Lab 7: Networks

Alejandro Santillana

Computational Topics

- Build and visualize food webs
- Write functions to implement mathematical equations

Conservation topics

- Paleofood webs
- Species extinction

In this lab we will practice our network visualization and manipulation skills using the paleo food web data from Yeakel et al. 2014 (https://doi.org/10.1073/pnas.1408471111).

Paleoweb
See the beautiful, animated version of the graphic above here (https://infograficos.estadao.com.br/public/cidades/extincoes-egito/)

With some interaction networks we can observe the interactions, for example plant-pollinator networks, seed-disperal networks, human social networks. In food webs sometimes feeding interactions are observed directly, through camera traps, people doing timed observations, and now molecular analysis of gut contents/scat. However, often with food webs people build probabilistic models of who interacts with who based on body size (as in the Yeakel et al. 2014), especially with paleowebs. Thus the data from Yeakel et al. is 1) an occurrence matrix

(Figure 2 from the publication) and a matrix of body sizes (two columns, females then males). We will use these data to build the foodwebs for each time period. This lab is pretty challenging because it will use many of our core programming skills (for loops, writing functions, subsetting data) and our network skills.

First we will read in the data. The matrix we are reading in has no row or column names, we will have to set them.

```
sp_occ <- read.table(file="data/egypt_data.txt", header = FALSE)
str(sp_occ)
```

```
## 'data.frame':    39 obs. of  23 variables:
##  $ V1 : int  1 1 1 1 1 1 1 1 0 1 ...
##  $ V2 : int  1 1 1 1 1 1 1 1 0 1 ...
##  $ V3 : int  1 1 1 1 0 1 1 1 0 1 ...
##  $ V4 : int  1 1 1 1 0 1 1 1 0 1 ...
##  $ V5 : int  1 1 1 1 0 1 1 1 0 1 ...
##  $ V6 : int  1 1 1 1 0 1 1 1 0 1 ...
##  $ V7 : int  1 1 1 1 0 1 1 1 0 1 ...
##  $ V8 : int  1 1 1 1 0 0 1 1 0 1 ...
##  $ V9 : int  1 1 1 1 0 0 1 1 0 0 ...
##  $ V10: int  1 1 1 1 0 0 1 1 0 0 ...
##  $ V11: int  1 1 1 1 0 0 1 1 0 0 ...
##  $ V12: int  1 1 1 1 0 0 1 1 1 0 ...
##  $ V13: int  1 1 1 1 0 0 1 1 1 0 ...
##  $ V14: int  1 1 0 1 0 0 1 1 1 0 ...
##  $ V15: int  1 1 0 1 0 0 1 1 1 0 ...
##  $ V16: int  1 1 0 1 0 0 1 1 1 0 ...
##  $ V17: int  1 1 0 1 0 0 1 1 1 0 ...
##  $ V18: int  1 1 0 1 0 0 0 1 1 0 ...
##  $ V19: int  1 1 0 1 0 0 0 1 1 0 ...
##  $ V20: int  1 1 0 1 0 0 0 1 1 0 ...
##  $ V21: int  1 1 0 1 0 0 0 1 0 0 ...
##  $ V22: int  1 1 0 1 0 0 0 1 0 0 ...
##  $ V23: int  1 1 0 1 0 0 0 0 0 0 ...
```

```
sp_mass <- read.table(file="data/egypt_mass.txt", header=FALSE)
str(sp_mass)
```

```
## 'data.frame':    39 obs. of  2 variables:
##  $ V1: int  6 4 18 25 40 122 122 50 35 2200 ...
##  $ V2: int  15 8 36 55 90 260 260 60 65 6300 ...
```

```
colnames(sp_mass) <- c("f","m")
```

