10.1071/WR12062_AC

Accessory Publication: *Wildlife Research*, 2012, 39(5), 452-462

SUPPLEMENTARY MATERIAL

The R code developed to represent the three mixture models considered.

(i)

```
# R Code for Exponential segments Model
#Adapted from: Zucchini, W. & MacDonald, I. L. (2009) Hidden Markov Models for Time Series - An
Introduction Using R. Boca Raton, Chapman & Hall/CRC.
#

## Exponential segments using nlm
### Transform natural parameters to working parameters
glogit = function(p)
{     log(p/(1-sum(p)))     }
glogitinv = function(p)
{     exp(p)/(1+sum(exp(p)))   }

exp.mix.pn2pw = function(m,lambda)
{
tlambda = log(lambda)
params   = c(tlambda)
params
}

### Transform working parameters to natural parameters
exp.mix.pw2pn = function(m,params) {
lambda = exp(params[1:m])
list(lambda=lambda) }

### Segment model
exp.mixlike = function(m,params,x, model_offset){
lambda = exp.mix.pw2pn(m,params)$lambda
allprobs <- matrix(NA,length(x),m+1)
allprobs[,1] <- ifelse(x <= model_offset[1],0,NA)
allprobs[,(m+1)] <- ifelse(x >= model_offset[m],dexp(x,lambda[m]),NA)
  for (i in 2:(m)){
  allprobs[,i] <- ifelse(x >= model_offset[i-1] & x <= model_offset[i], dexp(x,lambda[i-1]),NA)}
  sums <- rowSums(allprobs,na.rm=T)
  sums <- ifelse(sums==0,NA,sums)
  foo = -sum(log(sums), na.rm=T)
  foo
}

### Compute the parameters which minimize the deviance of the segments model
exp.mix.mle = function(x,m,lambda0, model_offset){
params0 = exp.mix.pn2pw(m,lambda0)
mod     = nlm(exp.mixlike,params0,x=x,m=m, model_offset=model_offset)
pn      = exp.mix.pw2pn(m,mod$estimate)
minusl  = mod$minimum
 np      = length(params0)
```

```
 AIC     = 2*(minusl+np)
 n       = length(x)
 BIC     = 2*minusl+np*log(n)
list(lambda=pn$lambda, code=mod$code, minusl=minusl, AIC=AIC, BIC=BIC)}
```

(ii)

```
# R Code for Gamma Mixture Model including offsets
# Adapted from: Zucchini, W. & MacDonald, I. L. (2009) Hidden Markov Models for Time Series - An Introduction Using R. Boca Raton, Chapman & Hall/CRC.
#

## Gamma model using nlm
### Transform natural parameters to working parameters
glogit = function(p)
{     log(p/(1-sum(p)))     }
glogitinv = function(p)
{     exp(p)/(1+sum(exp(p)))   }
gamma.mix.pn2pw = function(m,delta,alpha,theta)
{
tdelta   = glogit(delta[1: (m-1)])
talpha  = log(alpha)
ttheta  = log(theta)
params   = c(tdelta, talpha, ttheta )
params
}

### Transform working parameters to natural parameters
gamma.mix.pw2pn = function(m,params) {
temp   = glogitinv(params[1: (m-1)])
delta  = c(temp,1-sum(temp))
alpha = exp(params[m: (2*m-1)])
theta = exp(params[(2*m): (3*m-1)]  )
list(delta=delta, alpha=alpha, theta=theta) }

### Compute the likelihood of mixture model
mixlike = function(m,params,x,model_offset){
delta   = gamma.mix.pw2pn(m,params)$delta
alpha  = gamma.mix.pw2pn(m,params)$alpha
theta  = gamma.mix.pw2pn(m,params)$theta
allprobs <- matrix(NA,length(x),m)
   for (i in 1:m){
   allprobs[,i] <- dgamma(x, alpha[i], scale=theta[i])}
   for (i in 2:m){
   allprobs[,i] <- ifelse(x<model_offset[i],0,allprobs[,i])}
foo     = -sum(log(allprobs%*%delta))
foo
}

### Compute the parameters which maximise the log-liklihood of the mixture model
```

```
gamma.mix.mle = function(x,m,delta0, alpha0, theta0, model_offset){
params0 = gamma.mix.pn2pw(m,delta0,alpha0,theta0)
mod     = nlm(mixlike,params0,x=x,m=m, model_offset=model_offset)
pn      = gamma.mix.pw2pn(m,mod$estimate)
minusl  = mod$minimum
 np      = length(params0)
 AIC     = 2*(minusl+np)
 n       = length(x)
 BIC     = 2*minusl+np*log(n)
list(delta=pn$delta,alpha=pn$alpha,theta=pn$theta,code=mod$code,minusl=minusl,AIC=AIC,BIC=BIC)}
```

