Plant community changes as ecological indicator of seabird colonies' impacts on Mediterranean Islands

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ABSTRACT

The aim of this study is to investigate vegetation changes on small Mediterranean islands under the impact of the drastic expansion of the gull colony, at local scale over eleven years using a set of permanent plots. First, we focused on functional aspects of vegetation in addition to its specific composition with regard to the plant functional types (Raunkiaer growth forms and Grime life strategies) as indicators of vegetation changes. Second, we used STATICO analysis to investigate patterns of change in the relationship between environmental variables and floristic composition. Third, we quantified the changes in the abundance of plant functional types by applying a simple comparison test between the two observation dates. Fourth, we investigated the relationship between vegetation changes (species turnover, plant functional type dynamics, and species richness) and gull density by performing simple linear regression. Our results show that gull density did not evolve equally for all plots. For areas where gull density increased, we recorded ruderalization of the vegetation. Surprisingly, in areas where there was a decrease in gull density, no clear pattern of vegetation change was apparent. We observed a statistically significant increase in the number of plant species due only to the increase in ruderal and stress ruderal and geophyte species. Gull colonies were responsible for high species turnover between 1997 and 2008. The higher the density of gulls, the lower the species number in 1997 and 2008. For high gull nest densities, we observed a high proportion of ruderal plant species and a low proportion of stress tolerant species. Gulls induced an increase of stress-ruderal species. We show that nest density recorded in 1997 is mainly responsible for the changes in vegetation composition, species turnover and proportions of plant functional types. We noted that a decrease in gull nest density does not necessarily induce a return to previous vegetation composition patterns. This may be seen as evidence of the inertial nature of the changes in island vegetation in the face of strong changes in environmental conditions such as the recent drastic expansion of gull colonies. Garbage management policy can have a strong and long-term impact on remote ecosystems.

1. Introduction

Global changes, mainly resulting from human activities, have had a strong negative impact on biodiversity (Vié et al., 2009). The Mediterranean Basin has been designated as one of the 34 world biodiversity hotspots (Mittermeier et al., 2005), because of its very high plant diversity (10% of the world's vascular plants on 1.6% of the Earth's surface) and endemism (50% of the total flora) (Médail and Quézel, 1997). Furthermore, the Mediterranean Basin, with thousands islands and islets (Delanoe et al., 1996), comprises one of the largest groups of islands in the world, and the flora on Mediterranean islands represents an important part of Mediterranean plant diversity as a whole. Even if the Mediterranean Basin has been inhabited by humans since antiquity (Blondel, 2006), human activities have recently reached unprecedented intensity and range, especially in the coastal areas (UNEP/MAP, 2009). However, human activities can also indirectly affect these ecosystems, especially when a biotic factor is altered (Chapin et al., 1997). The recent appearance and strong demographic expansion of seabird colonies on many Mediterranean islands, due to changes in the availability of food resulting from dumping and trawling, is a typical example of the indirect effects of human disturbances (Oro et al., 2004; Duhem et al., 2008). Seabird colonies have a very strong impact on ecosystem functioning and vegetation structure (Ellis, 2005) by affecting nutrient fluxes from marine to terrestrial ecosystems (Anderson and Polis, 1999), changing soil chemistry and vegetation productivity (García et al., 2002; Wait et al., 2005), altering plant population dynamics (Mulder and Keall, 2001; Calviño-Cancela, 2002), improving invasion success of plant species by dispersal (Padrón et al., 2010) or by driving plant species turnover at island

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scale (Vidal et al., 2000). Island scale and long term studies have elucidated general patterns of the effects of seabirds on plants (Ellis, 2005). However, how seabird densities and changes in them may affect the composition and dynamics of plant communities is still poorly understood, especially at very local scale (plot) (Kohn and Walsh, 1994). Furthermore, considering plant communities as an indicator of environmental change, the diachronic investigation of vegetation changes using a permanent plot survey through time offers the means to (i) quantify vegetation changes, (ii) highlight the causes of these changes, and (iii) understand the mechanisms which contribute to the changes (Bakker et al., 1996). These steps offer a basis for hypothesizing on processes driving vegetation changes, and attempting to predict the future pathway of vegetation changes. It also enables us to elucidate possible inertial effects of the presence of seabirds on island vegetation patterns and changes. This short time scale and fine spatial scale method is designed to highlight the heterogeneous nature of changes that cannot be detected at island scale. The use of permanent plots at such a short, fine scale allows investigation of vegetation changes not only on the basis of species richness and vegetation composition, but also of plant functional types which constitute relevant indicators for understanding functional homogenization and predicting their ecological consequences (Olden, 2006).