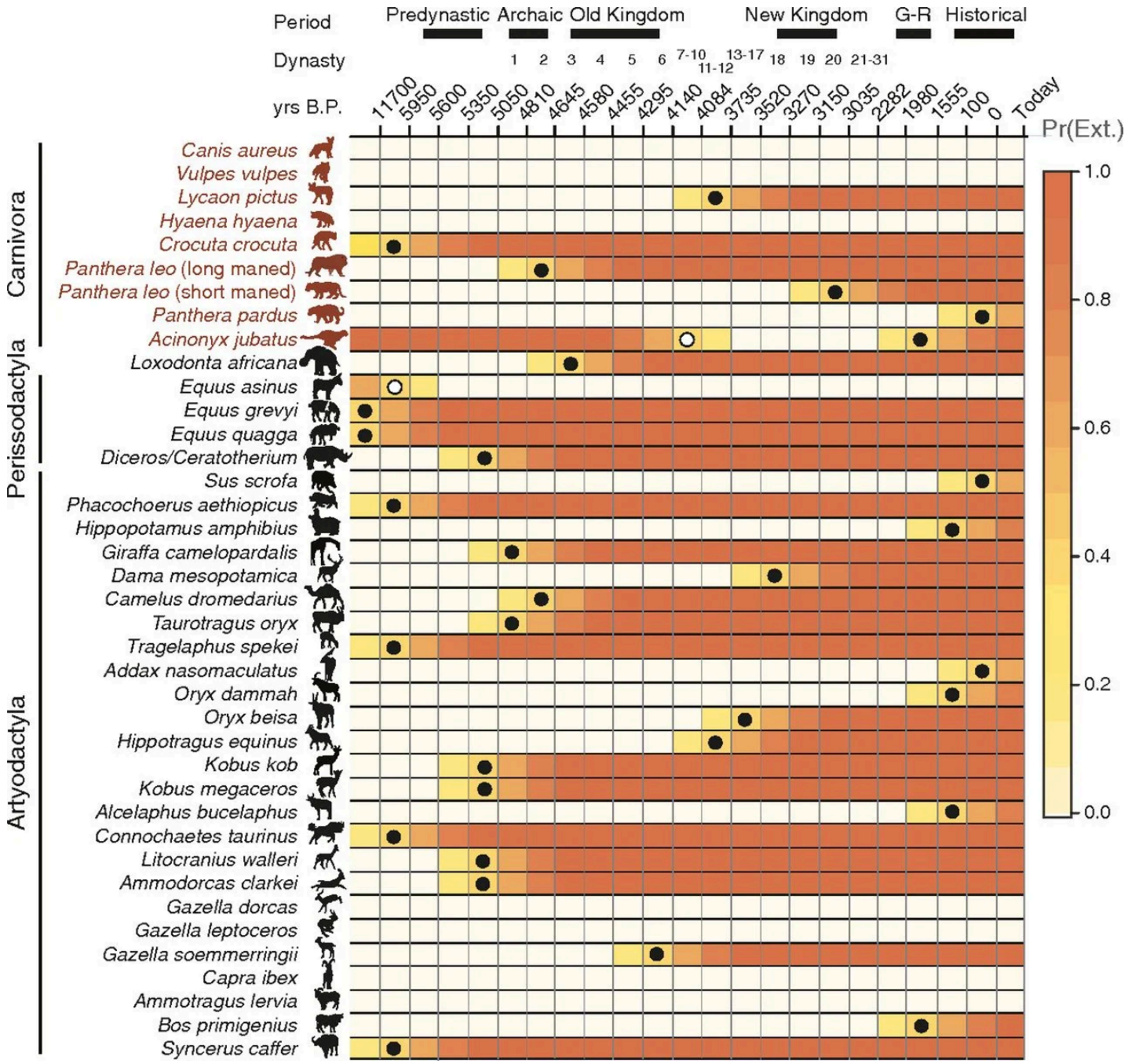


Figure 2

The rows are arranged in the order of Figure 2 of the manuscript. To set the rownames we can make a vector of the names then use the function ‘rownames’. We also have to note which species are predators (all those in the species in the Carnivora clade in figure 2). Otherwise we will create a web where giraffes are voracious predators consuming all of the other species (I made this mistake when constructing the networks originally). I have transcribed the data from figure 2 for you:

```
row_labs_sp <- c("Canis aureus", "Vulpes vulpes", "Lycaon pictus", "Hyaena hyaena", "Crocuta cro
cuta", "Panthera leo (long maned)", "Panthera leo (short maned)", "Panthera pardus", "Acinonyx j
ubatus", "Loxodonta africana", "Equus asinus", "Equus grevyi", "Equus quagga", "Diceros/Ceratoth
erium", "Sus scrofa",  "Phacochoerus aethiopicus", "Hippopotamus amphibius", "Giraffa camelopard
alis", "Dama mesopotamica", "Camelus dromedarius", "Taurotragus oryx", "Tragelaphus spekei", "Ad
dax nasomaculatus", "Oryx dammah", "Oryx beisa", "Hippotragus equinus", "Kobus kob", "Kobus mega
ceros", "Alcelaphus bucelaphus", "Connochaetes taurinus", "Litocranius walleri", "Ammodorcas cla
rkei", "Gazella dorcas", "Gazella leptoceros", "Gazella soemmerringii", "Capra ibex", "Ammotragu
s lervia", "Bos primigenius", "Syncerus caffer")

rownames(sp_occ) <- row_labs_sp
rownames(sp_mass) <- row_labs_sp

## Set 1 for predators, 0 for prey
carnivores <- c(rep(1, 9), rep(0, length(row_labs_sp)- 9))
names(carnivores) <- row_labs_sp
sp_occ <- cbind(sp_occ, carnivores)
sp_mass <- cbind(sp_mass, carnivores)
#sp_occ$Species <- rownames(sp_occ)
sp_mass$Species <- rownames(sp_mass)
```

Lab part 1: Creating our foodwebs based on body sizes.

a. Use the above vector of species names to label the row names of the species occurrence and the body size matrices. The columns of the species occurrence matrix are time points, so we can leave those as V1 etc., but we should set the column names of the mass matrix as “f”, “m” (female and male). Use ‘head’ to check each matrix to see if the names are displayed properly.

```
head(sp_mass)
```

```
##                              f   m carnivores                   Species
## Canis aureus                 6  15          1              Canis aureus
## Vulpes vulpes                4   8          1             Vulpes vulpes
## Lycaon pictus               18  36          1             Lycaon pictus
## Hyaena hyaena               25  55          1             Hyaena hyaena
## Crocuta crocuta             40  90          1           Crocuta crocuta
## Panthera leo (long maned) 122 260          1 Panthera leo (long maned)
```

```
head(sp_occ)
```

```
##                          V1 V2 V3 V4 V5 V6 V7 V8 V9 V10 V11 V12 V13 V14 V15
## Canis aureus              1  1  1  1  1  1  1  1  1   1   1   1   1   1   1
## Vulpes vulpes             1  1  1  1  1  1  1  1  1   1   1   1   1   1   1
## Lycaon pictus             1  1  1  1  1  1  1  1  1   1   1   1   1   0   0
## Hyaena hyaena             1  1  1  1  1  1  1  1  1   1   1   1   1   1   1
## Crocuta crocuta           1  1  0  0  0  0  0  0  0   0   0   0   0   0   0
## Panthera leo (long maned) 1  1  1  1  1  1  1  0  0   0   0   0   0   0   0
##                          V16 V17 V18 V19 V20 V21 V22 V23 carnivores
## Canis aureus               1   1   1   1   1   1   1   1          1
## Vulpes vulpes              1   1   1   1   1   1   1   1          1
## Lycaon pictus              0   0   0   0   0   0   0   0          1
## Hyaena hyaena              1   1   1   1   1   1   1   1          1
## Crocuta crocuta            0   0   0   0   0   0   0   0          1
## Panthera leo (long maned)  0   0   0   0   0   0   0   0          1
```

Yeakel recommended an updated equation to estimate the probability a predator consumed a prey based on their relative body masses from Rohr et al. 2010. (https://doi.org/10.1086/653667). The probability of existence of a trophic link between a predator of body-size m_i and a prey of body-size m_j is given by:

$$\text{logit}\Big(P\big(A_{ij}=1\big)\Big) = \alpha + \beta log\left(\frac{m_j}{m_i}\right) + \gamma log^2\left(\frac{m_j}{m_i}\right).$$

(P(A_{1j} = 1) is the probability predator i eats prey j).

a. Write a function and call it ‘probEat’ to implement the equation above. Round the probability to two decimal places.