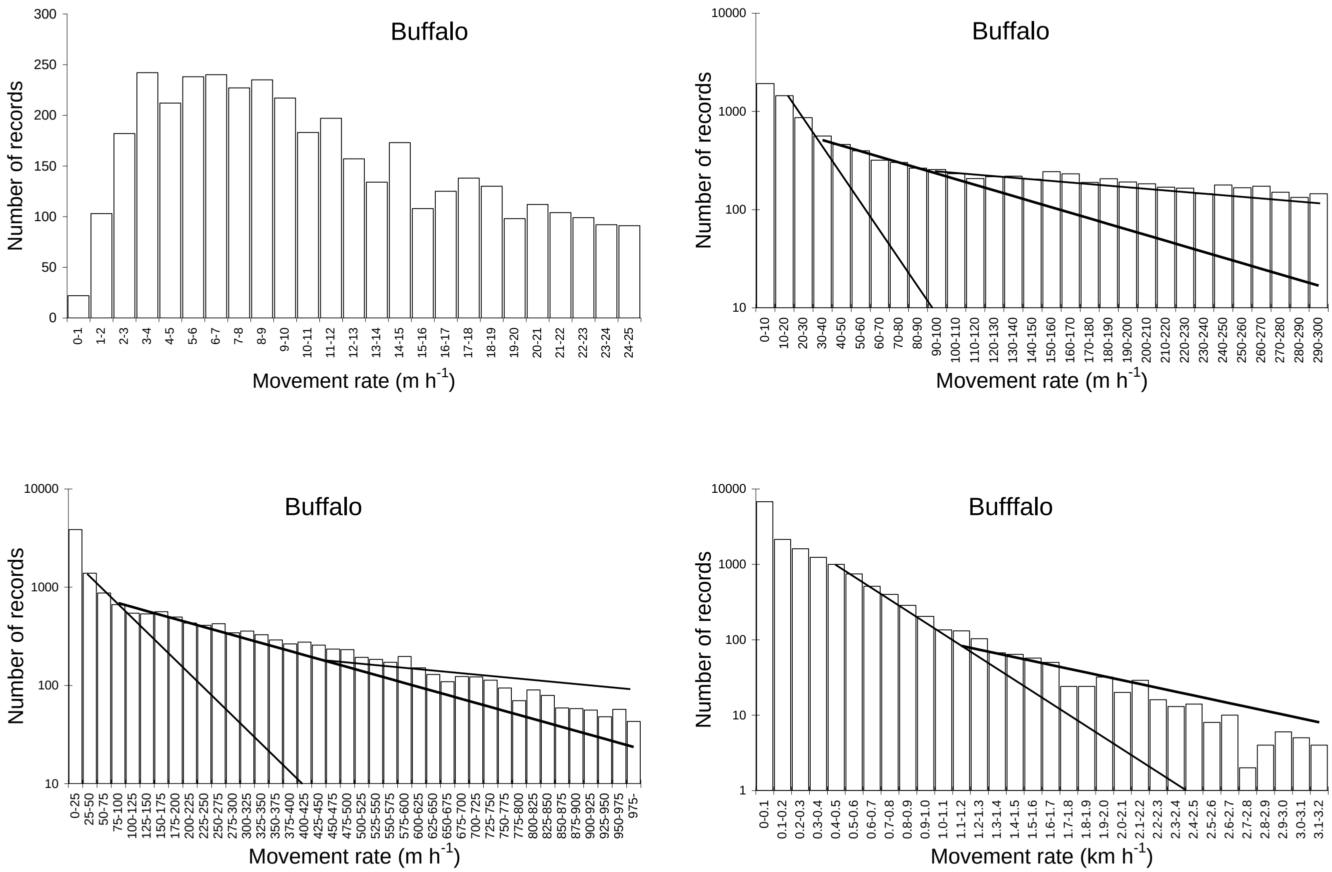
(iii)

```
# R Code for Log-normal Mixture Model
#Adapted from: Zucchini, W. & MacDonald, I. L. (2009) Hidden Markov Models for Time Series - An Introduction Using R. Boca Raton, Chapman & Hall/CRC.
#

## Log-normal model using nlm
### Transform natural parameters to working parameters
glogit = function(p)
{     log(p/(1-sum(p)))     }
glogitinv = function(p)
{     exp(p)/(1+sum(exp(p)))   }
lnorm.mix.pn2pw = function(m,delta,mu,sigma)
{
tdelta   = glogit(delta[1: (m-1)])
tsigma  = log(sigma)
params   = c(tdelta, mu, tsigma )
params
}

### Transform working parameters to natural parameters
lnorm.mix.pw2pn = function(m,params) {
temp   = glogitinv(params[1: (m-1)])
delta  = c(temp,1-sum(temp))
mu = params[m: (2*m-1)]
sigma = exp(params[(2*m): (3*m-1)]  )
list(delta=delta, mu=mu, sigma=sigma) }

### Compute the likelihood of mixture model
ln.mixlike = function(m,params,x){
delta   = lnorm.mix.pw2pn(m,params)$delta
mu  = lnorm.mix.pw2pn(m,params)$mu
