <- rnorm(years, 0.75*climate, 1)
soil_ph <- rnorm(years, -0.5*climate, 1)
freeze_depth <- rnorm(years, -1*climate, 1)
```

These environmental variables are also drivers of red-backed salamander density (which we can measure), and the relationships between the environmental variables and red-backed salamander density make up the observed pathways in our model.

```
mander_D <- rpois(years, exp(-2 -1*temp_var + 1*soil_mois + 1*soil_ph + 1*freez
e_depth))

lvm_data <- data.frame(temp_var,
                       soil_mois,
                       soil_ph,
                       freeze_depth,
                       mander_D)

lvm <- glm(mander_D ~ temp_var + soil_mois + soil_ph + freeze_depth, family="po
isson", data=lvm_data)

pred_mander_D <- predict(lvm, type="response")
```

What we find is that the relationship between the measureable environmental variables and red-backed salamander density is proportional to the relationship between climate and ecosystem health.

```
ggpairs(data.frame(climate, eco_health, log(pred_mander_D)),
        columnLabels = c("Climate", "Ecosystem Health", "Salamander Density (lo
g)"),
        ggplot2::aes(colour=I("blue"), alpha=0.5, size=1),
        diag=list("continuous"="blank"))+
  theme_bw()
```