Problem Set 3

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Species of concern: Bog Fritillary Butterfly (*Procolossiana eunomia*)

1. We chose to study this species due to concerns around its conservation. Like most other insects, the population dynamics of this species are poorly understood. However, there are indications that loss of bog habitat vital to the growth of its host plants has negative consequences on the butterfly population (Goffart et al., 2010). (Easton note: Very cool that you were able to include citations in the document.) Climate change is also thought to play a role on declining populations, as increased temperatures have various effects on life stages (Radchuk et al., 2013). The species has been observed to be absent from several areas from which it historically would have been found in (Morgun, 2019). Specifically, we are interested in the population dynamics in Belgium, as the population there is isolated from other Northern European populations due to lack of habitat that would allow for dispersal between them (Goffart et al., 2010).

2. We would like to answer the question, "Which life stage of the Bog Fritillary butterfly should be considered most important for conservation?"

3. Calculate eigenvalue, stable age distribution, elasticity, and sensitivity. What do these tell you about the population?

```
A
```

```
##        [,1] [,2]  [,3] [,4] [,5]
## [1,] 0.0000 0.00 0.000 0.00   89
## [2,] 0.7444 0.00 0.000 0.00    0
## [3,] 0.0000 0.49 0.000 0.00    0
## [4,] 0.0000 0.00 0.025 0.00    0
## [5,] 0.0000 0.00 0.000 0.75    0
```

```
# calculate eigenvalue
my_eigen <- eigen(A)
my_eigen$values[5]
```

```
## [1] 0.9054798+0i
```

```
# calculate stable age dist.
eigen.analysis(A)
```

```
## $lambda1
## [1] 0.9054798
##
## $rho
## [1] 3.236068
```

```
##
## $sensitivities
##           [,1]      [,2]     [,3]      [,4]        [,5]
## [1,] 0.0000000 0.0000000 0.000000 0.0000000 0.002034786
## [2,] 0.2432777 0.0000000 0.000000 0.0000000 0.000000000
## [3,] 0.0000000 0.3695836 0.000000 0.0000000 0.000000000
## [4,] 0.0000000 0.0000000 7.243838 0.0000000 0.000000000
## [5,] 0.0000000 0.0000000 0.000000 0.2414613 0.000000000
## attr(,"class")
## [1] "leslie.matrix"
##
## $elasticities
##      [,1] [,2] [,3] [,4] [,5]
## [1,]  0.0  0.0  0.0  0.0  0.2
## [2,]  0.2  0.0  0.0  0.0  0.0
## [3,]  0.0  0.2  0.0  0.0  0.0
## [4,]  0.0  0.0  0.2  0.0  0.0
## [5,]  0.0  0.0  0.0  0.2  0.0
## attr(,"class")
## [1] "leslie.matrix"
##
## $stable.age
## [1] 0.436787133 0.359085159 0.194318787 0.005365078 0.004443842
##
## $repro.value
## [1]  1.000000  1.216389  2.247786 81.413004 98.290436
```

```r
stable_age <- eigen.analysis(A)$stable.age
stable_age
```

```
## [1] 0.436787133 0.359085159 0.194318787 0.005365078 0.004443842
```

```r
# calculate sensitivities
sensitivities <- eigen.analysis(A)$sensitivities
sensitivities
```

```
##           [,1]      [,2]     [,3]      [,4]        [,5]
## [1,] 0.0000000 0.0000000 0.000000 0.0000000 0.002034786
## [2,] 0.2432777 0.0000000 0.000000 0.0000000 0.000000000
## [3,] 0.0000000 0.3695836 0.000000 0.0000000 0.000000000
## [4,] 0.0000000 0.0000000 7.243838 0.0000000 0.000000000
## [5,] 0.0000000 0.0000000 0.000000 0.2414613 0.000000000
## attr(,"class")
## [1] "leslie.matrix"
```

```r
# calculate elasticities
elasticities <- eigen.analysis(A)$elasticities
elasticities
```

```
##      [,1] [,2] [,3] [,4] [,5]
## [1,]  0.0  0.0  0.0  0.0  0.2
## [2,]  0.2  0.0  0.0  0.0  0.0
## [3,]  0.0  0.2  0.0  0.0  0.0
## [4,]  0.0  0.0  0.2  0.0  0.0
## [5,]  0.0  0.0  0.0  0.2  0.0
## attr(,"class")
## [1] "leslie.matrix"
```

The eigen value (0.91) (Easton note: Very cool that you used in-line code here. Also note that you can use commands like round() to further clean up the output.) indicates that the population is declining as it is less than 1. The stable age distribution (0.4367871, 0.3590852, 0.1943188, 0.0053651, 0.0044438), is the right eigen vector. It tells us that for the distribution of ages in the population to be stable, the majority of individuals should be in the 1st or 2nd life stages (egg and pre-diapausal larvae). Approximately 20% of individuals should be in the overwintering larvae stage. Only about 1% of the population should be in the pupa and adult stages for the population to be stable. At those frequencies, the distribution of ages in the population is stable.
The sensitivity matrix shows us that the third life stage, overwintering larvae, has the greatest sensitivity (7.243838). This indicates that a small change to the survival rate at this stage would have the greatest impact on the population. The elasticities for each vital rate were equal to 0.2, representing the proportional change in overall growth rate from changes in vital rates (such as fecundity or survivorship).

Easton note: Really good job throughout this section at interpretating the calculations and what they mean biologically.

4. Based on the sensitivities calculated, it is clear that implementing conservation strategies at the overwintering larval stage would provide the greatest increase in population growth. That stage is very sensitive, so to increase the eigenvalue to be greater than 1, an increase in the survival at this life stage is necessary (Easton note: It would have been interesting to see exactly how much of an increase in this survival rate would have led to an eigenvalue greater than 1). These strategies may include rearing additional larvae under controlled climate and habitat restoration to assure a proper microclimate for overwintering.

References

Goffart, P., Schtickzelle, N., & Turlure, C. (2010). Conservation and Management of the Habitats of Two Relict Butterflies in the Belgian Ardenne: Proclossiana eunomia and Lycaena helle. In J. C. Habel & T. Assmann (Eds.), *Relict species* (pp. 357–370). Springer Berlin Heidelberg.

Morgun, D. V. (2019). Boloria eunomia (Esper, 1799) (Lepidoptera: Nymphalidae) revised in the Caucasus: Taxonomy, life history, rediscovery and conservation in Armenia. *Kavkazskij Entomologiceskij Bulleten*, *15*(2), 359–365. https://doi.org/10.23885/181433262019152-359365

Radchuk, V., Turlure, C., & Schtickzelle, N. (2013). *Each life stage matters: The importance of assessing the response to climate change over the complete life cycle in butterflies* (Nos. 1; Vol. 82, pp. 275–285). https://doi.org/10.1111/j.1365-2656.2012.02029.x