In this context, we focused on the rapid expansion of colonies of the yellow-legged gull (*Larus michahellis*) on the Marseille archipelagoes and its impact on the island's vegetation. This phenomenon is the result of the availability of anthropogenic resources (i.e. open-air refuse dumps), which account for most of the trophic resources of this seabird species during the last decades (Vidal et al., 1998a; Duhem et al., 2003). Moreover, the Marseille islands exhibit high vascular plant richness (518 plant species on 337 ha) and typical Mediterranean plant species growing within harsh habitats (i.e. hyaline, hydric and wind stress).

Our study aims to explain vegetation changes between two dates (1997 and 2008) relative to gull density patterns and changes in them. We hypothesize that the changes we may expect to observe in island plant communities constitute a relevant indicator of the impact of seabirds on island ecosystems. To test this hypothesis, we have addressed the following questions: (1) are island vegetation patterns and changes in them driven by the presence of gulls and the changes in gull density between 1997 and 2008? (2) Are there relevant changes in species richness and plant functional types such as Grime life strategies (Grime, 1977) and Raunkiaer growth forms (Raunkiaer, 1934)? Finally, (3) are patterns of plant community composition and change surveyed in 1997 and 2008 related to gull density in 1997, in 2008 and/or to the change in density between these two dates?

2. Materials and methods

2.1. Study site

This study was conducted on two limestone archipelagoes near Marseille, in south-east France: the Riou archipelago (43°11′N, 5°21′E) and the Frioul archipelago (43°16′N, 5°18′E) (Fig. 1). These two archipelagoes are natural protected areas managed by the "Conservatoire-Etude des Ecosystèmes de Provence" (CEEP). With mean annual temperatures of 15.6 °C and a mean annual rainfall of *circa* 350 mm (Douguedroit, 1983), these islands have semi-arid climatic conditions and are within the thermo-Mediterranean bioclimatic belt (Quézel and Médail, 2003). They consist mainly of compact limestone, and soil is limited to thin proto rendzina patches (Vidal, 1998). These islands are of great biological interest, the Riou and Frioul archipelagoes harboring high levels of plant species richness. In addition, these plant species are adapted to
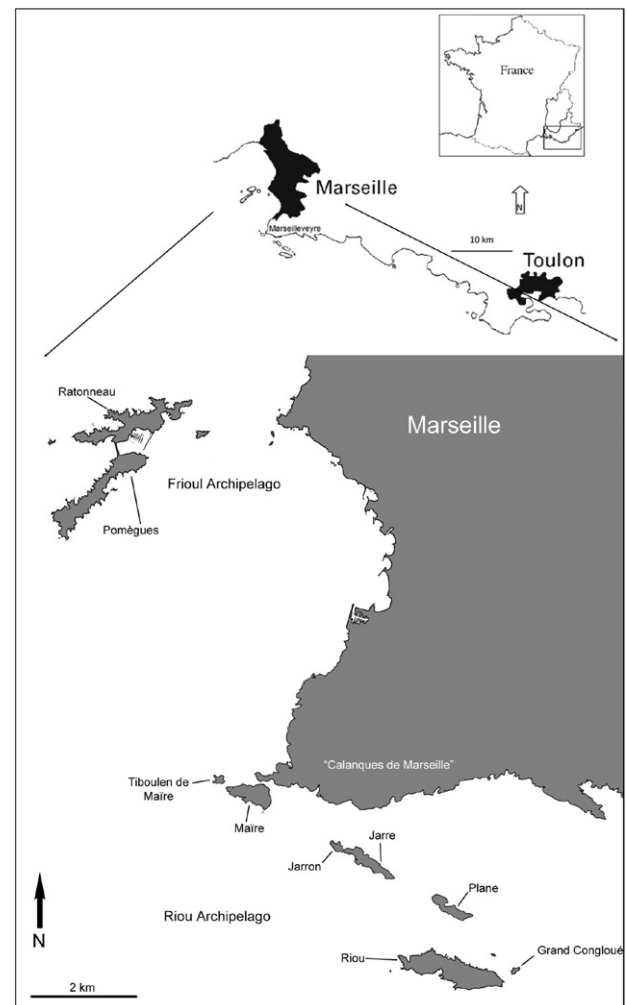