Below are the values of alpha, beta, and gamma for the Serengeti. In addition, you will need a function to compute the inverse logit function because this equation is for the logit of the probability, so to calculate the 0-1 probability you will need to take the inverse logit of the other side of the equation. Also note, log^2 is equivalent to (log(m_i/m_j))^2

```
# Define probEat function
probEat <- function(alpha, beta, gamma, m_j, m_i) {
  log_mass_ratio <- log(m_j / m_i)
  square_log_mass_ratio <- log_mass_ratio^2
  logit_prob <- alpha + beta * log_mass_ratio + gamma * square_log_mass_ratio
  probability <- exp(logit_prob) / (1 + exp(logit_prob))
  return(probability)
}

# Constants
alpha <- 2.51
beta <- 0.79
gamma <- -0.37


# Filter predators and prey
predators <- sp_mass[sp_mass$carnivore == 1, ]
prey <- sp_mass[sp_mass$carnivore == 0, ]

# Initialize results as a data frame
probability_results <- data.frame(predator = character(),
                      prey = character(),
                      probability = numeric(),
                      stringsAsFactors = FALSE)

# Nested loop for probabilities
for (i in 1:nrow(predators)) {
  for (j in 1:nrow(prey)) {
    m_j <- predators$f[i]
    m_i <- prey$f[j]
    probability <- probEat(alpha, beta, gamma, m_j, m_i)

    # Append to results
    probability_results <- rbind(probability_results, data.frame(
      predator = predators$Species[i],
      prey = prey$Species[j],
      probability = probability
    ))
  }
}

# Print results
print(probability_results)
```

```
##                    predator                    prey  probability
## 1             Canis aureus       Loxodonta africana 2.899179e-07
## 2             Canis aureus             Equus asinus 2.846500e-03
## 3             Canis aureus             Equus grevyi 1.090779e-03
## 4             Canis aureus             Equus quagga 1.256377e-02
## 5             Canis aureus    Diceros/Ceratotherium 6.567126e-05
## 6             Canis aureus              Sus scrofa 5.695797e-01
## 7             Canis aureus Phacochoerus aethiopicus 3.580329e-01
## 8             Canis aureus   Hippopotamus amphibius 2.478497e-04
## 9             Canis aureus   Giraffa camelopardalis 4.104377e-04
## 10            Canis aureus        Dama mesopotamica 8.764233e-02
## 11            Canis aureus     Camelus dromedarius 6.527585e-04
## 12            Canis aureus        Taurotragus oryx 1.940340e-03
## 13            Canis aureus       Tragelaphus spekei 4.205835e-01
## 14            Canis aureus     Addax nasomaculatus 2.191298e-01
## 15            Canis aureus             Oryx dammah 2.829276e-02
## 16            Canis aureus              Oryx beisa 4.412294e-02
## 17            Canis aureus     Hippotragus equinus 5.582491e-03
## 18            Canis aureus               Kobus kob 2.191298e-01
## 19            Canis aureus          Kobus megaceros 2.191298e-01
## 20            Canis aureus    Alcelaphus bucelaphus 4.412294e-02
## 21            Canis aureus    Connochaetes taurinus 2.534605e-02
## 22            Canis aureus      Litocranius walleri 5.695797e-01
## 23            Canis aureus       Ammodorcas clarkei 7.024425e-01
## 24            Canis aureus           Gazella dorcas 8.138893e-01
## 25            Canis aureus       Gazella leptoceros 8.284962e-01
## 26            Canis aureus    Gazella soemmerringii 4.479836e-01
## 27            Canis aureus              Capra ibex 3.039941e-01
## 28            Canis aureus        Ammotragus lervia 4.205835e-01
## 29            Canis aureus          Bos primigenius 1.345967e-05
## 30            Canis aureus          Syncerus caffer 3.745629e-03
## 31           Vulpes vulpes       Loxodonta africana 3.367834e-08
## 32           Vulpes vulpes             Equus asinus 6.218884e-04
## 33           Vulpes vulpes             Equus grevyi 2.201570e-04
## 34           Vulpes vulpes             Equus quagga 3.149058e-03
## 35           Vulpes vulpes    Diceros/Ceratotherium 1.075707e-05
## 36           Vulpes vulpes              Sus scrofa 3.580329e-01
## 37           Vulpes vulpes Phacochoerus aethiopicus 1.722708e-01
## 38           Vulpes vulpes   Hippopotamus amphibius 4.465151e-05
## 39           Vulpes vulpes   Giraffa camelopardalis 7.678233e-05
## 40           Vulpes vulpes        Dama mesopotamica 2.829276e-02
## 41           Vulpes vulpes     Camelus dromedarius 1.265314e-04
## 42           Vulpes vulpes        Taurotragus oryx 4.104377e-04
## 43           Vulpes vulpes       Tragelaphus spekei 2.191298e-01
## 44           Vulpes vulpes     Addax nasomaculatus 8.764233e-02
## 45           Vulpes vulpes             Oryx dammah 7.753809e-03
## 46           Vulpes vulpes              Oryx beisa 1.279939e-02
## 47           Vulpes vulpes     Hippotragus equinus 1.294350e-03
## 48           Vulpes vulpes               Kobus kob 8.764233e-02
## 49           Vulpes vulpes          Kobus megaceros 8.764233e-02
## 50           Vulpes vulpes    Alcelaphus bucelaphus 1.279939e-02
## 51           Vulpes vulpes    Connochaetes taurinus 6.856283e-03
```

```
## 52              Vulpes vulpes      Litocranius walleri 3.580329e-01
## 53              Vulpes vulpes       Ammodorcas clarkei 5.219777e-01
## 54              Vulpes vulpes           Gazella dorcas 6.941108e-01
## 55              Vulpes vulpes       Gazella leptoceros 7.190257e-01
## 56              Vulpes vulpes    Gazella soemmerringii 2.416239e-01
## 57              Vulpes vulpes              Capra ibex 1.363823e-01
## 58              Vulpes vulpes        Ammotragus lervia 2.191298e-01
## 59              Vulpes vulpes          Bos primigenius 1.980874e-06
## 60              Vulpes vulpes          Syncerus caffer 8.380164e-04
## 61              Lycaon pictus       Loxodonta africana 5.369303e-05
## 62              Lycaon pictus             Equus asinus 8.764233e-02
## 63              Lycaon pictus             Equus grevyi 4.340734e-02
## 64              Lycaon pictus             Equus quagga 2.313361e-01
## 65              Lycaon pictus    Diceros/Ceratotherium 4.771788e-03
## 66              Lycaon pictus              Sus scrofa 8.818325e-01
## 67              Lycaon pictus Phacochoerus aethiopicus 8.138893e-01
## 68              Lycaon pictus   Hippopotamus amphibius 1.379781e-02
## 69              Lycaon pictus   Giraffa camelopardalis 2.050152e-02
## 70              Lycaon pictus        Dama mesopotamica 5.695797e-01
## 71              Lycaon pictus      Camelus dromedarius 2.936718e-02
## 72              Lycaon pictus         Taurotragus oryx 6.653049e-02
## 73              Lycaon pictus       Tragelaphus spekei 8.379782e-01
## 74              Lycaon pictus      Addax nasomaculatus 7.354647e-01
## 75              Lycaon pictus             Oryx dammah 3.580329e-01
## 76              Lycaon pictus              Oryx beisa 4.387028e-01
## 77              Lycaon pictus      Hippotragus equinus 1.391993e-01
