Ecological Dynamic Regimes

Identification, characterization, and comparison

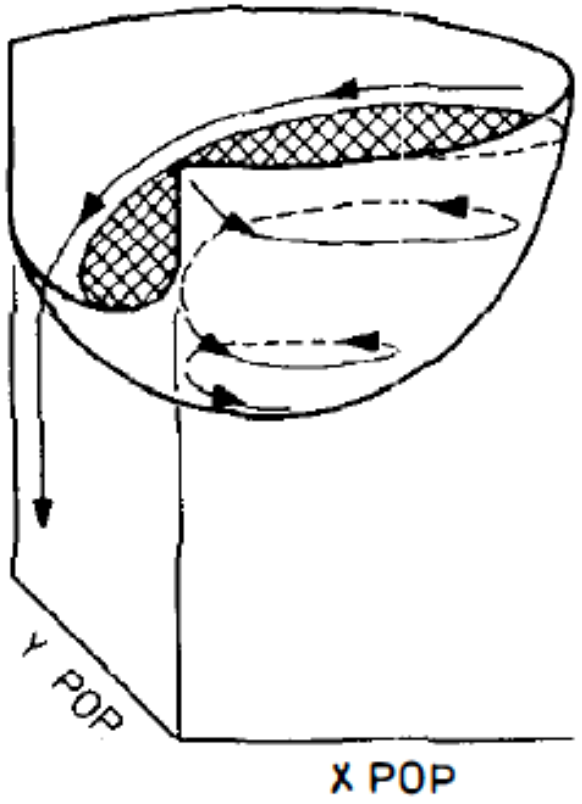
Martina Sánchez-Pinillos

Ecological Dynamic Regimes (EDR)

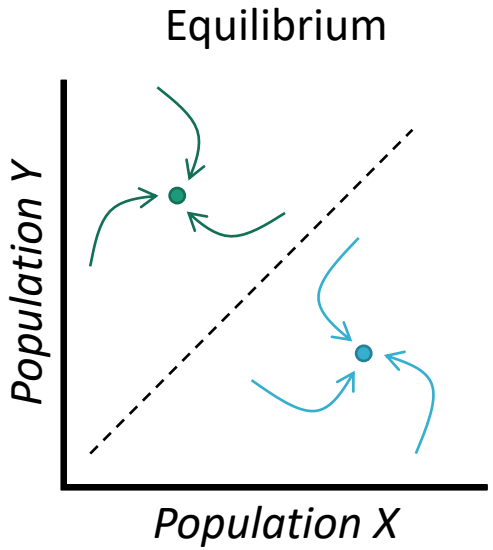
Natural fluctuations of ecosystem states around some trend or average resulting from an intricate mix of internal processes and external forces that push the system towards specific domains of attraction

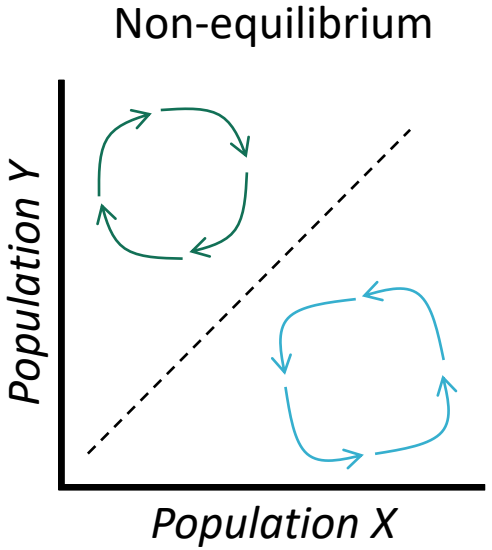
Ecological Dynamic Regimes and Resilience

Theoretically…



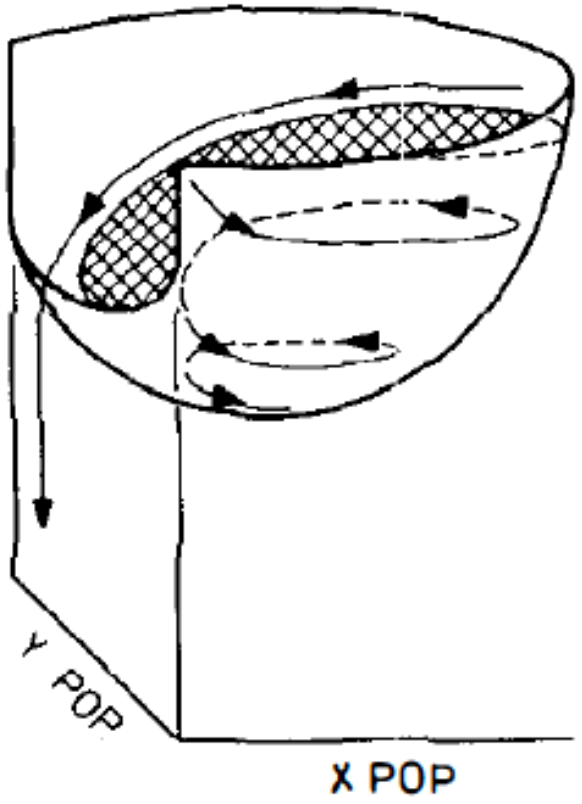
Holling (1973)





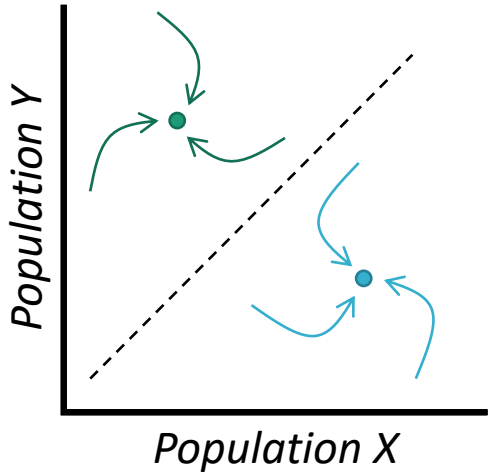
Ecological Dynamic Regimes and Resilience

Theoretically…

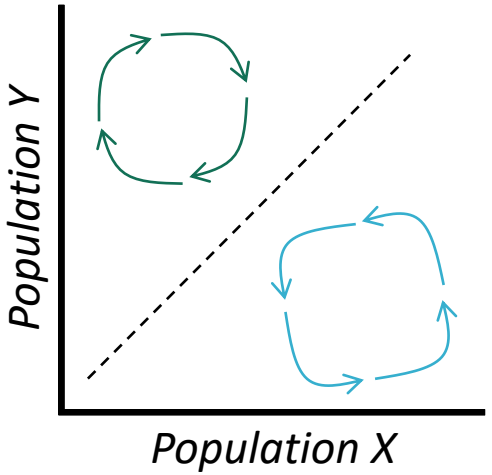


Holling (1973)

Equilibrium

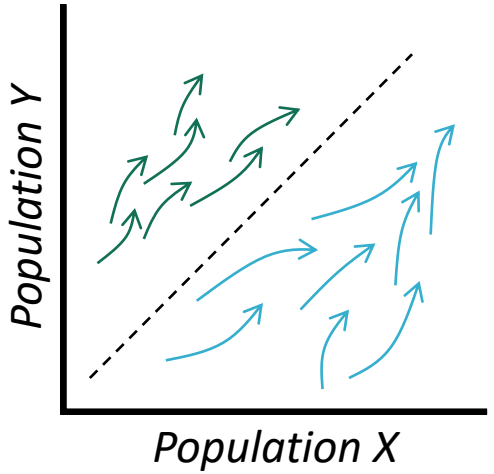


Non-equilibrium



In real ecosystems…

Transient states



- Interacting factors
- Heterogeneity
- Historical legacies
- Changing conditions
- Stochasticity

- Identify EDR
- Characterize EDR
- Compare EDR

... from empirical data

The EDR framework

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ARTICLE

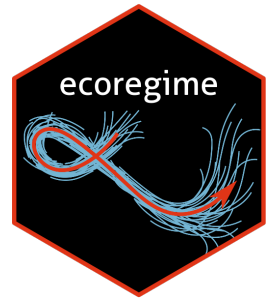
ECOLOGICAL MONOGRAPHS
ECOLOGICAL SOCIETY OF AMERICA

Ecological dynamic regimes: Identification, characterization, and comparison

Martina Sánchez-Pinillos[1] | **Sonia Kéfi**[1] | **Miquel De Cáceres**[2] | **Vasilis Dakos**[1]

OPEN ACCESS https://doi.org/10.1002/ecm.1589

The R package ‘ecoregime’



Analysis of Ecological Dynamic Regimes

A toolbox for implementing the Ecological Dynamic Regime framework

CRAN: https://CRAN.R-project.org/package=ecoregime

Website: https://mspinillos.github.io/ecoregime/

```
# Install and load ecoregime
install.packages("ecoregime")
library(ecoregime)
```

WARNING!