Fig. 1. Location of Frioul and Riou archipelagoes, Marseille, southeast France.

harsh habitats, since they are exposed to severe hyaline, hydric and wind stress. The islands are mainly covered by low vegetation from halophyte plants to mattoral shrub species. Between 1997 and 2008, populations of yellow-legged gulls *L. michahellis* nesting on these islands expanded drastically, showing growth rates ranging from 6% on the Riou archipelago to 177% on the Frioul archipelago (Duhem et al., 2008). This demographic explosion is mainly due to the abundant continental anthropogenic resources available, mainly from open-air refuse dumps (Duhem et al., 2003).

2.2. Sampling design

The vegetation of Marseille islands was first sampled in 1997 using permanent plots of 100 m² arranged on a grid pattern with a square mesh of 500 m. Vascular plant inventories were carried out in 1997 with a set of 171 plots and we performed factorial correspondence analysis (Benzecri, 1973). We clustered plots on the base of plot coordinates on the two first axes of factorial correspondence analysis using Euclidean distance and Ward grouping procedure (Ward, 1963). From the obtained typology, we selected 56 plots in order to represent different vegetation types (Table 1). We obtained a sub-set of 56 plots representative of the whole vegetation structure of the islands (Vidal, 1998). We surveyed this sub-set in both 1997 and 2008 using the same protocol.

We here consider gull nest density per plot as an indicator of gull pressure intensity. Hence, gull nest density was measured according to Bibby et al. (1992) within the 56 circular plots of

Table 1
Data of studied islands of Marseille archipelagoes, and number of plots surveyed in 1997 and 2008.

	Islands	Area (ha)	Distance to continental sea shore (m)	Altitude (m)	Number of plots in our sub-set ($n = 56$)	Number of plots in our initial set ($n = 171$)
Frioul Archipelago	Pomègues	89	2800	86	12	41
	Ratonneau	95	1800	74	13	35
Riou Archipelago	Riou	90.3	3100	190	16	51
	Maïre	27.6	50	141	4	15
	Plane	15	2100	22	3	9
	Jarre	18	800	57	3	11
	Jarron	3	800	33	1	3
	Grand Congloué	2	3525	50	1	3
	Tiboulen de Maïre	2.3	525	47	2	3

$500 \, \text{m}^2$ area. We recorded the number of nests during the egg-laying period in each plot in 1997 and 2008. The environmental variables measured were: elevation above sea level (Alt), distance from the sea shore (Dis) which reflects the amount of salt deposition on the soil surface (Barbour, 1978), slope (Slo), aspect (Exp), and cover rate of each substrate type: rock (Roc), block (Blc) i.e. Ø > 20 cm, stone (Sto) i.e. Ø < 20 cm, bare ground (Bar). The cover variables were estimated on the basis of a semi-quantitative mode using 6 cover classes (0: cover = 0%, 1: 0% < cover < 10%, 2: 10% ≤ cover < 25%, 3: 25% ≤ cover < 50%, 4: 50% ≤ cover < 75%, 5: cover ≥ 75%). The slope was estimated visually and a semi-quantitative value was given using 6 slope categories (0: flat, 1: 0% < slope < 10%, 2: 0% ≤ slope < 25%, 3: 25% ≤ slope < 50%, 4: 50% ≤ slope < 75%, 5: slope ≥ 75%). Two inventories (one in 1997 and one in 2008) were carried out within the 56 concentric plots of $100 \, \text{m}^2$ from April to May. We extracted from the BASECO data base (Gachet et al., 2005) the following easily accessible plant functional types: Raunkiaer growth form (Raunkiaer, 1934) and Grime life strategy (Grime, 1977) for each plant species.

