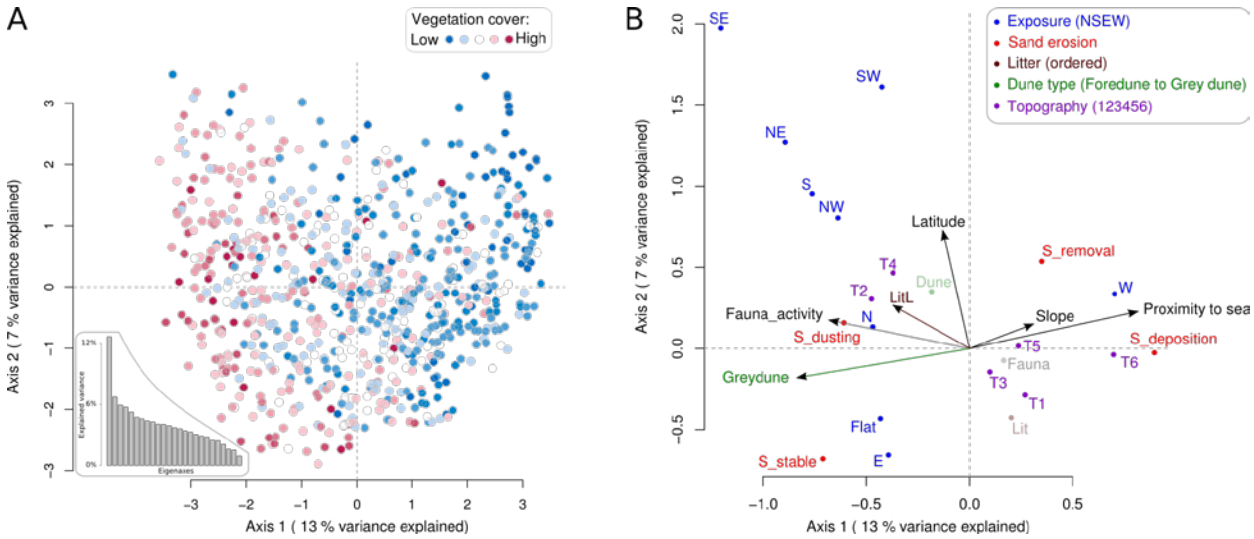
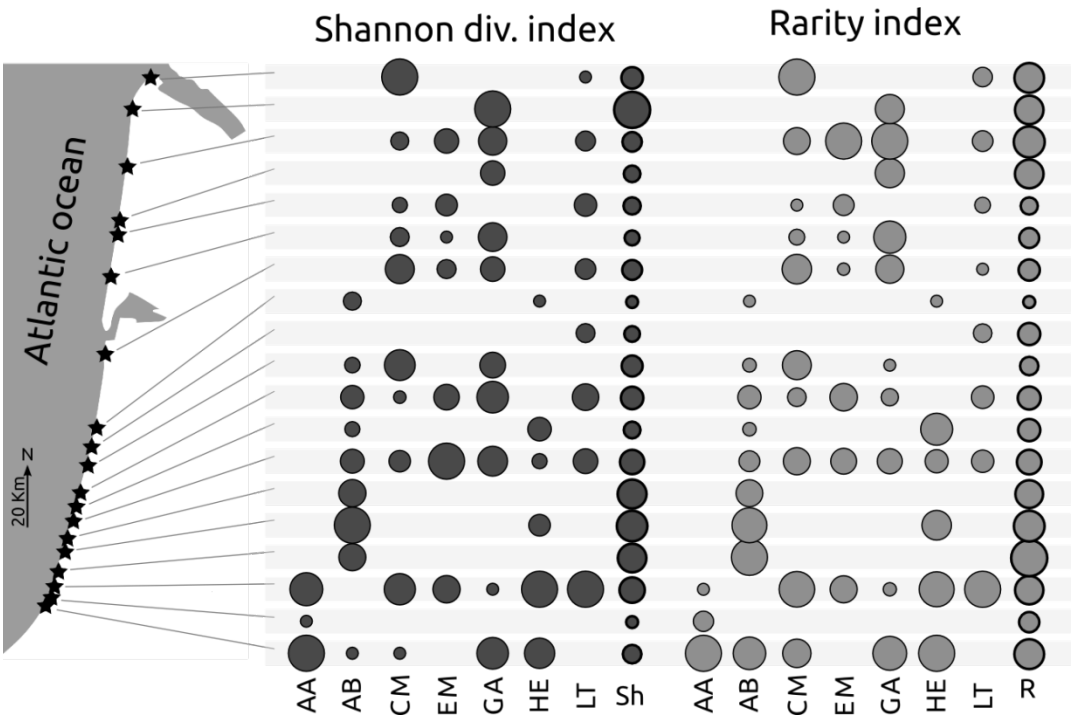
Supplementary materials for:

Parallel declines in species and genetic diversity driven by anthropogenic disturbance: a multi-species approach in a French Atlantic dune system