## 78              Lycaon pictus               Kobus kob 7.354647e-01
## 79              Lycaon pictus          Kobus megaceros 7.354647e-01
## 80              Lycaon pictus    Alcelaphus bucelaphus 4.387028e-01
## 81              Lycaon pictus    Connochaetes taurinus 3.390889e-01
## 82              Lycaon pictus      Litocranius walleri 8.818325e-01
## 83              Lycaon pictus       Ammodorcas clarkei 9.118609e-01
## 84              Lycaon pictus           Gazella dorcas 9.334997e-01
## 85              Lycaon pictus       Gazella leptoceros 9.361458e-01
## 86              Lycaon pictus    Gazella soemmerringii 8.472404e-01
## 87              Lycaon pictus              Capra ibex 7.886322e-01
## 88              Lycaon pictus        Ammotragus lervia 8.379782e-01
## 89              Lycaon pictus          Bos primigenius 1.311463e-03
## 90              Lycaon pictus          Syncerus caffer 1.062213e-01
## 91              Hyaena hyaena       Loxodonta africana 2.150731e-04
## 92              Hyaena hyaena             Equus asinus 1.877236e-01
## 93              Hyaena hyaena             Equus grevyi 1.041663e-01
## 94              Hyaena hyaena             Equus quagga 3.945327e-01
## 95              Hyaena hyaena    Diceros/Ceratotherium 1.433279e-02
## 96              Hyaena hyaena              Sus scrofa 9.132252e-01
## 97              Hyaena hyaena Phacochoerus aethiopicus 8.718947e-01
## 98              Hyaena hyaena   Hippopotamus amphibius 3.780232e-02
## 99              Hyaena hyaena   Giraffa camelopardalis 5.393836e-02
## 100             Hyaena hyaena        Dama mesopotamica 7.090902e-01
## 101             Hyaena hyaena      Camelus dromedarius 7.414967e-02
## 102             Hyaena hyaena         Taurotragus oryx 1.496005e-01
## 103             Hyaena hyaena       Tragelaphus spekei 8.866493e-01
```

```
## 104             Hyaena hyaena      Addax nasomaculatus 8.227068e-01
## 105             Hyaena hyaena             Oryx dammah 5.313305e-01
## 106             Hyaena hyaena              Oryx beisa 6.049412e-01
## 107             Hyaena hyaena      Hippotragus equinus 2.708034e-01
## 108             Hyaena hyaena               Kobus kob 8.227068e-01
## 109             Hyaena hyaena          Kobus megaceros 8.227068e-01
## 110             Hyaena hyaena    Alcelaphus bucelaphus 6.049412e-01
## 111             Hyaena hyaena    Connochaetes taurinus 5.127178e-01
## 112             Hyaena hyaena      Litocranius walleri 9.132252e-01
## 113             Hyaena hyaena       Ammodorcas clarkei 9.311790e-01
## 114             Hyaena hyaena           Gazella dorcas 9.435878e-01
## 115             Hyaena hyaena       Gazella leptoceros 9.449904e-01
## 116             Hyaena hyaena    Gazella soemmerringii 8.922902e-01
## 117             Hyaena hyaena              Capra ibex 8.562696e-01
## 118             Hyaena hyaena        Ammotragus lervia 8.866493e-01
## 119             Hyaena hyaena          Bos primigenius 4.324553e-03
## 120             Hyaena hyaena          Syncerus caffer 2.191298e-01
## 121           Crocuta crocuta       Loxodonta africana 1.361890e-03
## 122           Crocuta crocuta             Equus asinus 4.139429e-01
## 123           Crocuta crocuta             Equus grevyi 2.800273e-01
## 124           Crocuta crocuta             Equus quagga 6.313617e-01
## 125           Crocuta crocuta    Diceros/Ceratotherium 5.829090e-02
## 126           Crocuta crocuta              Sus scrofa 9.374177e-01
## 127           Crocuta crocuta Phacochoerus aethiopicus 9.177241e-01
## 128           Crocuta crocuta   Hippopotamus amphibius 1.302818e-01
## 129           Crocuta crocuta   Giraffa camelopardalis 1.722708e-01
## 130           Crocuta crocuta        Dama mesopotamica 8.356278e-01
## 131           Crocuta crocuta      Camelus dromedarius 2.191298e-01
## 132           Crocuta crocuta         Taurotragus oryx 3.580329e-01
## 133           Crocuta crocuta       Tragelaphus spekei 9.248399e-01
## 134           Crocuta crocuta      Addax nasomaculatus 8.936762e-01
## 135           Crocuta crocuta             Oryx dammah 7.313709e-01
## 136           Crocuta crocuta              Oryx beisa 7.772035e-01
## 137           Crocuta crocuta      Hippotragus equinus 5.150239e-01
## 138           Crocuta crocuta               Kobus kob 8.936762e-01
## 139           Crocuta crocuta          Kobus megaceros 8.936762e-01
## 140           Crocuta crocuta    Alcelaphus bucelaphus 7.772035e-01
## 141           Crocuta crocuta    Connochaetes taurinus 7.190257e-01
## 142           Crocuta crocuta      Litocranius walleri 9.374177e-01
## 143           Crocuta crocuta       Ammodorcas clarkei 9.453213e-01
## 144           Crocuta crocuta           Gazella dorcas 9.492570e-01
## 145           Crocuta crocuta       Gazella leptoceros 9.493853e-01
## 146           Crocuta crocuta    Gazella soemmerringii 9.275432e-01
## 147           Crocuta crocuta              Capra ibex 9.101357e-01
## 148           Crocuta crocuta        Ammotragus lervia 9.248399e-01
## 149           Crocuta crocuta          Bos primigenius 2.050152e-02
## 150           Crocuta crocuta          Syncerus caffer 4.550391e-01
## 151  Panthera leo (long maned)       Loxodonta africana 5.366696e-02
## 152  Panthera leo (long maned)             Equus asinus 8.387459e-01
## 153  Panthera leo (long maned)             Equus grevyi 7.801326e-01
## 154  Panthera leo (long maned)             Equus quagga 8.981503e-01
## 155  Panthera leo (long maned)    Diceros/Ceratotherium 5.001258e-01
```

```
## 156  Panthera leo (long maned)              Sus scrofa 9.473550e-01
## 157  Panthera leo (long maned) Phacochoerus aethiopicus 9.493032e-01
## 158  Panthera leo (long maned)   Hippopotamus amphibius 6.508930e-01
## 159  Panthera leo (long maned)   Giraffa camelopardalis 7.002593e-01
## 160  Panthera leo (long maned)        Dama mesopotamica 9.379692e-01
## 161  Panthera leo (long maned)      Camelus dromedarius 7.408155e-01
## 162  Panthera leo (long maned)         Taurotragus oryx 8.175219e-01
## 163  Panthera leo (long maned)       Tragelaphus spekei 9.493506e-01
## 164  Panthera leo (long maned)      Addax nasomaculatus 9.470647e-01
## 165  Panthera leo (long maned)              Oryx dammah 9.188047e-01
## 166  Panthera leo (long maned)               Oryx beisa 9.274995e-01
## 167  Panthera leo (long maned)      Hippotragus equinus 8.697679e-01
## 168  Panthera leo (long maned)               Kobus kob 9.470647e-01
## 169  Panthera leo (long maned)          Kobus megaceros 9.470647e-01
## 170  Panthera leo (long maned)    Alcelaphus bucelaphus 9.274995e-01
## 171  Panthera leo (long maned)    Connochaetes taurinus 9.163894e-01
## 172  Panthera leo (long maned)      Litocranius walleri 9.473550e-01
## 173  Panthera leo (long maned)       Ammodorcas clarkei 9.414513e-01
## 174  Panthera leo (long maned)           Gazella dorcas 9.269240e-01