There is no universal rule to perform the EDR framework.

Some analyses depend on the data characteristics and the objectives pursued.

Raw data

Inventory data

	Site	Obs.	sp1	sp2	sp3
1	A	1	0.8	0.2	0
2	A	2	0.6	0.4	0
3	A	3	0.2	0.8	0
4	B	1	0.1	0.3	0.6
5	B	2	0.1	0.1	0.8
⋮	⋮	⋮	⋮	⋮	⋮
N	M	n	0	1	0

State dissimilarities

Inventory data

	Site	Obs.	sp1	sp2	sp3
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⋮	⋮	⋮	⋮	⋮	⋮
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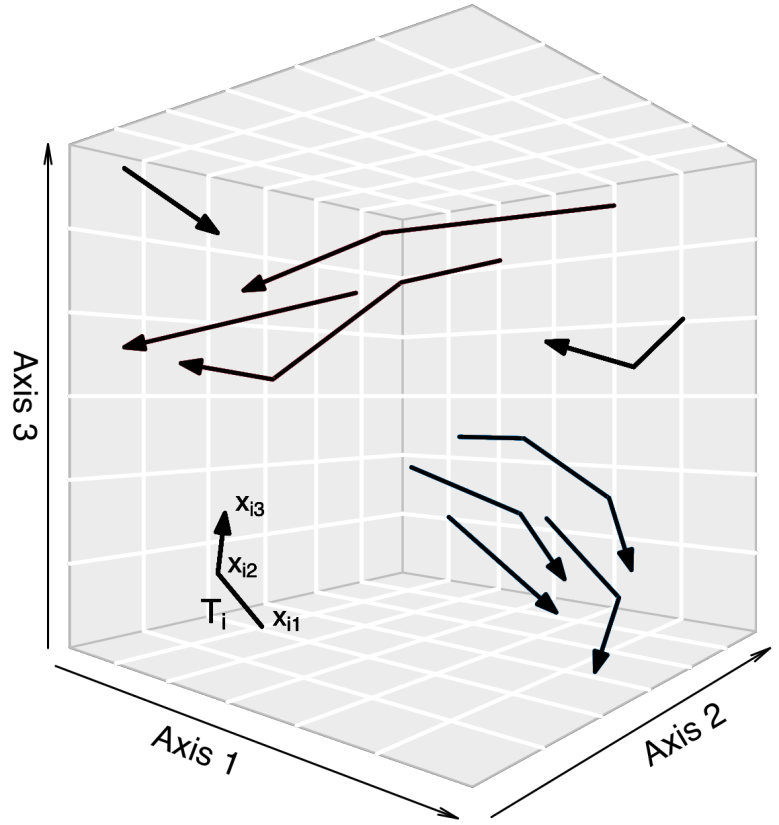
State dissimilarities

		A1	A2	A3	B1	B2	⋯	Mn
1	A1							
2	A2							
3	A3			$D_{P,NxN}$				
4	B1							
5	B2							
⋮	⋮							
N	Mn							

State space



State dissimilarities

		A1	A2	A3	B1	B2	⋯	Mn
1	A1							
2	A2							
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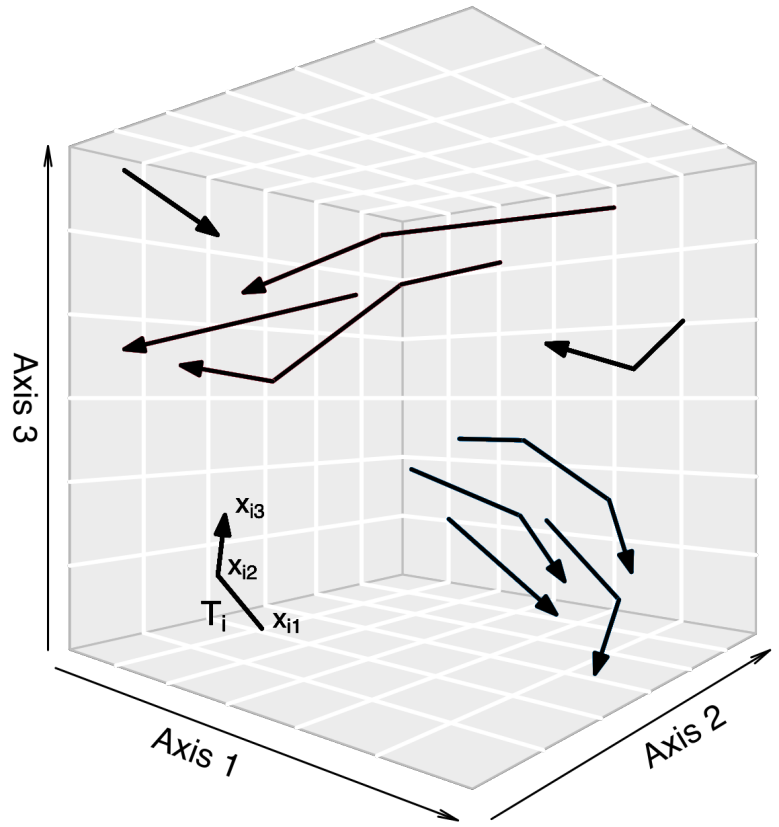
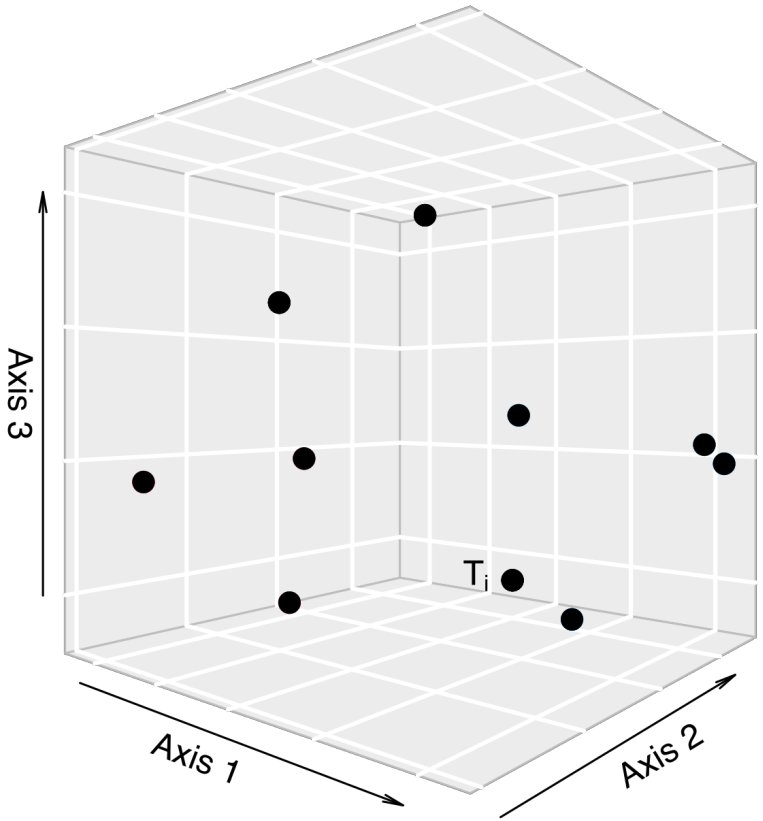
5	B2							
⋮	⋮							
N	Mn							