Supplementary figure S1 Principal Component Analysis of 773 vegetation plots sampled by the French National Forest Office (ONF) characterized for eight habitat descriptors related to natural disturbance in coastal sand dune habitats: (i) dune facies, (ii) exposure, (iii) litter amount, (iv) microtopography, (v) rabbit activity, (vi) ranged distance of sampling plots from forest to ocean (vii), slope and (viii) wind perturbation regime. **A.** Vegetation plots, labeled according to percentage of soil covered by vegetation. Vignette: proportion of variance explained by each eigenaxis. **B.** Environmental descriptors. Note that the first eigenaxis (EIG1) correlated with the natural disturbance gradient, with positive values outlining disturbed plots (closer to ocean, with low vegetation cover) whereas negative values point towards stable areas (located closer to forest with high vegetation cover). In subsequent analyses, EIG1 is used as a proxy of natural habitat disturbance. Note that the linear contribution of latitude to EIG1 is removed before performing analyses presented in the main text. The present PCA is applied on a mixture of quantitative (position of sampling plot, slope), semi-quantitative (dune facies, fauna activity and litter) and qualitative variables (exposure and topography), using methods implemented in the ade4 R CRAN package (“dudi.mix” function). This approach replaces semi-quantitative variables by their orthogonal polynomials (with linear and quadratic components figured as arrows and dots, respectively).



Supplementary figure S2 Genetic diversity estimated by the Shannon index and rarity index along the coastal north-south gradient of seven typical and abundant plant species (AA, *Alyssum loiseleurii*, AB, *Astragalus baionensis*, CM, *Cakile maritima*, EM, *Eryngium maritimum*, GA, *Galium arenarium*, HE, *Hieracium eriophorum*, LT, *Linaria thymifolia*) of the sand dunes of the French Atlantic Coast. Species diversities are averaged at the sampling site level, after being standardized (missing data are ignored). The resulting composite indexes, *Sh* and *R*, are used in the main manuscript as descriptors of habitat genetic diversity. All species except *A. loiseleurii*, *A. baionensis* and *H. eriophorum* are continuously distributed throughout the study region. The latter occur mainly in the southern part, where they are locally abundant (van der Maarel and van der Maarel-Versluys 1996; Favennec 1998).

Supplementary table S1 Species used for genetic analysis (van der Maarel and van der Maarel-Versluys, 1996; Favennec, 1998).

Name	Family	Ploidy	Distribution	Habitat	Life form	Mating system	Pollination	Dispersal
Alyssum loiseleurii P. Fourn.	Brassicaceae	2n = 4x = 32	endemic	grey dune	perennial	?	insect	gravity
Astragalus baionensis Loisel.	Fabaceae	?	endemic	transitional dune	perennial	?	insect	gravity
Cakile maritima Scop.	Brassicaceae	2n = 2x = 18	widespread	foredune	annual	allogamous/autogamous	insect/self	water
Eryngium maritimum L.	Apiaceae	2n = 2x = 16	widespread	white dune	perennial	?	insect	animals/water
Galium arenariu Loisel.	Rubiaceae	2n = 6x = 66	endemic	transitional dune	perennial	?	insect	gravity
Hieracium eriophorum St.-Amans	Asteraceae	2n = 2x = 18	endemic	transitional dune	perennial	allogamous	insect	wind
Linaria thymifolia (Vahl) DC. in Lam. & DC.	Plantaginaceae	?	endemic	White dune/transitional dune	bisannual	?	insect	wind

Supplementary table S3 Proxy data for human disturbance of the coastal sand dunes including resident population census in 2009 (*Pop*), number of housings in 2009 (*Log*), amount of urbanized surface within 10 km coastline in 2006 (*St*) and tourist accommodation capacity in number of beds in 1999 (*Cht*). Data are provided by the French National Sea and Coast Observatory (*Obsérvatoire national de la mèr et du littoral*; ONML; available at http://www.onml.fr/outil-de-cartographie/presentation-de-loutil/)

Postcode	Municipality	Latitude	Pop	Log	St	Cht
33544	Le Verdon-sur-Mer	45.544724	1334	1817	277.9	3621
33514	Soulac-sur-Mer	45.514168	2711	4901	555.76	21076
33193	Grayan-et-l'Hopital	45.445	1174	2383	407.87	15410
33541	Vensac	45.399445	854	690	29.01	2784
33540	Vendays-Montalivet	45.355831	2288	4279	579.93	21830
33300	Naujac-sur-Mer	45.254166	810	576	109.23	3362
33203	Hourtin	45.18528	3001	3361	420.46	15638
33097	Carcans	45.079445	2165	3755	418.62	19972
33214	Lacanau	44.977779	4412	8782	1108.65	38597
33333	Le Porge	44.873055	2428	2130	363.71	7445
33236	Lège-Cap-Ferret	44.797222	7527	10712	1550.55	47312
33009	Arcachon	44.658333	11441	16339	677.88	46202
33529	La Teste-de-Buch	44.632778	24597	15236	3278.75	24039
40046	Biscarrosse	44.395	12163	10207	2240.88	38596
40108	Gastes	44.324722	602	726	222.21	3497
40257	Sainte-Eulalie-en-Born	44.272778	1116	825	71.8	2859
40184	Mimizan	44.201111	7000	7457	942.32	25421
40266	Saint-Julien-en-Born	44.061943	1450	1598	263.81	8302
40157	Lit-et-Mixe	44.033611	1497	1603	286.45	8605
40326	Vielle-Saint-Girons	43.916668	1160	1197	325.08	13092
40187	Moliets-et-Maa	43.849724	888	3277	516.99	12052
40181	Messanges	43.815277	986	1131	234.09	14796
40328	Vieux-Boucau-les-Bains	43.787498	1577	3978	255.58	16608
40310	Soustons	43.75639	7240	5699	653.21	8275
40296	Seignosse	43.690277	3307	6483	554.57	27825