## 175  Panthera leo (long maned)       Gazella leptoceros 9.231621e-01
## 176  Panthera leo (long maned)    Gazella soemmerringii 9.492168e-01
## 177  Panthera leo (long maned)              Capra ibex 9.488401e-01
## 178  Panthera leo (long maned)        Ammotragus lervia 9.493506e-01
## 179  Panthera leo (long maned)          Bos primigenius 3.122850e-01
## 180  Panthera leo (long maned)          Syncerus caffer 8.523026e-01
## 181 Panthera leo (short maned)       Loxodonta africana 5.366696e-02
## 182 Panthera leo (short maned)             Equus asinus 8.387459e-01
## 183 Panthera leo (short maned)             Equus grevyi 7.801326e-01
## 184 Panthera leo (short maned)             Equus quagga 8.981503e-01
## 185 Panthera leo (short maned)    Diceros/Ceratotherium 5.001258e-01
## 186 Panthera leo (short maned)              Sus scrofa 9.473550e-01
## 187 Panthera leo (short maned) Phacochoerus aethiopicus 9.493032e-01
## 188 Panthera leo (short maned)   Hippopotamus amphibius 6.508930e-01
## 189 Panthera leo (short maned)   Giraffa camelopardalis 7.002593e-01
## 190 Panthera leo (short maned)        Dama mesopotamica 9.379692e-01
## 191 Panthera leo (short maned)      Camelus dromedarius 7.408155e-01
## 192 Panthera leo (short maned)         Taurotragus oryx 8.175219e-01
## 193 Panthera leo (short maned)       Tragelaphus spekei 9.493506e-01
## 194 Panthera leo (short maned)      Addax nasomaculatus 9.470647e-01
## 195 Panthera leo (short maned)              Oryx dammah 9.188047e-01
## 196 Panthera leo (short maned)               Oryx beisa 9.274995e-01
## 197 Panthera leo (short maned)      Hippotragus equinus 8.697679e-01
## 198 Panthera leo (short maned)               Kobus kob 9.470647e-01
## 199 Panthera leo (short maned)          Kobus megaceros 9.470647e-01
## 200 Panthera leo (short maned)    Alcelaphus bucelaphus 9.274995e-01
## 201 Panthera leo (short maned)    Connochaetes taurinus 9.163894e-01
## 202 Panthera leo (short maned)      Litocranius walleri 9.473550e-01
## 203 Panthera leo (short maned)       Ammodorcas clarkei 9.414513e-01
## 204 Panthera leo (short maned)           Gazella dorcas 9.269240e-01
## 205 Panthera leo (short maned)       Gazella leptoceros 9.231621e-01
## 206 Panthera leo (short maned)    Gazella soemmerringii 9.492168e-01
## 207 Panthera leo (short maned)              Capra ibex 9.488401e-01
```

```
## 208 Panthera leo (short maned)        Ammotragus lervia 9.493506e-01
## 209 Panthera leo (short maned)          Bos primigenius 3.122850e-01
## 210 Panthera leo (short maned)          Syncerus caffer 8.523026e-01
## 211            Panthera pardus       Loxodonta africana 3.085524e-03
## 212            Panthera pardus             Equus asinus 5.313305e-01
## 213            Panthera pardus             Equus grevyi 3.945327e-01
## 214            Panthera pardus             Equus quagga 7.190257e-01
## 215            Panthera pardus    Diceros/Ceratotherium 1.041663e-01
## 216            Panthera pardus              Sus scrofa 9.435878e-01
## 217            Panthera pardus Phacochoerus aethiopicus 9.301586e-01
## 218            Panthera pardus   Hippopotamus amphibius 2.107724e-01
## 219            Panthera pardus   Giraffa camelopardalis 2.665707e-01
## 220            Panthera pardus        Dama mesopotamica 8.718947e-01
## 221            Panthera pardus      Camelus dromedarius 3.246097e-01
## 222            Panthera pardus         Taurotragus oryx 4.766822e-01
## 223            Panthera pardus       Tragelaphus spekei 9.351033e-01
## 224            Panthera pardus      Addax nasomaculatus 9.132252e-01
## 225            Panthera pardus              Oryx dammah 7.958097e-01
## 226            Panthera pardus               Oryx beisa 8.296452e-01
## 227            Panthera pardus      Hippotragus equinus 6.228608e-01
## 228            Panthera pardus                Kobus kob 9.132252e-01
## 229            Panthera pardus          Kobus megaceros 9.132252e-01
## 230            Panthera pardus    Alcelaphus bucelaphus 8.296452e-01
## 231            Panthera pardus    Connochaetes taurinus 7.865675e-01
## 232            Panthera pardus      Litocranius walleri 9.435878e-01
## 233            Panthera pardus       Ammodorcas clarkei 9.482989e-01
## 234            Panthera pardus           Gazella dorcas 9.490591e-01
## 235            Panthera pardus       Gazella leptoceros 9.486356e-01
## 236            Panthera pardus    Gazella soemmerringii 9.369640e-01
## 237            Panthera pardus              Capra ibex 9.248399e-01
## 238            Panthera pardus        Ammotragus lervia 9.351033e-01
## 239            Panthera pardus          Bos primigenius 4.003430e-02
## 240            Panthera pardus          Syncerus caffer 5.695797e-01
## 241           Acinonyx jubatus       Loxodonta africana 8.198377e-04
## 242           Acinonyx jubatus             Equus asinus 3.433357e-01
## 243           Acinonyx jubatus             Equus grevyi 2.191298e-01
## 244           Acinonyx jubatus             Equus quagga 5.695797e-01
## 245           Acinonyx jubatus    Diceros/Ceratotherium 4.003430e-02
## 246           Acinonyx jubatus              Sus scrofa 9.323264e-01
## 247           Acinonyx jubatus Phacochoerus aethiopicus 9.078861e-01
## 248           Acinonyx jubatus   Hippopotamus amphibius 9.431179e-02
## 249           Acinonyx jubatus   Giraffa camelopardalis 1.277646e-01
## 250           Acinonyx jubatus        Dama mesopotamica 8.074978e-01
## 251           Acinonyx jubatus      Camelus dromedarius 1.665390e-01
## 252           Acinonyx jubatus         Taurotragus oryx 2.900589e-01
## 253           Acinonyx jubatus       Tragelaphus spekei 9.166680e-01
## 254           Acinonyx jubatus      Addax nasomaculatus 8.783291e-01
## 255           Acinonyx jubatus              Oryx dammah 6.833708e-01
## 256           Acinonyx jubatus               Oryx beisa 7.373322e-01
## 257           Acinonyx jubatus      Hippotragus equinus 4.447852e-01
## 258           Acinonyx jubatus                Kobus kob 8.783291e-01
## 259           Acinonyx jubatus          Kobus megaceros 8.783291e-01
```

```
## 260          Acinonyx jubatus    Alcelaphus bucelaphus 7.373322e-01
## 261          Acinonyx jubatus    Connochaetes taurinus 6.690202e-01
## 262          Acinonyx jubatus      Litocranius walleri 9.323264e-01
## 263          Acinonyx jubatus       Ammodorcas clarkei 9.425155e-01
## 264          Acinonyx jubatus           Gazella dorcas 9.485214e-01
## 265          Acinonyx jubatus       Gazella leptoceros 9.489825e-01
## 266          Acinonyx jubatus    Gazella soemmerringii 9.200134e-01
## 267          Acinonyx jubatus               Capra ibex 8.985445e-01
## 268          Acinonyx jubatus        Ammotragus lervia 9.166680e-01
## 269          Acinonyx jubatus          Bos primigenius 1.343062e-02
## 270          Acinonyx jubatus          Syncerus caffer 3.837879e-01
```