$D_{P,NxN}$

State space



Trajectory space



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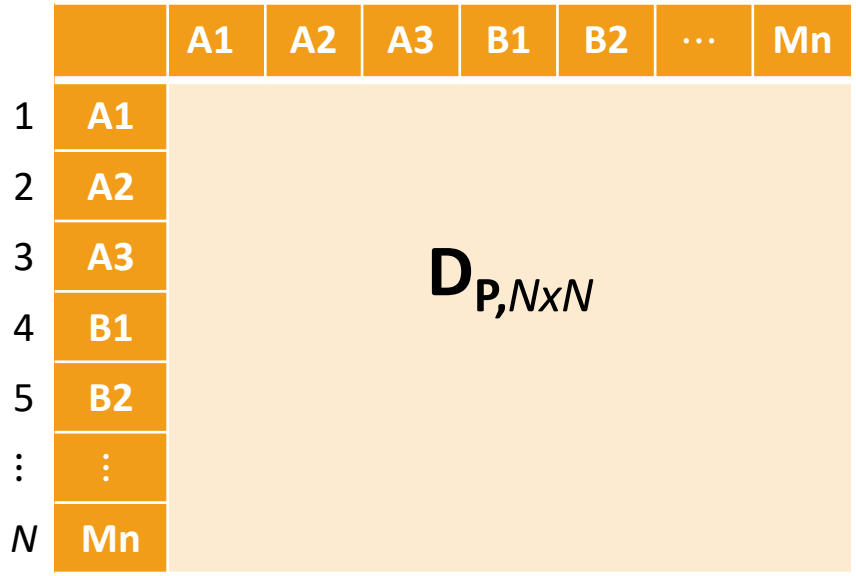
⋮	⋮	⋮	⋮	⋮	⋮
N	M	n	0	1	0

```
# Species abundances
abun <- rbind(EDR_data$EDR1$abundance,
              EDR_data$EDR2$abundance,
              EDR_data$EDR3$abundance)
# ID trajectory
abun$ID <- paste0(abun$EDR, "_", abun$traj)
```

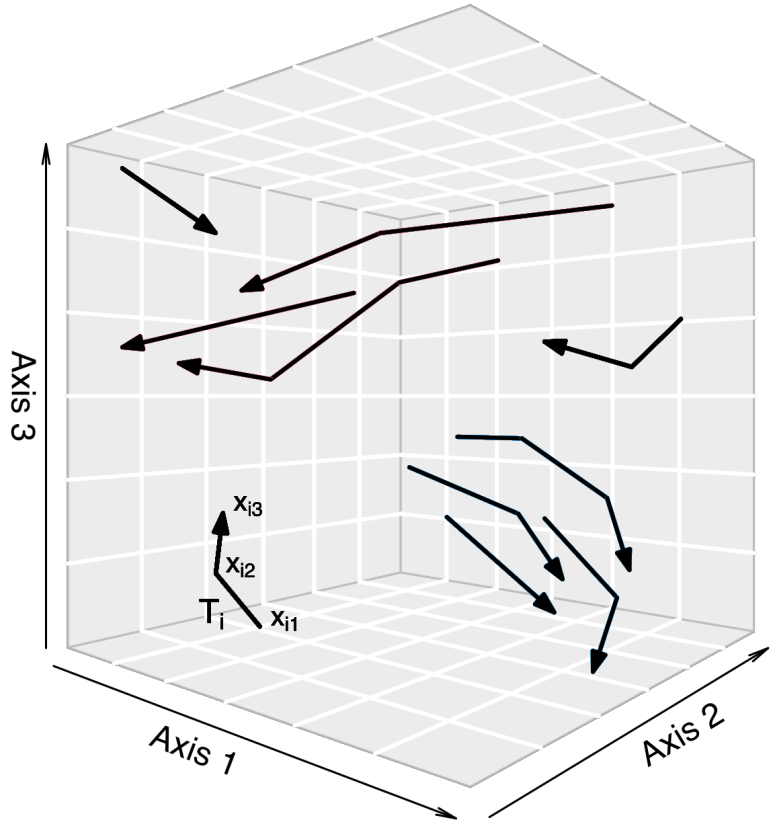
State dissimilarities

```
# State dissimilarities (e.g. Bray-Curtis)
library(vegan)
dStates <- vegdist(x = abun[, paste0("sp", 1:12)],
                   method = "bray")   *
```

State dissimilarities



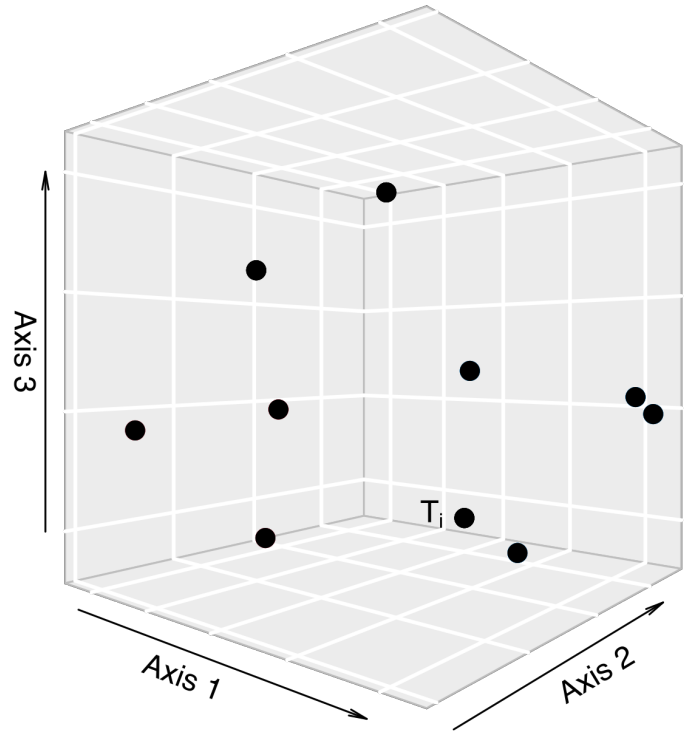
State space




```
# Plot trajectories
library(ecotraj)
trajectoryPCoA(d = dStates,
               sites = abun$ID,
               surveys = abun$state)
```

Trajectory space

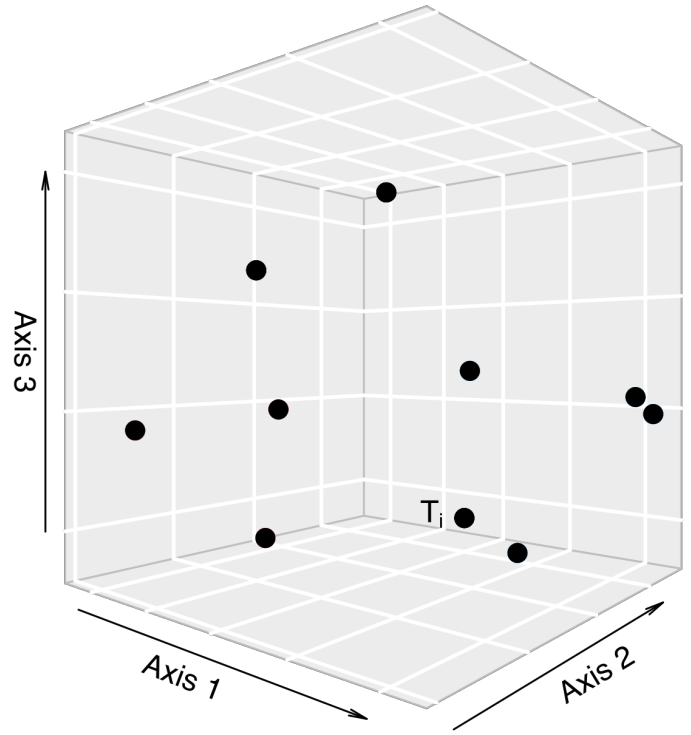
```
# Trajectory dissimilarities
dTraj <- trajectoryDistances(d = dStates,
                             sites = abun$ID,
                             surveys = abun$state,
                             distance.type = "DSPD")  *
```