40304	Soorts-Hossegor	43.665833	3668	5134	721.58	15564
40065	Capbreton	43.646389	7864	9859	686.46	32013
40133	Labenne	43.59528	4644	2299	530.99	8739
40209	Ondres	43.562222	4479	2207	329.83	2970
40312	Tarnos	43.540279	11798	5768	982.79	960

Analyses including non-native species

Script S1

```
require(vegan)
CorDecomp = function(Y, X, Z){
  ### Input parameters:
  # Y = two columns matrix (SG and SD)
  # X = environmental predictors of interest
  # Z = confound (a single variable), of which we remove the effect


  ### Output:
  A list containing the following items:
  out$Mainterms = SGDC contributions of the environmental predictors
        (matrix format).
  out$Interactions = SGDC contributions of pairwise interactions of
                        environmental predictors (matrix format, pred1:pred2,
                    pred1:pred3, pred2:pred, etc).
  out$SGDCglobal = Pearson correlation between SG and DC (corresponds to
          sum of out$MainTerms + out$Interactions).
  out$PctDecomp = Summary statistics, showing global contributions (as %)
         of MainTerms, Interactions and Residuals to SGDCglobal.

  ### Script
  # remove confounding effects of Z
  TMP = cbind(Y, X, Z)
  for(i in 1:ncol(TMP)){
    tmp = residuals(lm(TMP[, i] ~ TMP[, ncol(TMP)]))
    TMP[, i] = tmp
    }
  Y = TMP[, 1:ncol(Y)]
  X = TMP[, (ncol(Y) + 1) : (ncol(TMP) - 1)]


  # standardize everything
  Y = decostand(Y, method = "standardize")
  X = decostand(X, method = "standardize")
  Z = decostand(Z, method = "standardize")


  # compute correlation and covariance matrix among predictors
  varsX = apply(X, 2, var)
```

```
covsX = cov(X)
corsY = cor(Y)


# regress Y on each X (multiple regressions)
# retrieve coefficients and residuals out of it
coeffs = NULL
resids = NULL
for(i in 1:2){
  tmp = data.frame(Y = Y[, i], X)
  vars = colnames(tmp)
  form = formula(paste("Y ~", paste(vars[-1], collapse = ' + ' )))
  model = lm(form, data = tmp)
  coeffs = cbind(coeffs, coefficients(model))
  resids = cbind(resids, residuals(model))
  }
coeffs = coeffs[ -1,]

# compute covariance among residuals
covsResid = cov(resids)


# compute contributions of each predictor the the SGDC correlation
Rcontrib = function(i, j, ...){
  sumAB = coeffs[i, 1] * coeffs[j, 2] +  coeffs[j, 1] * coeffs[i, 2]
  covsX[i, j] * sumAB
  }
ix = 1:ncol(X)
pp=outer(ix[-1], ix[-length(ix)], function(ivec, jvec) sapply(seq(along =ivec),
  function(k) {
  i=ivec[k]
  j=jvec[k]
  if (i > j)
  Rcontrib(i, j)
  else NA
  }))
rownames(pp) = colnames(X)[-1]
colnames(pp) = colnames(X)[-ncol(X)]
contribinteraction = pp
```

```
  # produce outputs
  contribpreds = apply(cbind(varsX, coeffs), 1, prod)
  interct = sum(contribinteraction, na.rm = T)
  rsds = cov(resids)[1, 2]
  global = sum(contribpreds) + interct + rsds

  list(MainTerms = data.frame(contribpreds),
       Interactions = contribinteraction,
       Residuals = rsds,
       SGDCglobal = c(global, corsY[1, 2]),
       PctDecomp = round(100 * data.frame(MainTerms = sum(contribpreds),
                         interct,
                         rsds) / global, 2))

   }

### Usage:
# CorDecomp(Y, X, Z)
```

References

Favennec J. 1998. Guide de la flore des dunes littorales non boisées. Éditions sud ouest, Luçon.

Frey, D. J., Haag, C. R., Kozlowski, G., Tison, J.-M., & Mráz, P. (2012). High genetic and morphological diversity despite range contraction in the diploid Hieracium eriophorum (Asteraceae) endemic to the coastal sand dunes of south-west France. Botanical Journal of the Linnean Society, 169(2), 365-377.

Maarel, E. v. d. and M. v. d. Maarel-Versluys. 1996. Distribution and Conservation Status of Littoral Vascular Plant Species along the European Coasts. Journal of Coastal Conservation **2**:73-92