c. Now create networks of who eats whom. We will start with adjacency matrices. We will assume all of our species are the size of females. For this step, don't worry about predators vs. prey yet, just calculate all of the feeding probabilities based on body sizes.

Hint: if you start with a square matrix of all zeros (one row and one column for each species), you can use a for loop to fill in that matrix with probabilities calculated from your function above.

```
#Empty matrix
species_list <- sp_mass$Species
num_species <- length(species_list)
feeding_matrix <- matrix(0, nrow = num_species, ncol = num_species, dimnames = list(species_lis
t, species_list))

# Fill in the matrix with feeding probabilities based on body sizes
for (i in 1:num_species) {
  for (j in 1:num_species) {
    if (i != j) {  # Ensure we're not calculating a species eating itself
      m_j <- sp_mass$f[i]
      m_i <- sp_mass$f[j]
      probability <- probEat(alpha, beta, gamma, m_j, m_i)
      feeding_matrix[i, j] <- probability
    }
  }
}
```

d. Now that you have your matrix of potential feeding interactions based on body size, use the 'carnivores' vector created above to set all of the feeding interactions of herbivores (0s in that vector) to zero. In food webs the columns are the higher trophic level and the rows are the lower. HINT: the function 'sweep' may be useful, though there are many approaches to do the needed matrix multiplication. Print the row and column sums.

```
# Now use the carnivores vector to zero out interactions involving herbivores
feeding_matrix <- sweep(feeding_matrix, 2, carnivores, "*")  # Zero out columns of herbivores

# Print the row and column sums
row_sums <- rowSums(feeding_matrix)
col_sums <- colSums(feeding_matrix)

# Print the sums to see feeding interactions
print("Row sums (predator feeding counts):") #number of species each predator feeds on
```

```
## [1] "Row sums (predator feeding counts):"
```

```
# How likely a predator (species i) is to feed on any of the prey species (species j), summed ac
ross all prey species.
print(row_sums)
```

```
##               Canis aureus              Vulpes vulpes
##                   3.653397                   2.624839
##             Lycaon pictus             Hyaena hyaena
##                   6.107261                   6.629648
##            Crocuta crocuta  Panthera leo (long maned)
##                   7.108173                   7.182140
## Panthera leo (short maned)           Panthera pardus
##                   7.182140                   7.230153
##           Acinonyx jubatus         Loxodonta africana
##                   7.004501                   3.340770
##               Equus asinus               Equus grevyi
##                   7.350024                   6.991301
##               Equus quagga      Diceros/Ceratotherium
##                   7.845624                   5.931349
##                 Sus scrofa   Phacochoerus aethiopicus
##                   7.778380                   8.104993
##     Hippopotamus amphibius     Giraffa camelopardalis
##                   6.436817                   6.624679
##          Dama mesopotamica        Camelus dromedarius
##                   8.215087                   6.798155
##           Taurotragus oryx         Tragelaphus spekei
##                   7.207914                   8.033013
##        Addax nasomaculatus                Oryx dammah
##                   8.211863                   8.048611
##                Oryx beisa        Hippotragus equinus
##                   8.131776                   7.589451
##                 Kobus kob            Kobus megaceros
##                   8.211863                   8.211863
##      Alcelaphus bucelaphus      Connochaetes taurinus
##                   8.131776                   8.024807
##        Litocranius walleri         Ammodorcas clarkei
##                   7.778380                   7.368397
##             Gazella dorcas         Gazella leptoceros
##                   6.687505                   6.549228
##      Gazella soemmerringii                 Capra ibex
##                   7.996055                   8.154993
##          Ammotragus lervia            Bos primigenius
##                   8.033013                   5.260322
##            Syncerus caffer
##                   7.449649
```

```
print("Column sums (prey being fed upon counts):") #number of predators feeding on each prey spe
cies
```

```
## [1] "Column sums (prey being fed upon counts):"
```

```
# The total feeding probability for that species as prey (across all predators).
print(col_sums)
```

```
##               Canis aureus              Vulpes vulpes
##                   27.83918                   24.97777
##             Lycaon pictus             Hyaena hyaena
##                   32.65088                   33.08111
##           Crocuta crocuta  Panthera leo (long maned)
##                   32.96384                   29.00279
## Panthera leo (short maned)           Panthera pardus
##                   29.00279                   32.62155
##           Acinonyx jubatus         Loxodonta africana
##                   33.08000                    0.00000
##               Equus asinus               Equus grevyi
##                    0.00000                    0.00000
##               Equus quagga     Diceros/Ceratotherium
##                    0.00000                    0.00000
##                 Sus scrofa   Phacochoerus aethiopicus
##                    0.00000                    0.00000
##     Hippopotamus amphibius     Giraffa camelopardalis
##                    0.00000                    0.00000
##          Dama mesopotamica        Camelus dromedarius
##                    0.00000                    0.00000
##           Taurotragus oryx         Tragelaphus spekei
##                    0.00000                    0.00000
##        Addax nasomaculatus               Oryx dammah
##                    0.00000                    0.00000
##                Oryx beisa        Hippotragus equinus
##                    0.00000                    0.00000
##                 Kobus kob            Kobus megaceros
##                    0.00000                    0.00000
##      Alcelaphus bucelaphus      Connochaetes taurinus
##                    0.00000                    0.00000
##        Litocranius walleri         Ammodorcas clarkei
##                    0.00000                    0.00000
##             Gazella dorcas         Gazella leptoceros
##                    0.00000                    0.00000
##      Gazella soemmerringii                Capra ibex
##                    0.00000                    0.00000
##          Ammotragus lervia            Bos primigenius
##                    0.00000                    0.00000
##            Syncerus caffer
##                    0.00000
```

Lab part 2: Breaking the networks into time periods

a. With our matrix of feeding interaction we can create a web for each time period, including only the species that were not extinct in the period. Try first just using the second time period (the second column of ‘sp_occ’).

Use the function ‘empty’ from the bipartite package to empty the matrix of rows and columns with no interactions. The number of species in the second time period is 36 ‘sum(sp_occ[,2])’. Check to see that the number of rows in your network with probabilities > 0 is 36.

HINT: You will need to zero out the rows where a species in not present in that time period and the columns. The function ‘sweep’ may be useful again.

```
# Extract the presence vector for the second time period
presence <- sp_occ[, 2]  # Second column of species occurrence matrix

# Zero out rows and columns of extinct species in the feeding matrix
filtered_matrix <- sweep(feeding_matrix, 1, presence, "*")  # Zero out rows
filtered_matrix <- sweep(filtered_matrix, 2, presence, "*")  # Zero out columns

active_species <- rowSums(filtered_matrix) > 0  # Rows with interaction probabilities > 0
print(paste("Number of species in the second time period:", sum(active_species)))  # Should be 3
6
```

```
## [1] "Number of species in the second time period: 36"
```

```
#cleaned_matrix <- empty(filtered_matrix)
print(nrow(filtered_matrix))
```

```
## [1] 39
```

```
print(sum(sp_occ[,2]))
```

```
## [1] 36
```

b. Now create a network for all of the time points by creating a list where each element is a network. You will need to use a for loop, or an ‘lapply’ if you feel like experimenting with apply functions. Print the first 5 columns and rows of the 5th time period.

HINT: If choosing the for loop route, remember to create an empty list of a specific length use the function ‘vector’. To access a specific element of a list, use [[]], for example cool_list[[1]] accesses the first element of the list.

```
num_time_periods <- ncol(sp_occ)
time_period_networks <- vector("list", length = num_time_periods)

# Loop through each time period and create a filtered network
for (i in 1:num_time_periods) {
  # Extract the presence vector for the current time period
  presence <- sp_occ[, i]

  # Zero out rows and columns for extinct species
  filtered_matrix <- sweep(feeding_matrix, 1, presence, "*")  # Zero out rows
  filtered_matrix <- sweep(filtered_matrix, 2, presence, "*")  # Zero out columns

  # Clean the matrix to remove empty rows and columns
  time_period_networks[[i]] <- filtered_matrix
}

# Extract the matrix for the 5th time period
matrix_time_5 <- time_period_networks[[5]]

# Print the first 5 rows and columns
print(matrix_time_5[1:5, 1:5])
```

```
##                Canis aureus Vulpes vulpes Lycaon pictus Hyaena hyaena
## Canis aureus       0.0000000     0.9410046     0.7677278     0.6522657
## Vulpes vulpes      0.8936762     0.0000000     0.6188681     0.4550391
## Lycaon pictus      0.9493738     0.9458942     0.0000000     0.9011932
## Hyaena hyaena      0.9470427     0.9379146     0.9387502     0.0000000
## Crocuta crocuta    0.0000000     0.0000000     0.0000000     0.0000000
##                Crocuta crocuta
## Canis aureus                 0
## Vulpes vulpes                0
## Lycaon pictus                0
## Hyaena hyaena                0
## Crocuta crocuta              0
```