Trajectory space

```
# Trajectory dissimilarities
dTraj <- trajectoryDistances(d = dStates,
                             sites = abun$ID,
                             surveys = abun$state,
                             distance.type = "DSPD")  *


# Trajectory space (PCoA)
pcoa_traj <- cmdscale(dTraj, k = nrow(as.matrix(dTraj)) - 1, add = T)
traj_coord <- pcoa_traj$points
# Plot the trajectory space
plot(x = traj_coord[, 1], y = traj_coord[, 2],
     xlab = "Axis 1", ylab = "Axis 2",
     main = "Trajectory space")
```



How do we identify EDRs from empirical data?

Identify EDRs

Identifying subsets of ecological trajectories with more similar geometric patterns between each other than with any other trajectory in the same state space

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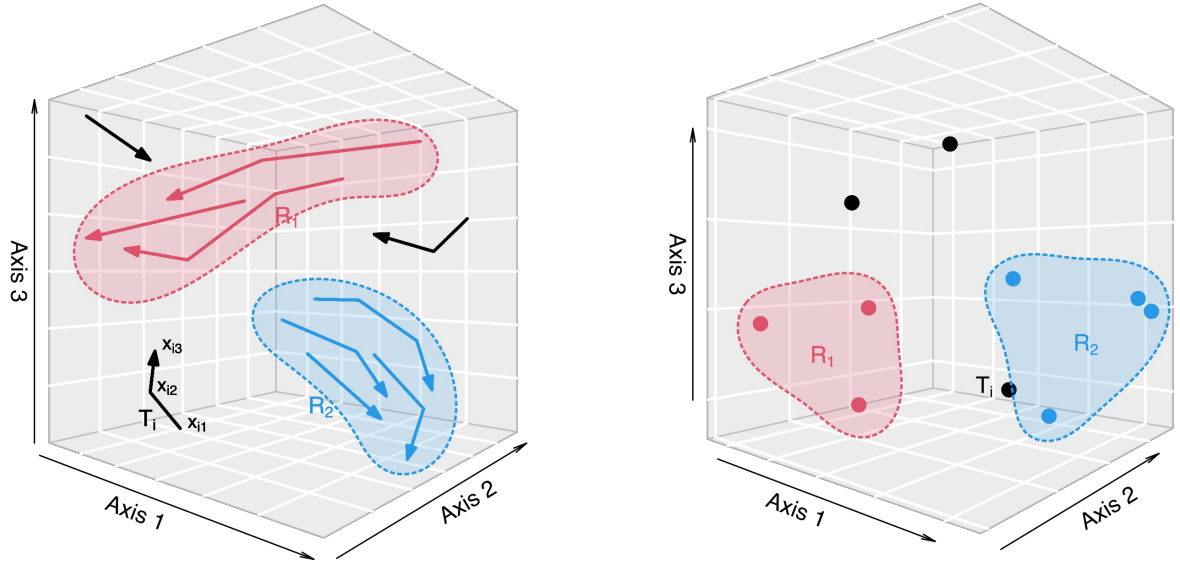
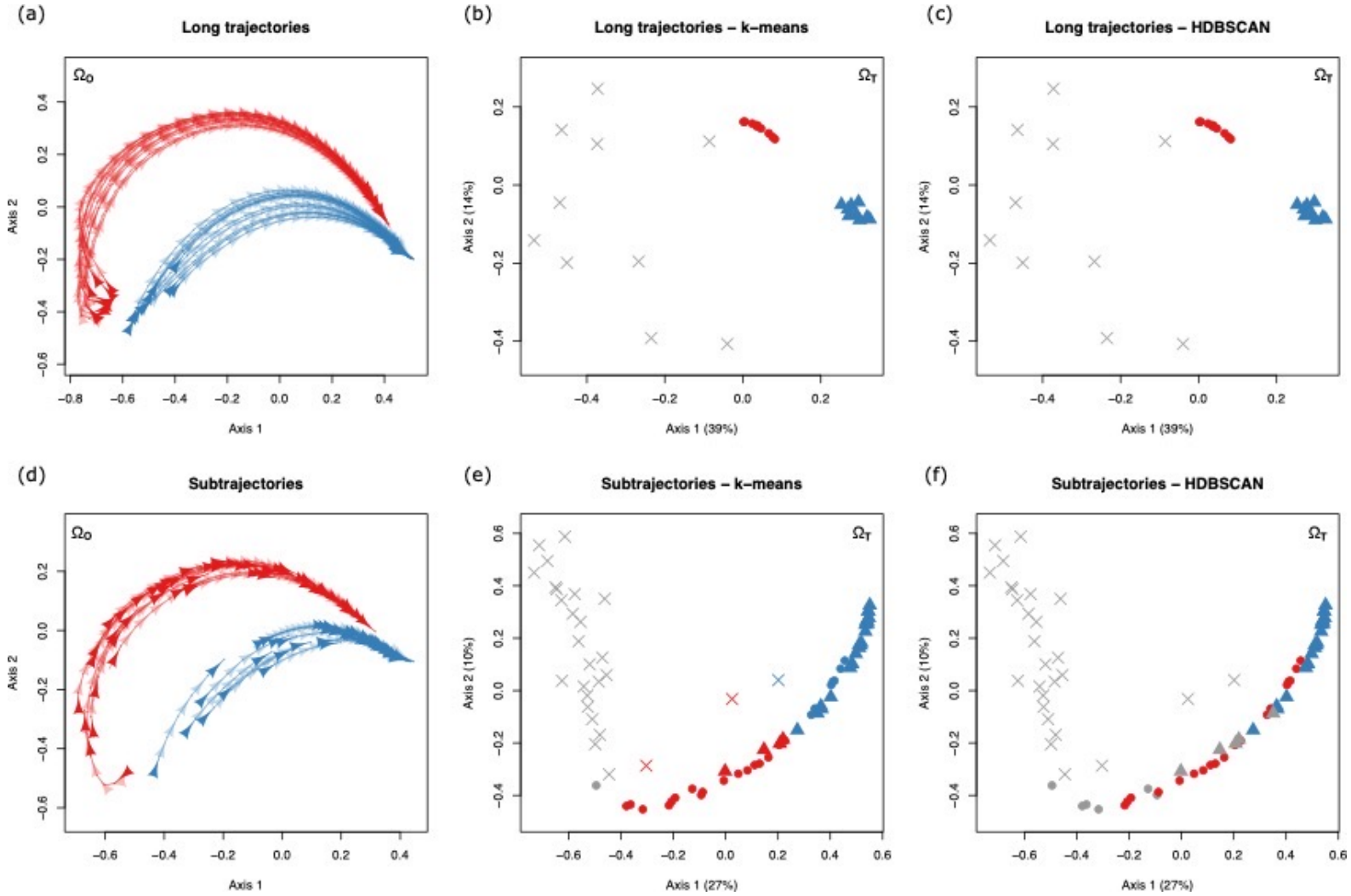
Identifying subsets of ecological trajectories with more similar geometric patterns between each other than with any other trajectory in the same state space