sigma  = lnorm.mix.pw2pn(m,params)$sigma
allprobs <- matrix(NA,length(x),m)
   for (i in 1:m){
   allprobs[,i] <- dlnorm(x, mu[i], sigma[i])}
foo     = -sum(log(allprobs%*%delta))
foo
}
```

```
### Compute the parameters which maximise the log-liklihood of the mixture model
lnorm.mix.mle = function(x,m,delta0, mu0, sigma0){
params0 = lnorm.mix.pn2pw(m,delta0,mu0,sigma0)
mod     = nlm(ln.mixlike,params0,x=x,m=m)
pn      = lnorm.mix.pw2pn(m,mod$estimate)
minusl  = mod$minimum
 np      = length(params0)
 AIC     = 2*(minusl+np)
 n       = length(x)
 BIC     = 2*minusl+np*log(n)
list(delta=pn$delta,mu=pn$mu,sigma=pn$sigma,code=mod$code,minusl=minusl,AIC=AIC,BIC=BIC)}
```

Fig. S1. Log-frequency distributions of hourly movement rates over different bin resolutions, from amalgamated data over the entire year for all herds of (*a*) buffalo and (*b*) zebra.

(*a*) Buffalo



(*b*) Zebra

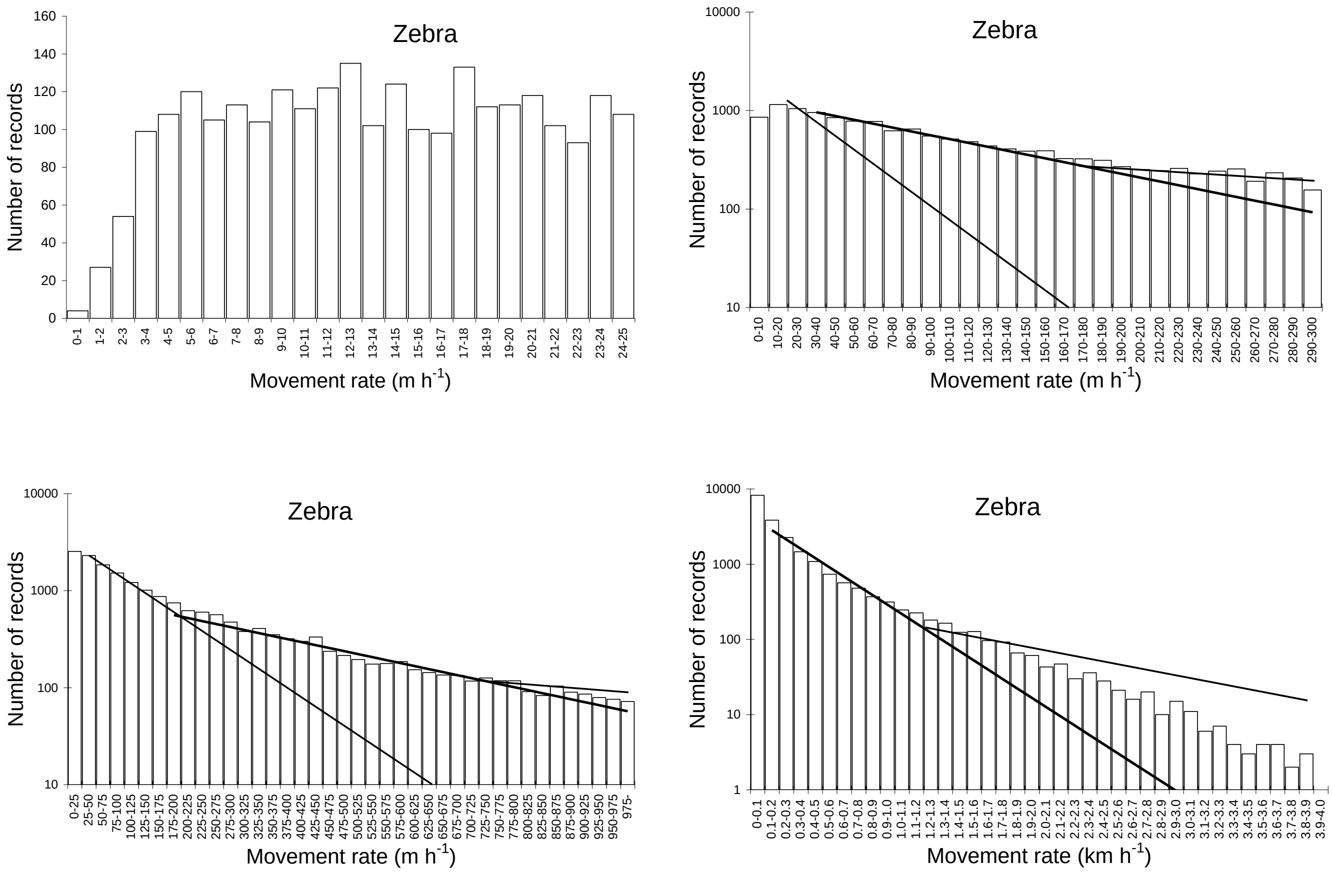
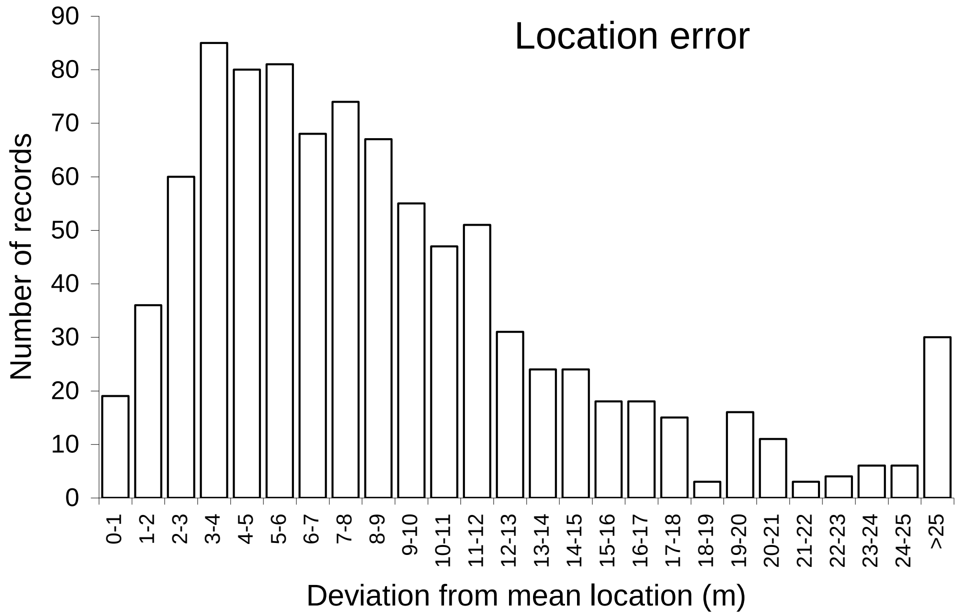