Lab part 3: Visualize the networks

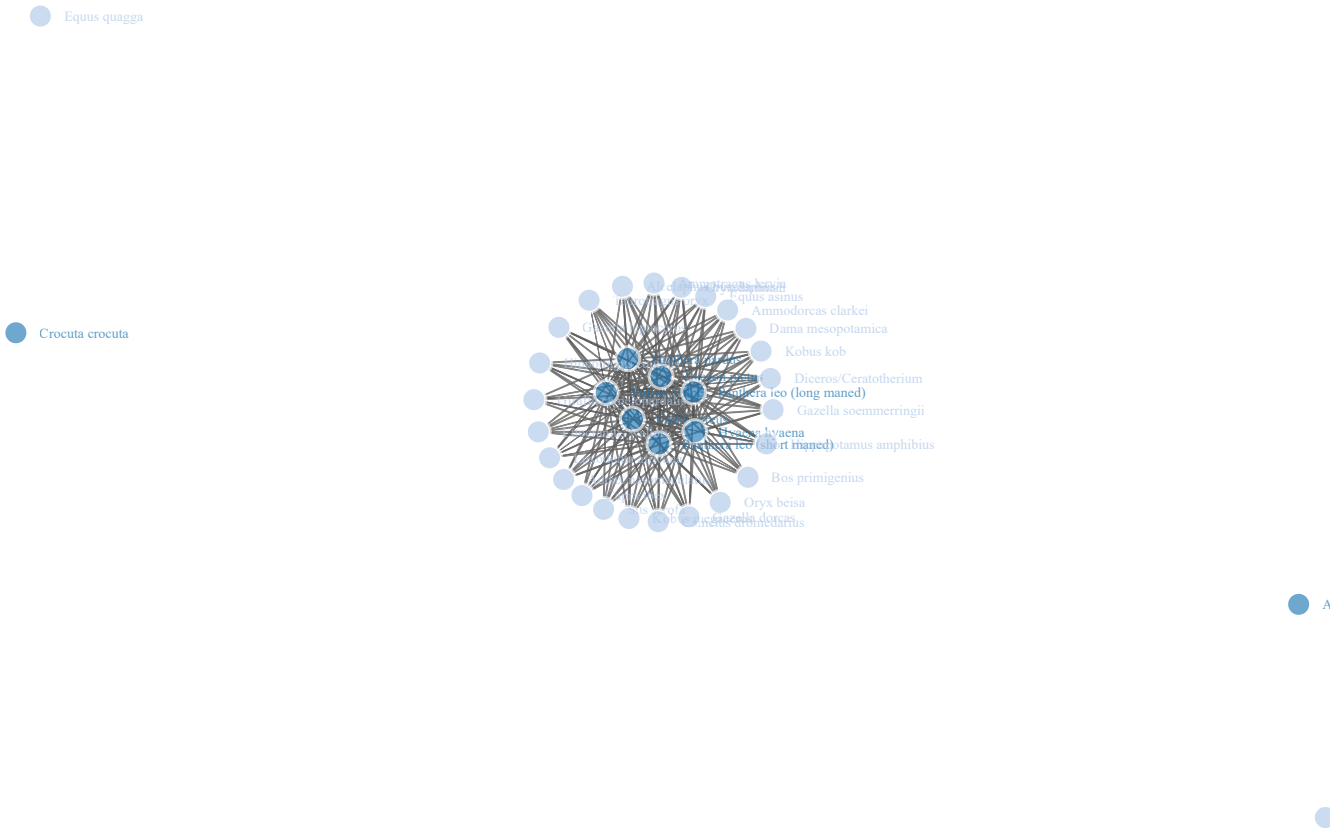
a. Convert the adjacency matrices to igraph class objects using the function ‘graph_from_adjacency_matrix’. You can use a for loop or an lapply. Because these are food webs, set the argument mode to “directed” and the argument diag to FALSE (this means a species cannot consumer members of its own species, i.e., no canabalism/self-loops). Also remember that these interactions are weighted.

```
# Convert adjacency matrices to igraph objects
igraph_networks <- lapply(time_period_networks, function(matrix) {
  graph_from_adjacency_matrix(
    matrix,
    mode = "directed",
    weighted = TRUE,
    diag = FALSE
  )
})
```

b. Plot three networks of your choice, using different colors for the predators and prey.

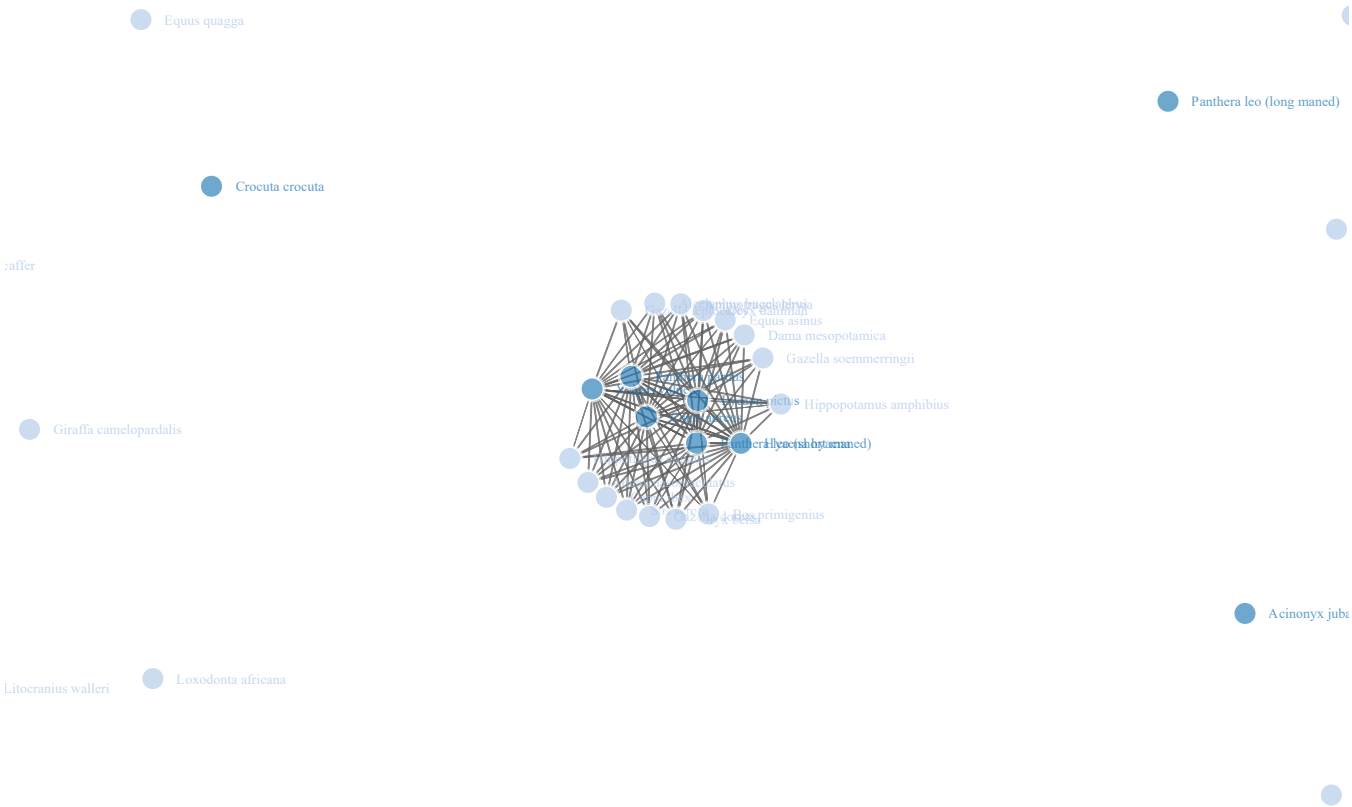
```
# Define colors based on carnivore status
node_colors <- ifelse(carnivores == 1, "red", "green")  # Red for predators, green for prey
groups <- ifelse(carnivores == 1, "Predator", "Prey")


# Choose three networks to plot
graph_time_5 <- igraph_networks[[5]]
graph_time_10 <- igraph_networks[[10]]
graph_time_20 <- igraph_networks[[20]]

# Convert igraph objects to networkD3 objects with group information
network_time_5 <- igraph_to_networkD3(graph_time_5, group = groups)
network_time_10 <- igraph_to_networkD3(graph_time_10, group= groups)
network_time_20 <- igraph_to_networkD3(graph_time_20, group = groups)

plot(
  graph_time_5,
  vertex.label = V(graph_time_5)$name,  # Add species names as labels
  edge.width = E(graph_time_5)$weight * 5,  # Scale edge width by feeding probability
  vertex.size = 10,  # Uniform vertex size
  edge.arrow.size = 0.5,  # Smaller arrow size
  layout = layout_in_circle  # Choose a circular layout
)
```


```
# Plot with forceNetwork
forceNetwork(
  Links = network_time_5$links,
  Nodes = network_time_5$nodes,
  Source = "source",
  Target = "target",
  Value = "value",
  NodeID = "name",
  Group = "group",
  opacity = 0.8,
  zoom=TRUE,
  opacityNoHover = 0.9
)
```