Clustering algorithms



Sánchez-Pinillos et al. (2023) *Ecol. Monogr.*

Identify EDRs

```
# Clustering analysis (e.g., HDBSCAN) *
library(dbscan)
EDR <- hdbscan(x = dTraj, minPts = 10)
EDR_cluster <- data.frame(ID = unique(abun$ID),
                          EDR_cluster = EDR$cluster)
```

Identify EDRs

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EDR <- hdbscan(x = dTraj, minPts = 10)
EDR_cluster <- data.frame(ID = unique(abun$ID),
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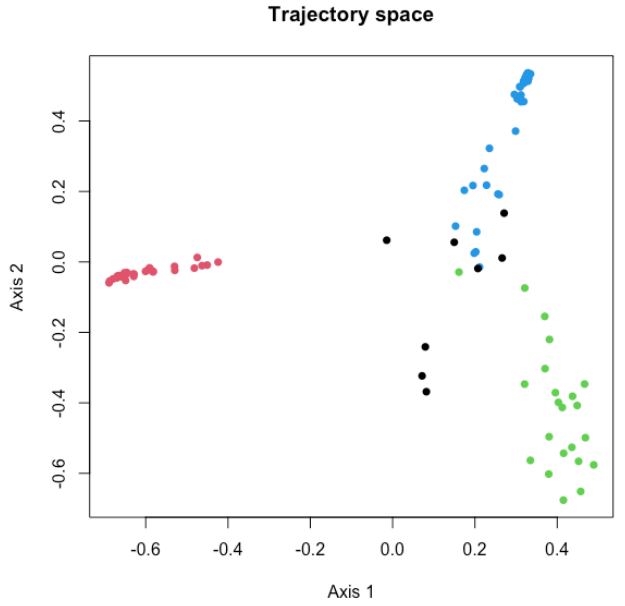
# Plot the trajectory space

plot(x = traj_coord[, 1], y = traj_coord[, 2],
     xlab = "Axis 1", ylab = "Axis 2",
     main = "Trajectory space",
     col = EDR_cluster$EDR_cluster + 1)
```



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     xlab = "Axis 1", ylab = "Axis 2",
     main = "Trajectory space",
     col = EDR_cluster$EDR_cluster + 1)

# Plot trajectories in the state space

trajectoryPCoA(d = dStates,
               sites = abun$ID,
               surveys = abun$state,
               traj.colors = EDR_cluster$EDR_cluster + 1)
```
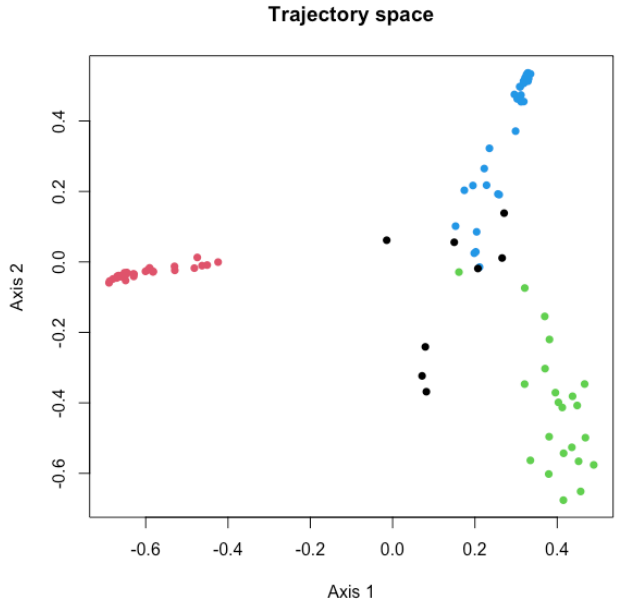
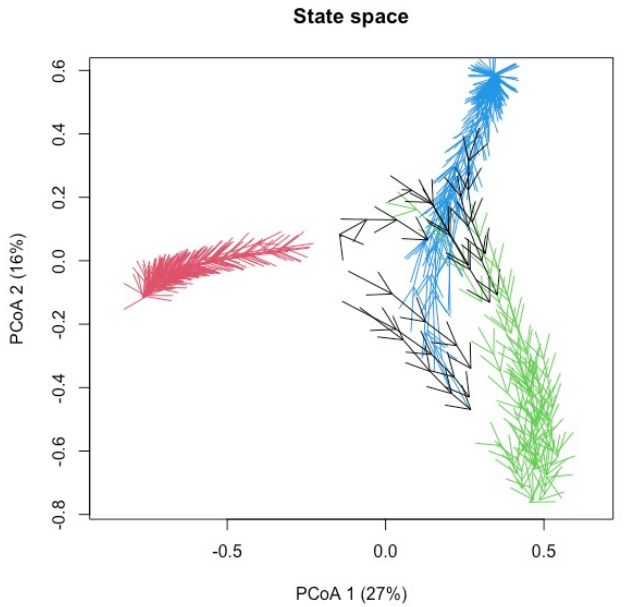
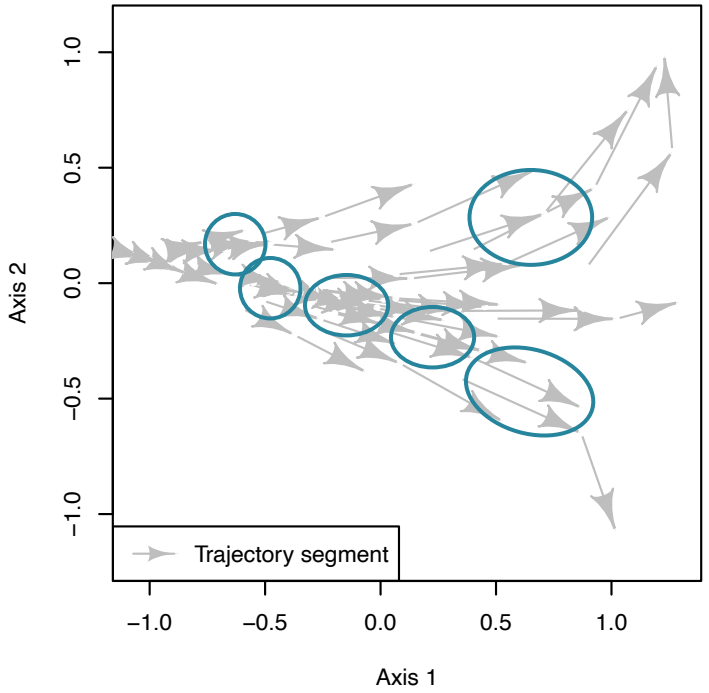





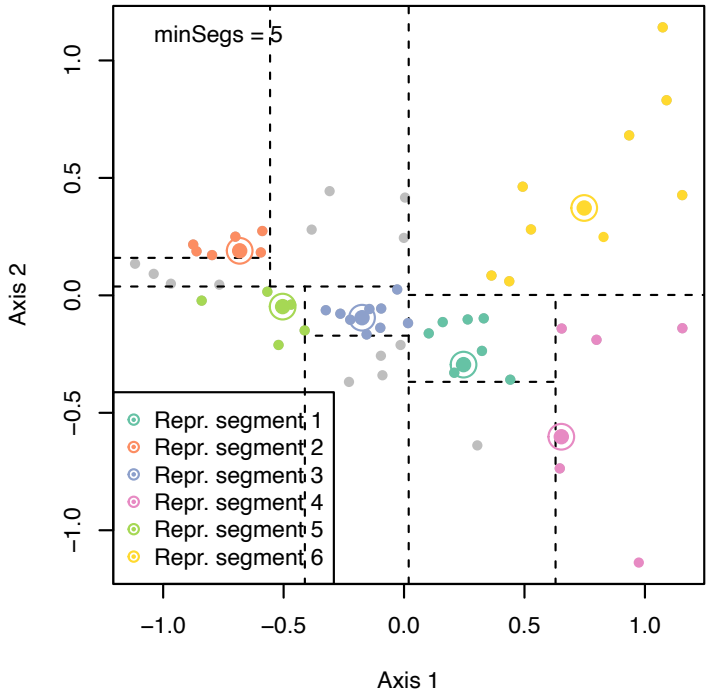
Can we summarize the main dynamical patterns of an EDR?