Zebra
Number of records
Movement rate (m h-1)
Zebra
Number of records
Movement rate (m h-1)
Zebra
Number of records
Movement rate (m h-1)
Zebra
Number of records
Movement rate (km h-1)

Fig. S2. Error distribution around the mean generated by stationary GPS collars left in trees or other locations. High errors were generally associated with high dilution of precision (PDOP) in the GPS locations

(*a*) Distribution of the GPS locations




(*b*) Distribution of hourly differences between successive GPS locations

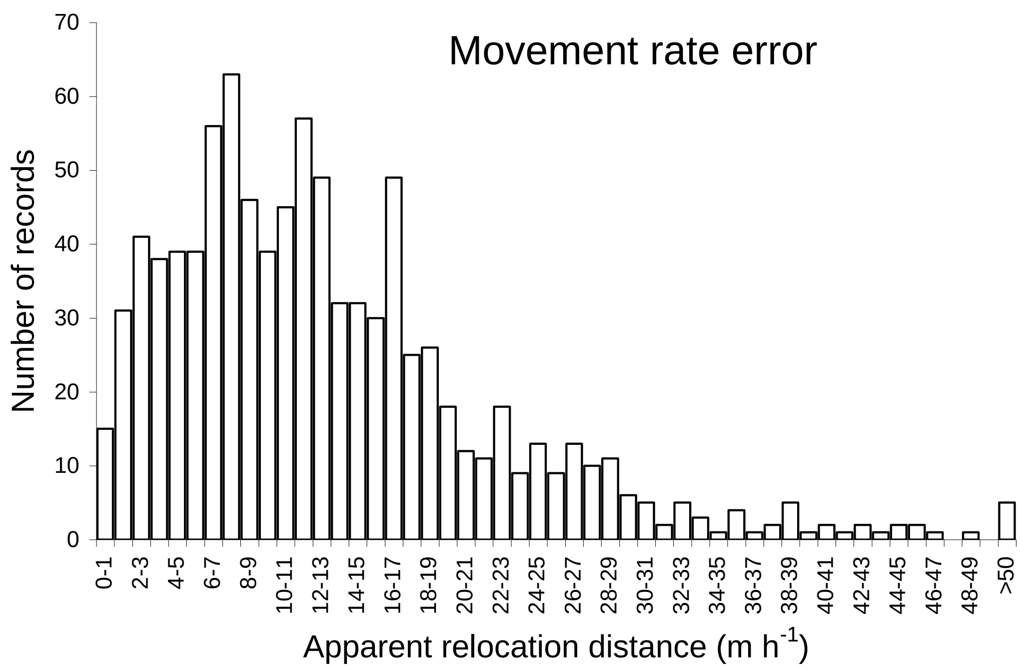
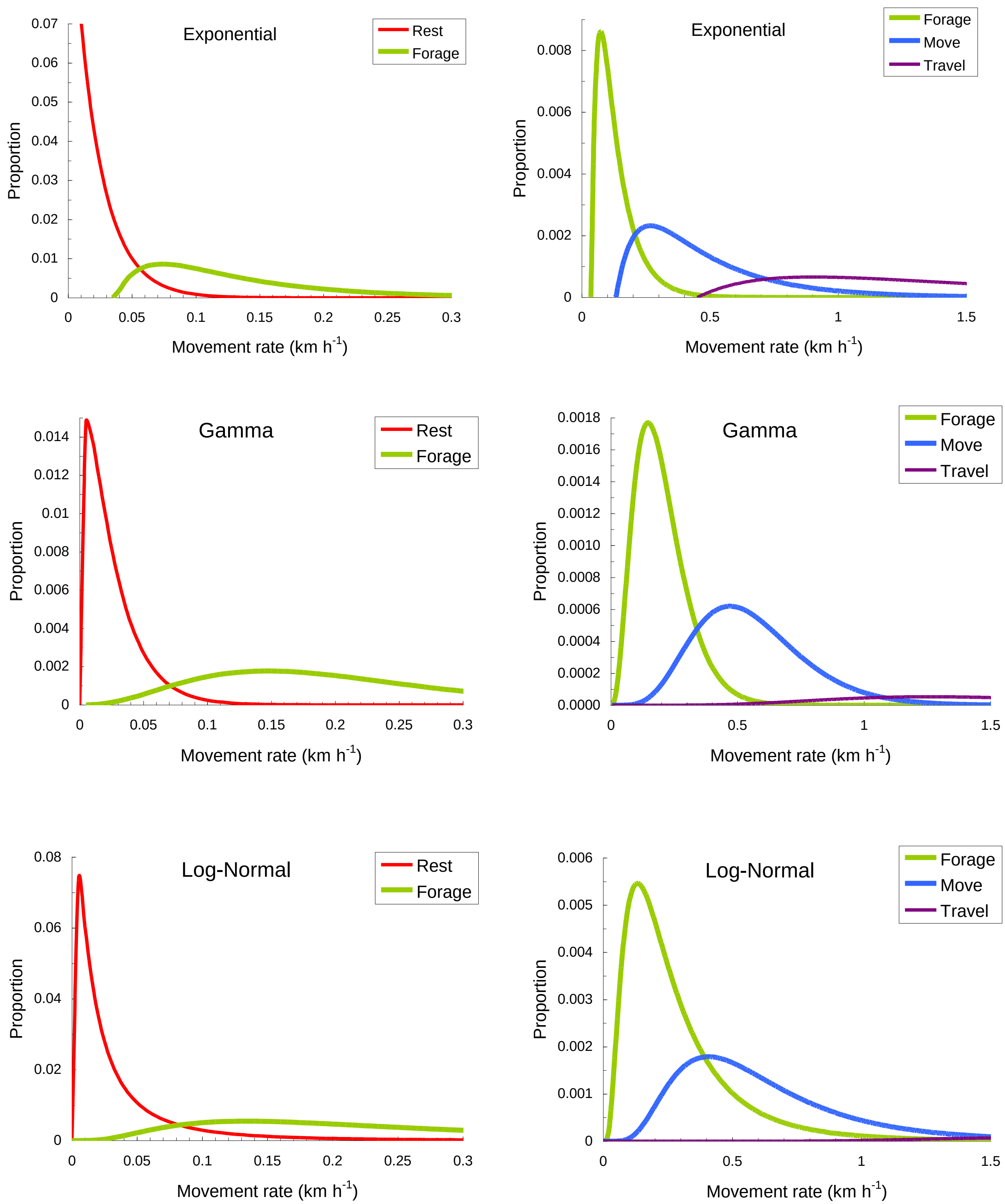