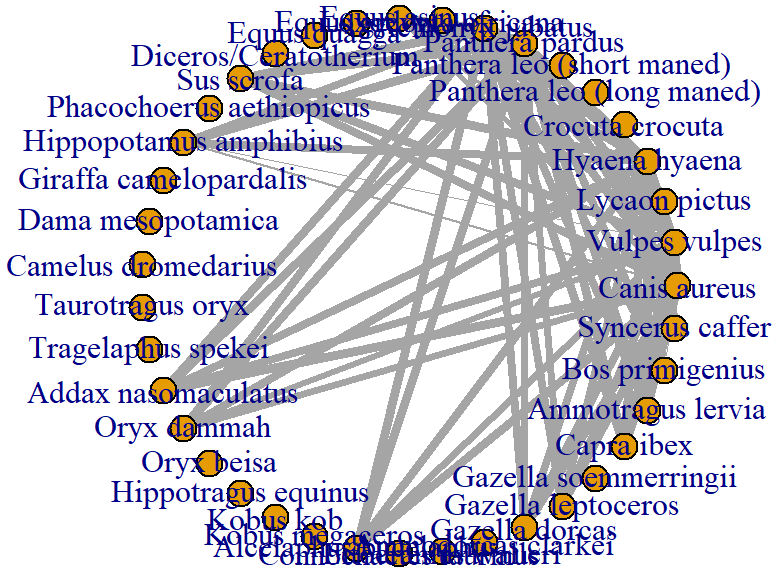



```
plot(
  graph_time_10,
  vertex.label = V(graph_time_10)$name,  # Add species names as labels
  edge.width = E(graph_time_10)$weight * 5,  # Scale edge width by feeding probability
  vertex.size = 10,  # Uniform vertex size
  edge.arrow.size = 0.5,  # Smaller arrow size
  layout = layout_in_circle  # Choose a circular layout
)
```

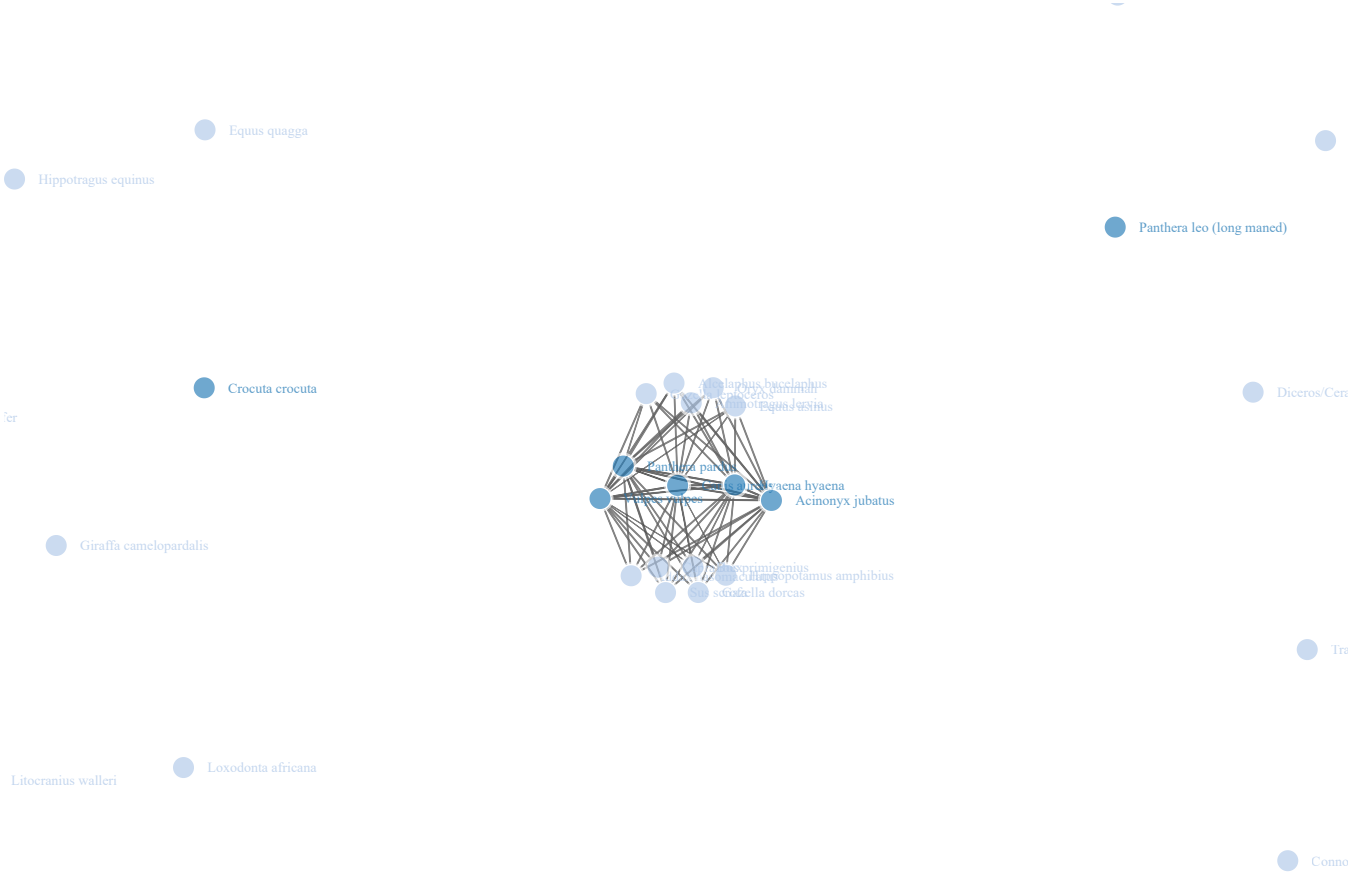

```
# Plot with forceNetwork
forceNetwork(
  Links = network_time_10$links,
  Nodes = network_time_10$nodes,
  Source = "source",
  Target = "target",
  Value = "value",
  NodeID = "name",
  Group = "group",
  opacity = 0.8,
  zoom=TRUE,
  opacityNoHover = 0.9
)
```




```
plot(
  graph_time_20,
  vertex.label = V(graph_time_20)$name,  # Add species names as labels
  edge.width = E(graph_time_20)$weight * 5,  # Scale edge width by feeding probability
  vertex.size = 10,  # Uniform vertex size
  edge.arrow.size = 0.5,  # Smaller arrow size
  layout = layout_in_circle  # Choose a circular layout
)
```




```
# Plot with forceNetwork
forceNetwork(
  Links = network_time_20$links,
  Nodes = network_time_20$nodes,
  Source = "source",
  Target = "target",
  Value = "value",
  NodeID = "name",
  Group = "group",
  opacity = 0.8,
  zoom=TRUE,
  opacityNoHover = 0.9
)
```


Equus quagga
Hippotragus equinus
Panthera leo (long maned)
Crocuta crocuta
Diceros/Cera
Panthera pardus
Hyaena hyaena
Acinonyx jubatus
Giraffa camelopardalis
Tra
Loxodonta africana
Litocranius walleri
Conno