Characterize EDRs

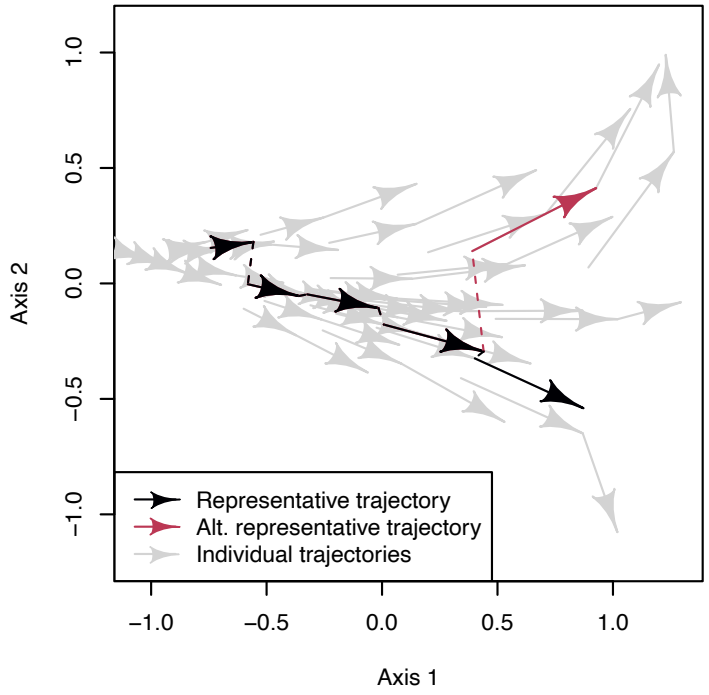
RETRA-EDR: REpresentative TRAjectories in EDRs



Look for dense regions in the EDR



Identify representative segments of each dense region



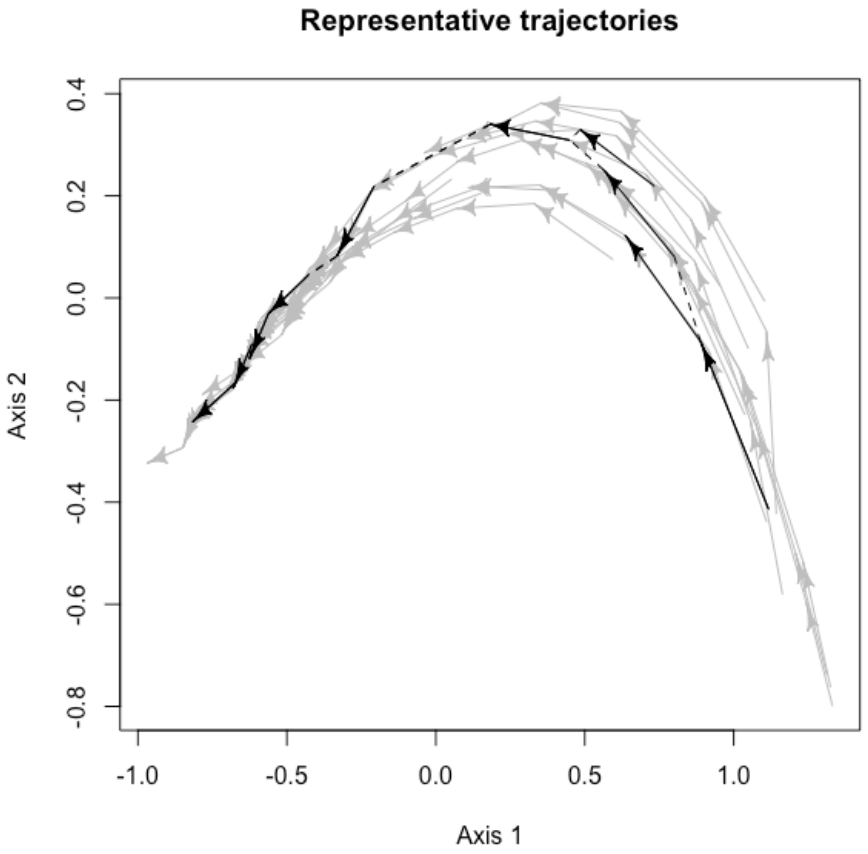
Merge representative segments

Representative trajectories

```
# Select the EDR
ID_EDR <- which(abun$EDR == 1)

# Apply RETRA-EDR
RT <- retra_edr(d = as.matrix(dStates)[ID_EDR, ID_EDR],
                trajectories = abun[ID_EDR]$traj,
                states = abun[ID_EDR]$state,
                minSegs = 5) *
```

Representative trajectories

```r
# Select the EDR
ID_EDR <- which(abun$EDR == 1)

# Apply RETRA-EDR
RT <- retra_edr(d = as.matrix(dStates)[ID_EDR, ID_EDR],
                trajectories = abun[ID_EDR]$traj,
                states = abun[ID_EDR]$state,
                minSegs = 5) *

# Plot representative trajectories
plot(x = RT, d = as.matrix(dStates)[ID_EDR, ID_EDR],
     trajectories = abun[ID_EDR]$traj,
     states = abun[ID_EDR]$state,
     main = "Representative trajectories")
```

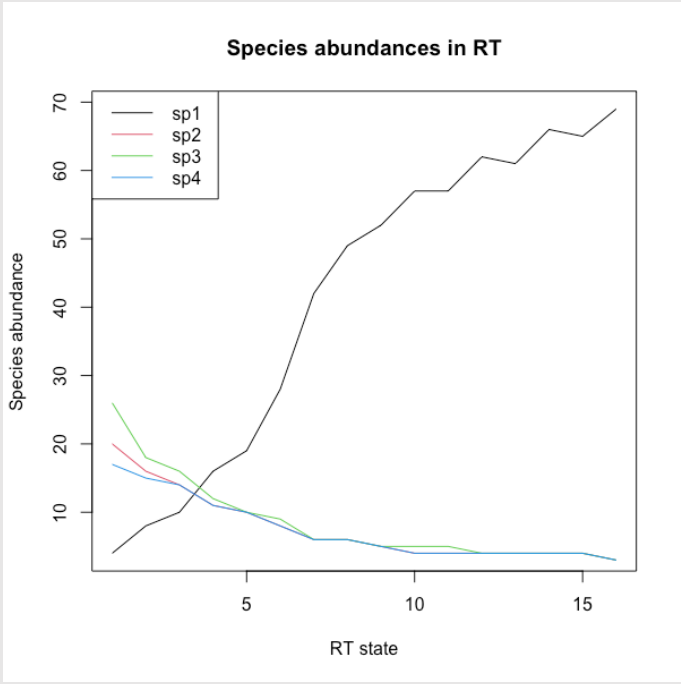


Representative trajectories

```
# Extract field data for representative trajectories
seg_components <- strsplit(gsub("\\]", "", gsub("\\[", "-", RT$T2$Segments)), "-")
RT_data <- do.call(rbind, lapply(seg_components, function(iseg){
  data.frame(traj = rep(iseg[[1]], 2),
             state = c(iseg[[2]], iseg[[3]]))
}))
RT_data <- merge(RT_data, abun[EDR == 1], all.x = T, sort = F)
```