Fig. S3. Component distributions of alternative models fitted to the movement data, interpreted as representing resting, foraging, mixed movement and travelling activity states. For the gamma distribution mixture for zebra, dotted lines represent the split of the first component between resting and slow foraging for the five- component model. (*a*) Buffalo, (*b*) zebra.

(*a*) Buffalo



(*b*) Zebra

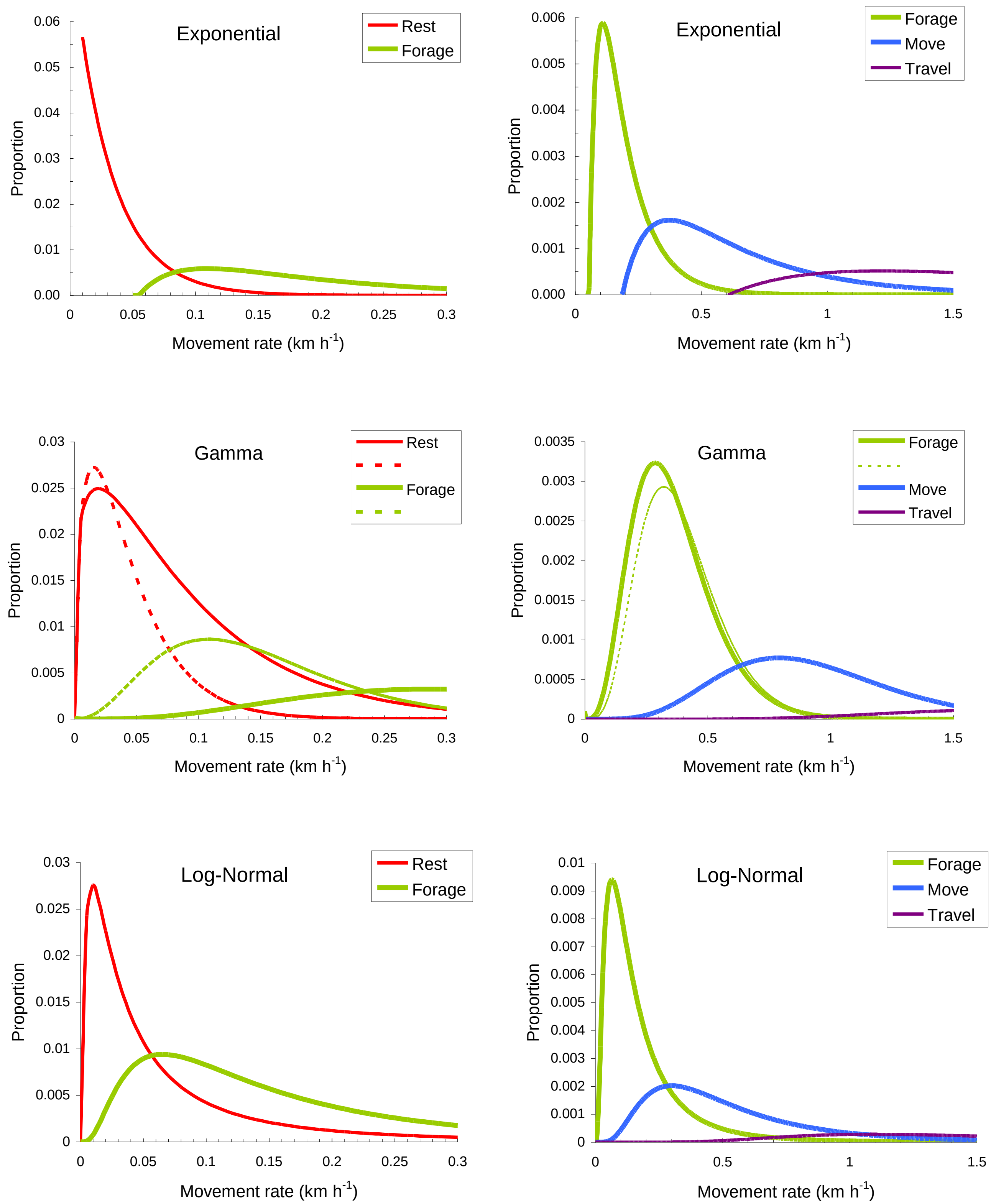
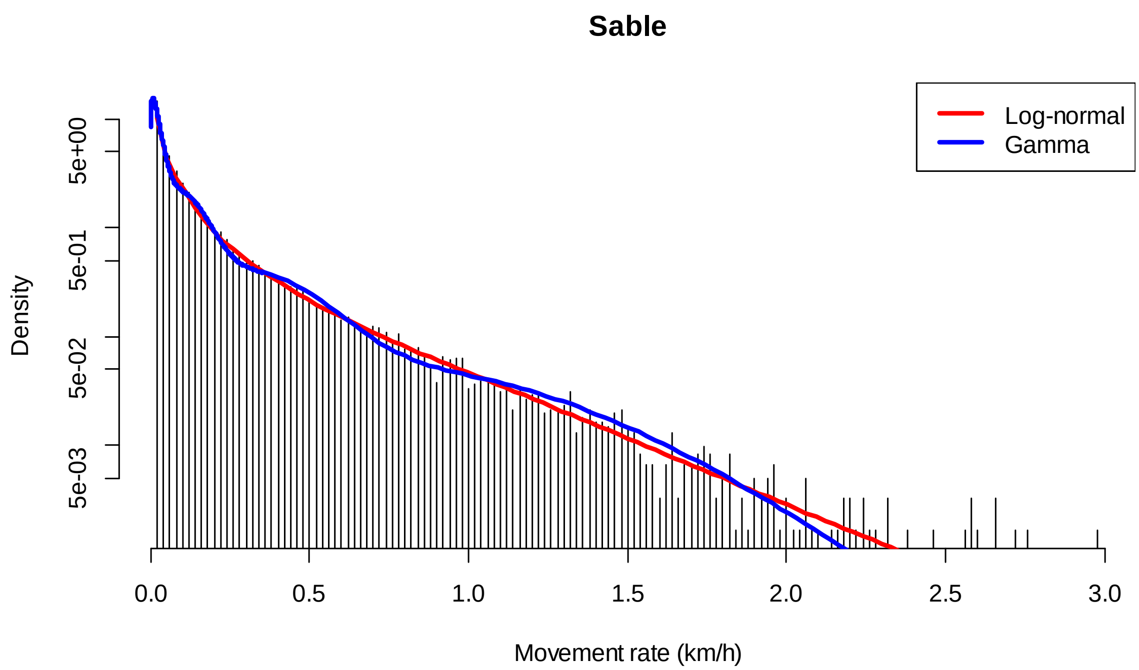
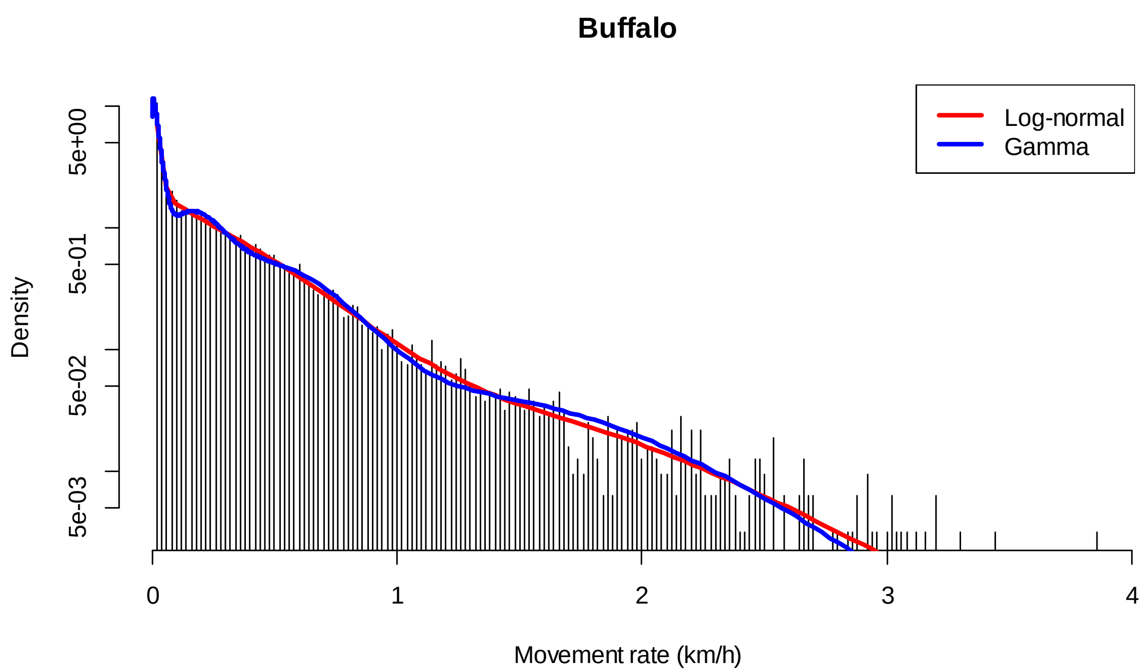

Exponential
Rest
Forage
Proportion
Movement rate (km h-1)
Exponential
Forage
Move
Travel
Proportion
Movement rate (km h-1)
Gamma
Rest
Forage
Proportion
Movement rate (km h-1)
Gamma
Forage
Move
Travel
Proportion
Movement rate (km h-1)
Log-Normal
Rest
Forage
Proportion
Movement rate (km h-1)
Log-Normal
Forage
Move
Travel
Proportion
Movement rate (km h-1)

Fig. S4. Comparative fit of the alternative models to the amalgamated data distribution across herds and seasons of each ungulate species

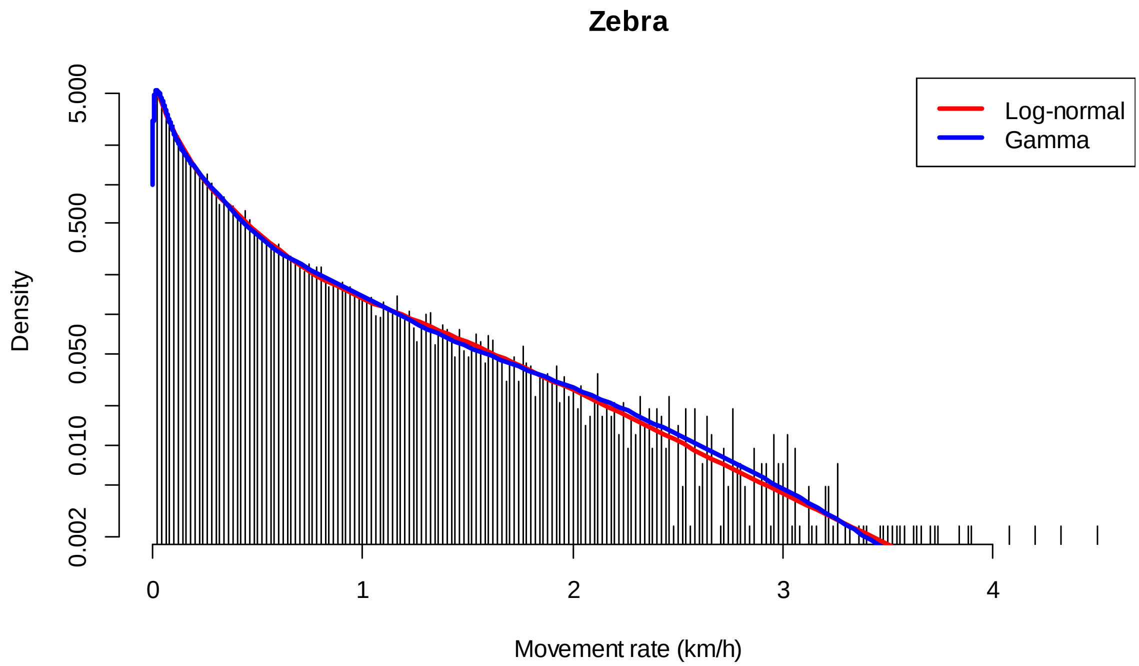
(*a*) Sable




(*b*) Buffalo



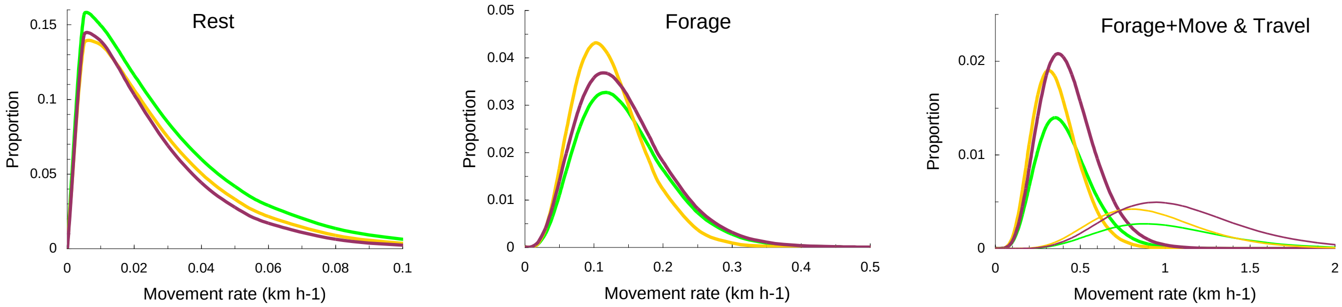
(*c*) Zebra



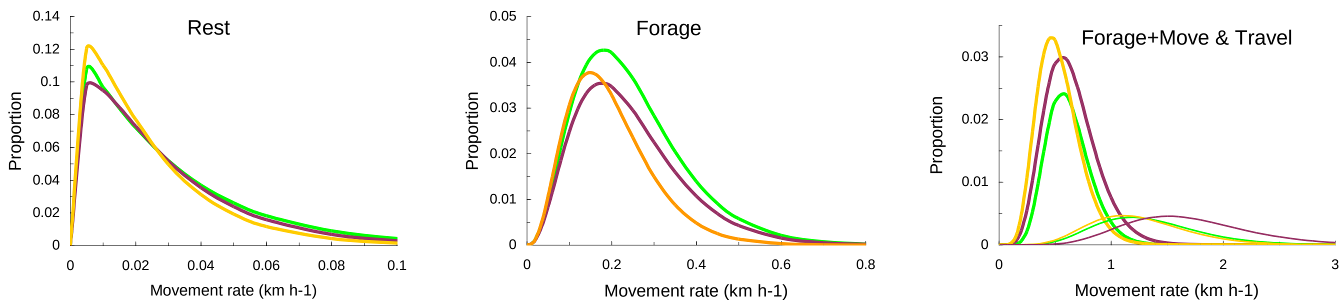
Zebra
Density
5.000
0.500
0.050
0.010
0.002
0
1
2
3
4
Movement rate (km/h)
Log-normal
Gamma

Fig. S5. Comparisons of the gamma functions representing the activity states among seasonal blocks. Green lines represents Wet season (December-March), gold line Early dry season (April-July), and purple line Late dry season (August-November).

(*a*) Sable




(*b*) Buffalo




(*c*) Zebra

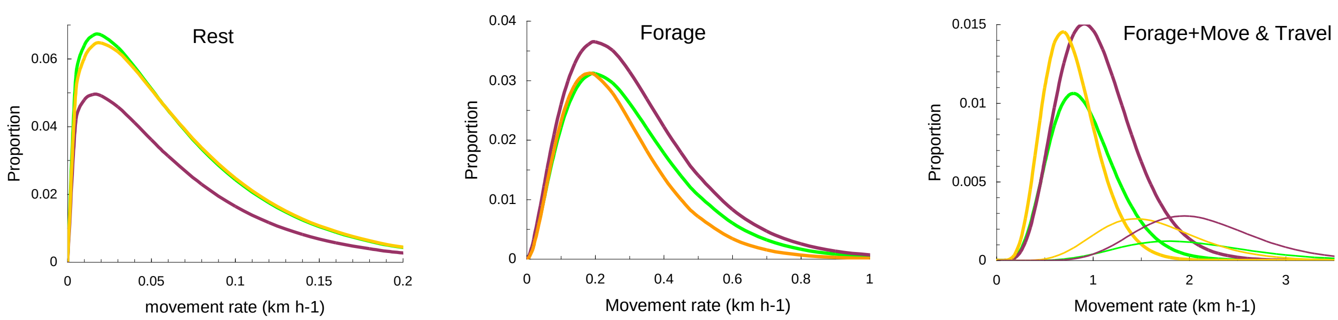
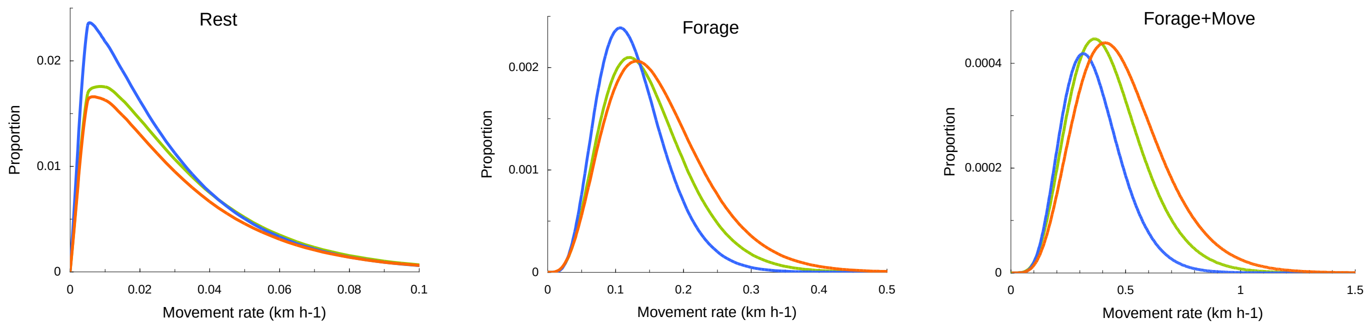


Fig. S6. Comparison of gamma functions representing the activity states derived among three different herds of sable and zebra