Representative trajectories

```
# Extract field data for representative trajectories
seg_components <- strsplit(gsub("\\]", "", gsub("\\[", "-", RT$T2$Segments)), "-")
RT_data <- do.call(rbind, lapply(seg_components, function(iseg){
  data.frame(traj = rep(iseg[[1]], 2),
             state = c(iseg[[2]], iseg[[3]]))
}))
RT_data <- merge(RT_data, abun[EDR == 1], all.x = T, sort = F)
# Plot changes in species abundances
plot(x = 1:nrow(RT_data), y = RT_data$sp1, type = "l",
     xlab = "RT state", ylab = "Species abundance",
     main = "Species abundances in RT")
lines(x = 1:nrow(RT_data), y = RT_data$sp2, col = 2)
lines(x = 1:nrow(RT_data), y = RT_data$sp3, col = 3)
lines(x = 1:nrow(RT_data), y = RT_data$sp4, col = 4)
legend("topleft", paste0("sp", 1:4), lty = 1, col = 1:4)
```



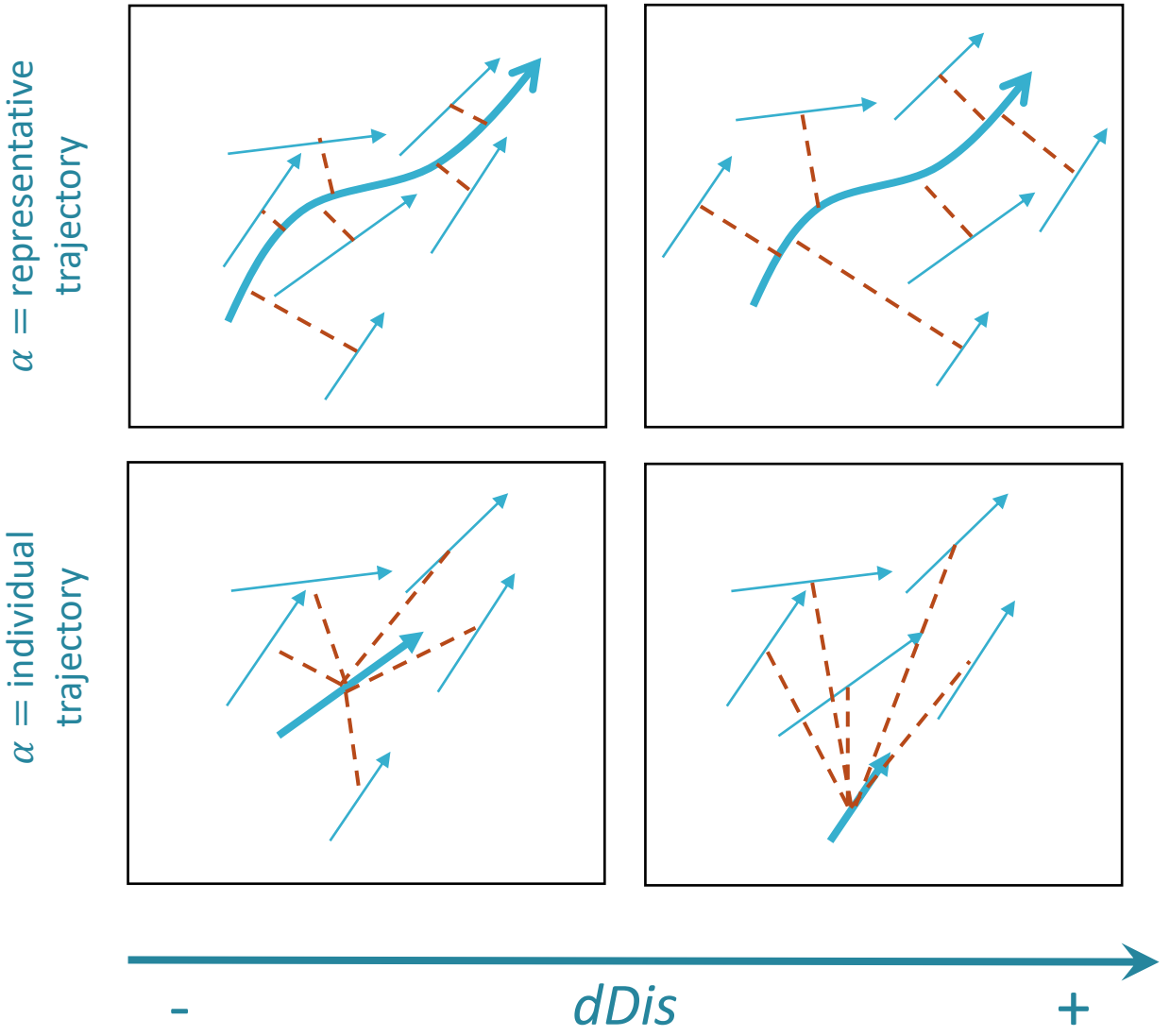
How is the distribution of individual trajectories in an EDR?

Characterize EDRs

Dynamic dispersion *(dDis)*

$$dDis = \frac{\sum_{i=1}^{m} d_{i\alpha}}{m}$$

Average distance to a trajectory of reference

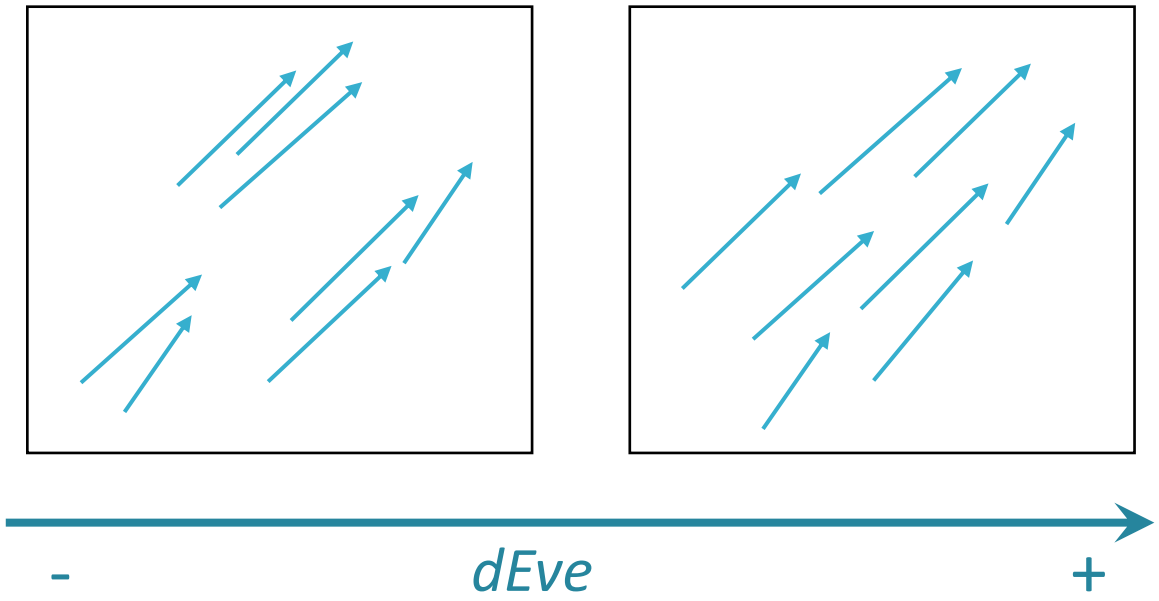


Characterize EDRs

Dynamic evenness *(dEve)*

$$dEve = \frac{\sum_{l=1}^{m-1} \min\left(\frac{d_{ij}}{\sum_{l=1}^{m-1} d_{ij}}, \frac{1}{m-1}\right) - \frac{1}{m-1}}{1 - \frac{1}{m-1}}$$

Regularity with which the EDR is filled by the individual trajectories

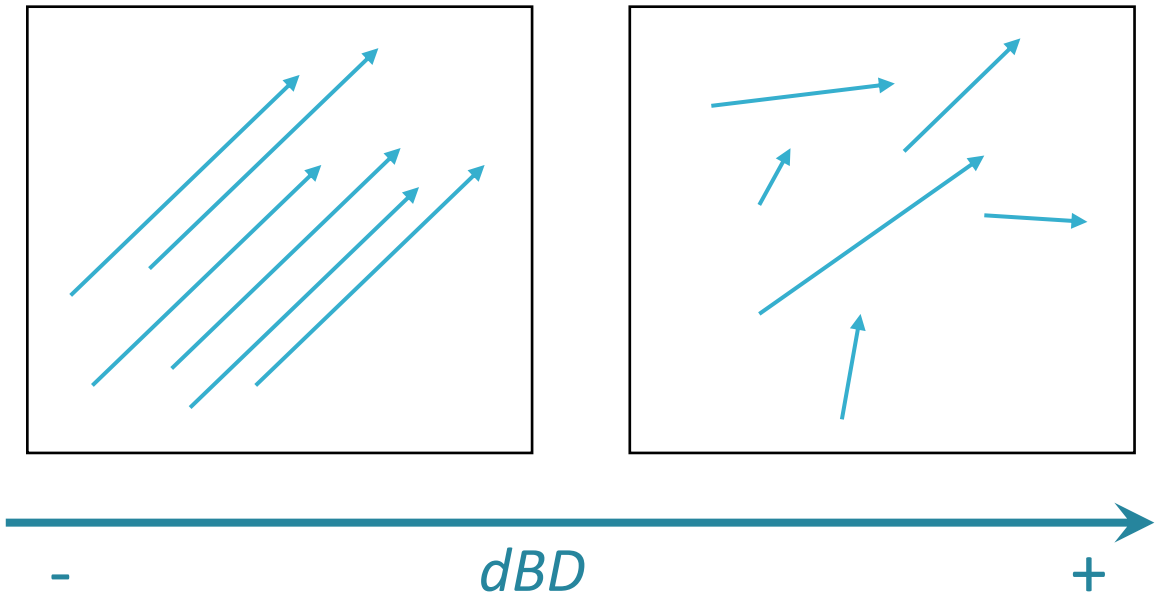


Characterize EDRs

Dynamic beta diversity *(dBD)*

$$dBD = \frac{\sum_{i=1}^{m-1} \sum_{j=i+1}^{m} d_{ij}^2}{m(m-1)}$$

Overall variation of ecological trajectories belonging to the same EDR



Distribution of the trajectories in the EDR

```
# Dynamic dispersion
dDis <- dDis(d = as.matrix(dStates)[ID_EDR, ID_EDR], d.type = "dStates",
             trajectories = abun[ID_EDR]$traj,
             states = abun[ID_EDR]$state,
             reference = 28)
```

Distribution of the trajectories in the EDR

```
# Dynamic dispersion
dDis <- dDis(d = as.matrix(dStates)[ID_EDR, ID_EDR], d.type = "dStates",
             trajectories = abun[ID_EDR]$traj,
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# Dynamic evenness
dEve <- dEve(d = as.matrix(dStates)[ID_EDR, ID_EDR], d.type = "dStates",
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# Dynamic evenness
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           states = abun[ID_EDR]$state)

# Dynamic beta diversity
dBD <- dBD(d = as.matrix(dStates)[ID_EDR, ID_EDR], d.type = "dStates",
           trajectories = abun[ID_EDR]$traj,
           states = abun[ID_EDR]$state)
```

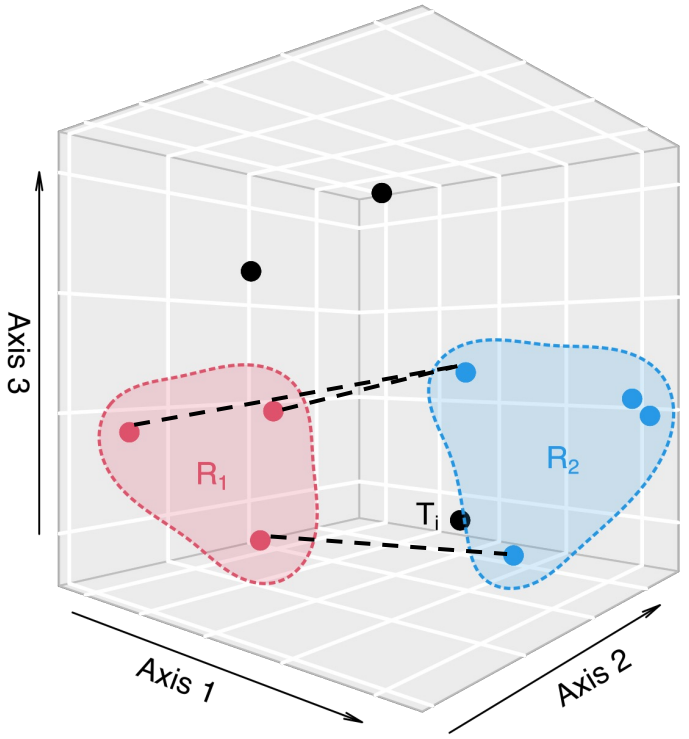
Can we compare multiple EDRs?

Compare EDRs

Dynamic regime dissimilarity (D_{DR})

$$D_{DR}(R_1, R_2) = \frac{1}{m_1}\sum_{i=1}^{m_1} D_{DSP}(T_{1i}, R_2)$$

$$D_{DSP}(T_{1i}, R_2) = \min\{D_{DSP}(T_{1i}, T_{21}), \ldots, D_{DSP}(T_{1i}, T_{2m_2})\}$$



Compare EDRs

```
# Identify EDRs in the abundance matrix
abun <- merge(abun, EDR_cluster, by = "ID", all.x = T)


# EDR dissimilarity
dDR <- dist_edr(d = dStates, d.type = "dStates",
                trajectories = abun$ID,
                states = abun$state,
                edr = abun$EDR_cluster)
```

What are the applications and challenges of the EDR framework?

Applications and challenges

Applications

- ✓ Ecological resilience
- ✓ Ecosystem dynamics
- ✓ Space-for-time substitution

Challenges

- ➢ Trajectory dissimilarity
- ➢ Clustering analyses
- ➢ “Curse of dimensionality”

Coming soon...

- *Ecological dynamic regimes: A key concept for assessing ecological resilience*
  M. Sánchez-Pinillos, V. Dakos, S. Kéfi *(under review)*
- *Resiliencia forestal post-incendio en base a trayectorias sucesionales al nicho climático de las especies*
  G. Codina, E. Batllori, F. Lloret, M. Sánchez-Pinillos *(in progress)*

To know more...

The publication

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ECOLOGICAL SOCIETY OF AMERICA

Ecological dynamic regimes: Identification, characterization, and comparison

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Appendix S2

Ecological Monographs

Ecological Dynamic Regimes:
Identification, characterization, and comparison

Martina Sánchez-Pinillos [1*], Sonia Kéfi [1], Miquel De Cáceres [2], Vasilis Dakos [1]

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Appendix S2. Additional technical information

To know more...

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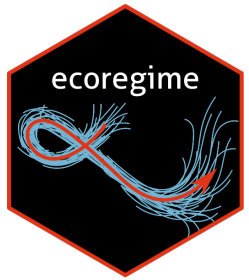
The R package 'ecoregime'



CRAN: https://CRAN.R-project.org/package=ecoregime

Website: https://mspinillos.github.io/ecoregime/

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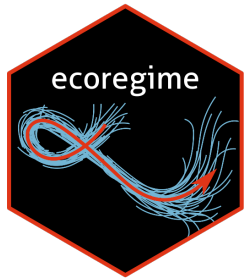

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¡Muchas gracias!

Eskerrik asko!

Moitas grazas!

Moltes gràcies!

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