(*a*) Sable




(*b*) Zebra

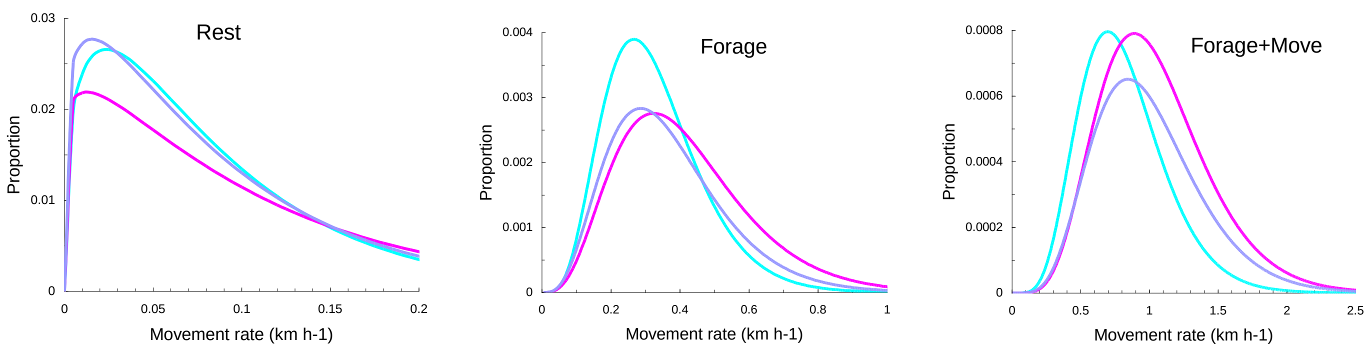


Table S1. Comparative parameter estimates for 4-component log-normal and gamma models derived from Microsoft Excel versus R programme

| Species | Season | N | Model | States | Software | o1 | o2 | o3 | p1 | p2 | p3 | p4 | alpha1 | beta1 | alpha2 | beta2 | alpha3 | beta3 | alpha4 | beta4 | Log Likelihood |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Sable | Year | 30453 | Log-normal | 4 | Excel | | | | 0.616 | 0.196 | 0.163 | 0.025 | -3.844 | 1.189 | -2.229 | 0.594 | -1.071 | 0.600 | -0.090 | 0.417 | 34859 |
| | | | | | R | | | | 0.618 | 0.194 | 0.163 | 0.025 | -3.837 | 1.192 | -2.228 | 0.591 | -1.074 | 0.600 | -0.091 | 0.418 | 34855 |
| Sable | Wet | 10291 | Log-normal | 4 | Excel | | | | 0.668 | 0.113 | 0.181 | 0.038 | -3.794 | 1.235 | -2.557 | 0.520 | -1.514 | 0.645 | -0.372 | 0.482 | 13375 |
| | | | | | R | | | | 0.672 | 0.111 | 0.179 | 0.038 | -3.786 | 1.239 | -2.553 | 0.517 | -1.512 | 0.643 | -0.372 | 0.482 | 13373 |
| Sable | Early Dry | 7439 | Log-normal | 3 | Excel | | | | 0.550 | 0.305 | 0.138 | 0 | -3.946 | 1.115 | -2.256 | 0.628 | -0.939 | 0.563 | - | - | 8885 |
| | | | | | R | | | | 0.550 | 0.304 | 0.146 | - | -3.946 | 1.116 | -2.255 | 0.637 | -0.904 | 0.621 | - | - | 8888 |
| Sable | Late Dry | 12725 | Log-normal | 4 | Excel | | | | 0.593 | 0.245 | 0.138 | 0.024 | -3.871 | 1.173 | -1.925 | 0.647 | -0.776 | 0.534 | 0.086 | 0.373 | 12776 |
| | | | | | R | | | | 0.595 | 0.243 | 0.139 | 0.024 | -3.867 | 1.176 | -1.925 | 0.646 | -0.778 | 0.534 | 0.085 | 0.374 | 12779 |
| Sable | Year | 30451 | Gamma | 4 | Excel | 0.035 | 0.11 | 0.35 | 0.573 | 0.255 | 0.134 | 0.037 | 1.311 | 0.021 | 5.062 | 0.027 | 6.494 | 0.063 | 7.619 | 0.135 | 34461 |
| | | | | | R | 0.035 | 0.11 | 0.35 | 0.573 | 0.255 | 0.134 | 0.037 | 1.311 | 0.021 | 5.059 | 0.027 | 6.492 | 0.063 | 7.618 | 0.135 | 34460 |
| Sable | Wet | 10291 | Gamma | 4 | Excel | 0.035 | 0.11 | 0.33 | 0.640 | 0.233 | 0.103 | 0.024 | 1.232 | 0.024 | 4.938 | 0.030 | 6.503 | 0.064 | 7.259 | 0.135 | 13242 |
| | | | | | R | 0.035 | 0.11 | 0.33 | 0.640 | 0.233 | 0.103 | 0.024 | 1.232 | 0.024 | 4.938 | 0.030 | 6.503 | 0.064 | 7.530 | 0.135 | 13241 |
| Sable | Early Dry | 7439 | Gamma | 4 | Excel | 0.035 | 0.11 | 0.33 | 0.560 | 0.273 | 0.131 | 0.035 | 1.353 | 0.020 | 5.555 | 0.023 | 7.010 | 0.052 | 7.937 | 0.116 | 8788 |
| | | | | | R | 0.035 | 0.11 | 0.33 | 0.560 | 0.273 | 0.132 | 0.035 | 1.353 | 0.020 | 5.557 | 0.023 | 7.010 | 0.052 | 7.937 | 0.116 | 8783 |
| Sable | Late Dry | 12725 | Gamma | 4 | Excel | 0.035 | 0.12 | 0.37 | 0.533 | 0.268 | 0.152 | 0.047 | 1.359 | 0.018 | 4.694 | 0.031 | 6.649 | 0.066 | 7.732 | 0.141 | 12621 |
| | | | | | R | 0.035 | 0.12 | 0.37 | 0.533 | 0.268 | 0.152 | 0.047 | 1.358 | 0.018 | 4.686 | 0.031 | 6.648 | 0.066 | 7.734 | 0.141 | 12626 |
| Buffalo | Year | 15734 | Log-normal | 4 | Excel | | | | 0.424 | 0.336 | 0.223 | 0.017 | -3.908 | 1.205 | -1.495 | 0.722 | -0.610 | 0.537 | 0.583 | 0.283 | 6519 |
| | | | | | R | | | | 0.425 | 0.336 | 0.222 | 0.017 | -3.903 | 1.208 | -1.492 | 0.721 | -0.608 | 0.535 | 0.582 | 0.283 | 6517 |
| Buffalo | Wet | 4861 | Log-normal | 4 | Excel | | | | 0.440 | 0.399 | 0.139 | 0.022 | -3.785 | 1.311 | -1.402 | 0.715 | -0.588 | 0.455 | 0.358 | 0.334 | 2169 |
| | | | | | R | | | | 0.442 | 0.404 | 0.132 | 0.023 | -3.777 | 1.316 | -1.389 | 0.715 | -0.582 | 0.443 | 0.347 | 0.336 | 2169 |
| Buffalo | Early Dry | 5269 | Log-normal | 3 | Excel | | | | 0.398 | 0.290 | 0.311 | 0 | -4.143 | 1.114 | -1.720 | 0.790 | -0.782 | 0.636 | - | - | 2813 |
| | | | | | R | | | | 0.400 | 0.291 | 0.308 | | -4.136 | 1.118 | -1.711 | 0.786 | -0.777 | 0.635 | - | - | 2812 |
| Buffalo | Late Dry | 5605 | Log-normal | 4 | Excel | | | | 0.422 | 0.272 | 0.280 | 0.027 | -3.830 | 1.171 | -1.510 | 0.703 | -0.552 | 0.559 | 0.674 | 0.242 | 1623 |
| | | | | | R | | | | 0.422 | 0.272 | 0.280 | 0.027 | -3.828 | 1.172 | -1.508 | 0.702 | -0.581 | 0.558 | 0.674 | 0.242 | 1623 |

| | | | | | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Buffalo | Year | 15734 | Gamma | 4 | Excel | 0.045 | 0.18 | 0.55 | 0.397 | 0.346 | 0.209 | 0.048 | 1.220 | 0.022 | 3.846 | 0.059 | 7.918 | 0.076 | 8.532 | 0.177 | 6303 |
| | | | | | R | 0.045 | 0.18 | 0.55 | 0.397 | 0.346 | 0.209 | 0.048 | 1.220 | 0.022 | 3.846 | 0.059 | 7.915 | 0.076 | 8.532 | 0.177 | 6304 |
| Buffalo | Wet | 4861 | Gamma | 4 | Excel | 0.045 | 0.17 | 0.50 | 0.403 | 0.403 | 0.145 | 0.048 | 1.115 | 0.027 | 3.672 | 0.068 | 10.423 | 0.060 | 8.503 | 0.157 | 2107 |
| | | | | | R | 0.045 | 0.17 | 0.50 | 0.398 | 0.352 | 0.203 | 0.047 | 1.133 | 0.026 | 4.173 | 0.053 | 8.394 | 0.068 | 8.740 | 0.155 | 2110 |
| Buffalo | Early Dry | 5269 | Gamma | 4 | Excel | 0.041 | 0.16 | 0.47 | 0.399 | 0.327 | 0.225 | 0.049 | 1.265 | 0.018 | 3.963 | 0.050 | 7.948 | 0.068 | 8.409 | 0.149 | 2732 |
| | | | | | R | 0.041 | 0.16 | 0.47 | 0.399 | 0.327 | 0.225 | 0.049 | 1.264 | 0.018 | 3.964 | 0.050 | 7.949 | 0.068 | 8.409 | 0.150 | 2732 |
| Buffalo | Late Dry | 5606 | Gamma | 4 | Excel | 0.045 | 0.18 | 0.59 | 0.391 | 0.334 | 0.216 | 0.060 | 1.290 | 0.022 | 3.663 | 0.066 | 7.702 | 0.084 | 9.432 | 0.179 | 1558 |
| | | | | | R | 0.045 | 0.18 | 0.59 | 0.391 | 0.334 | 0.216 | 0.060 | 1.290 | 0.022 | 3.660 | 0.066 | 7.701 | 0.084 | 9.433 | 0.179 | 1559 |
| Zebra | Year | 21028 | Log-normal | 4 | Excel | | | | 0.333 | 0.362 | 0.232 | 0.073 | -3.177 | 1.226 | -2.033 | 0.833 | -0.807 | 0.629 | 0.276 | 0.430 | 4300 |
| | | | | | R | | | | 0.334 | 0.361 | 0.232 | 0.073 | -3.171 | 1.228 | -2.031 | 0.833 | -0.806 | 0.628 | 0.276 | 0.430 | 4300 |
| Zebra | Wet | 7416 | Log-normal | 4 | Excel | | | | 0.363 | 0.413 | 0.175 | 0.049 | -3.107 | 1.287 | -2.064 | 0.925 | -0.807 | 0.622 | 0.184 | 0.474 | 2760 |
| | | | | | R | | | | 0.363 | 0.415 | 0.174 | 0.049 | -3.105 | 1.288 | -2.064 | 0.928 | -0.807 | 0.623 | 0.184 | 0.474 | 2759 |
| Zebra | Early Dry | 5628 | Log-normal | 4 | Excel | | | | 0.327 | 0.429 | 0.168 | 0.076 | -3.178 | 1.244 | -2.101 | 0.861 | -0.917 | 0.634 | 0.018 | 0.465 | 2115 |
| | | | | | R | | | | 0.328 | 0.429 | 0.167 | 0.076 | -3.174 | 1.245 | -2.099 | 0.861 | -0.915 | 0.634 | 0.018 | 0.464 | 2115 |
| Zebra | Late Dry | 7986 | Log-normal | 4 | Excel | | | | 0.194 | 0.328 | 0.361 | 0.117 | -3.693 | 1.024 | -2.195 | 0.755 | -0.903 | 0.645 | 0.330 | 0.414 | 319 |
| | | | | | R | | | | 0.201 | 0.311 | 0.370 | 0.117 | -3.658 | 1.034 | -2.209 | 0.737 | -0.915 | 0.648 | 0.329 | 0.415 | 319 |
| Zebra | Year | 21028 | Gamma | 4 | Excel | 0.01 | 0.055 | 0.19 | 0.426 | 0.348 | 0.172 | 0.054 | 1.266 | 0.072 | 4.828 | 0.075 | 6.843 | 0.135 | 9.911 | 0.197 | 4232 |
| | | | | | R | 0.01 | 0.055 | 0.19 | 0.439 | 0.330 | 0.165 | 0.068 | 1.391 | 0.045 | 3.092 | 0.081 | 4.383 | 0.157 | 5.477 | 0.283 | 4263 |
| Zebra | Wet | 7416 | Gamma | 4 | Excel | 0.01 | 0.06 | 0.19 | 0.501 | 0.322 | 0.143 | 0.034 | 1.384 | 0.046 | 3.042 | 0.086 | 4.477 | 0.163 | 5.307 | 0.312 | 2753 |
| | | | | | R | 0.01 | 0.06 | 0.19 | 0.503 | 0.321 | 0.143 | 0.033 | 1.376 | 0.047 | 3.031 | 0.087 | 4.445 | 0.166 | 5.438 | 0.309 | 2752 |
| Zebra | Early Dry | 5628 | Gamma | 4 | Excel | 0.01 | 0.06 | 0.18 | 0.464 | 0.311 | 0.159 | 0.065 | 1.449 | 0.042 | 3.388 | 0.063 | 4.964 | 0.119 | 5.145 | 0.252 | 2108 |
| | | | | | R | 0.01 | 0.06 | 0.18 | 0.467 | 0.309 | 0.158 | 0.065 | 1.443 | 0.043 | 3.395 | 0.063 | 4.979 | 0.119 | 5.150 | 0.252 | 2108 |
| Zebra | Late Dry | 7986 | Gamma | 4 | Excel | 0.01 | 0.06 | 0.21 | 0.356 | 0.380 | 0.187 | 0.076 | 1.368 | 0.044 | 2.950 | 0.093 | 4.410 | 0.186 | 7.133 | 0.247 | 343 |
| | | | | | R | 0.01 | 0.06 | 0.21 | 0.356 | 0.380 | 0.189 | 0.075 | 1.368 | 0.044 | 2.947 | 0.093 | 4.382 | 0.188 | 7.189 | 0.246 | 343 |