2.3. Data analyses

In order to investigate the relationship between plant communities and environmental variables (including gull factor) through time, the multivariate method STATICO (Dray et al., 2003) was used to analyze simultaneously the three dimensions of our data set: floristic matrix × environmental matrix × time series (Simier et al., 1999). Floristic and environmental matrices of the two dates have identical statistical individuals (rows), i.e. plots. This statistical method is based on Partial Triadic Analysis of K-tables developed by Thioulouse and Chessel (1987) combined with a co-inertia analysis (Dolédec and Chessel, 1994). The first step of this analysis is to perform co-inertia analysis on the two first dimensions (i.e. floristic matrix and environment matrix) for each date. The aim of co-inertia analysis is to find co-inertia axes which maximize covariance between row coordinates (plots) of environment and species matrices. The significance of the co-inertia was tested using Monte Carlo permutation procedure with $n = 999$ permutations. In a second step, a compromise analysis between the two dates was performed which allows the projection of the image of the mean species–environment co-structure. Finally, this multivariate analysis allows the description of the trends for changes in the plots regarding environmental variables (including gull factor) and plant species composition.

In order to quantify changes in vegetation communities, we compared mean total number of species and mean number of each Raunkier growth form and Grime life strategy within the 56 plots between 1997 and 2008. For this, we applied unilateral student test on paired samples. For each plot, we clustered species into one of the six Raunkiaer growth forms (T: therophyte, H: hémicryptophyte, G: geophyte, CH: chamaephyte and NP: nano-phanerophyte) and the six Grime life strategies (S: stress tolerant

species, R: ruderal species, RS: ruderal-stress tolerant species, SR: stress tolerant-ruderal species, SC: stress tolerant-competitive species and CS: competitive-stress tolerant species). The number of species, Raunkiaer growth forms and Grime life strategies were square-root transformed prior to analysis (Gotteli and Ellison, 2004).

We used simple linear regressions to test the statistical relationship between response variables (i.e. species turnover, number of species in 1997 and 2008, changes in species number, changes of the proportion of each plant functional type, and the proportion of each plant functional type in 1997 and in 2008) and predictive variables (i.e. gull nest density in 1997 and in 2008). Only response variables measured in 2008 were confronted with gull nest density measured in 2008. Species turnover "Sr" was calculated regarding to the Morrison (1997; Gotteli and Ellison, 2004) annual relative turnover equation as $Sr \, (\% \, \text{year}^{-1}) = 100 \times [(I + E)/(S1 + S2) \times t]$, where I is the number of new immigrant species only present in the second date survey (2008 in our case), E is the number of extinct species only present in the first date survey (1997 in our case), and $S1$ and $S2$ correspond to the total number of species on the first (1997) and the second date respectively (2008). The t term corresponds to the number of years elapsed between two censuses. The change of species number was expressed in percent in order to avoid the effect of the total number of species on the regression analysis.

All statistical analyses were carried out with R software (R Development Core Team, 2010) and null hypotheses were rejected when p-value was inferior to 0.05.

3. Results

3.1. Vegetation structure in relation to environmental variables and gull density between 1997 and 2008

STATICO analysis showed a statistically significant co-structure between descriptors and vegetation communities (RV = 0.29, $p = 0.001$, $n = 999$ permutations) explaining 57.66% of the total variability on the two first axes (34.96% and 22.70% respectively) (Figs. 2 and 3). Concerning environmental variables and gull nest densities, we observed that gull nest density was a contributive factor (Fig. 2A) as it was significantly correlated to the first axis (simple linear regression, $r = 0.434$, $p < 0.001$). The second axis of the STATICO analysis represented exposure and substratum gradient from plots at low altitude with steep slope and high exposure values to high altitude plots on flat ground mainly covered by stones and/or rocks. A shift along the nest density gradient characterized changes in plots between 1997 and 2008 (Fig. 2A and B). However, not all plots took the same direction in terms of changes in nest density. Most plots in the Riou archipelago in 1997 (i.e. black dots) showed high nest density values that drastically decreased between 1997 and 2008 (i.e. grey dots corresponding to same Riou archipelago plot in 2008, Fig. 2B). In contrast, most
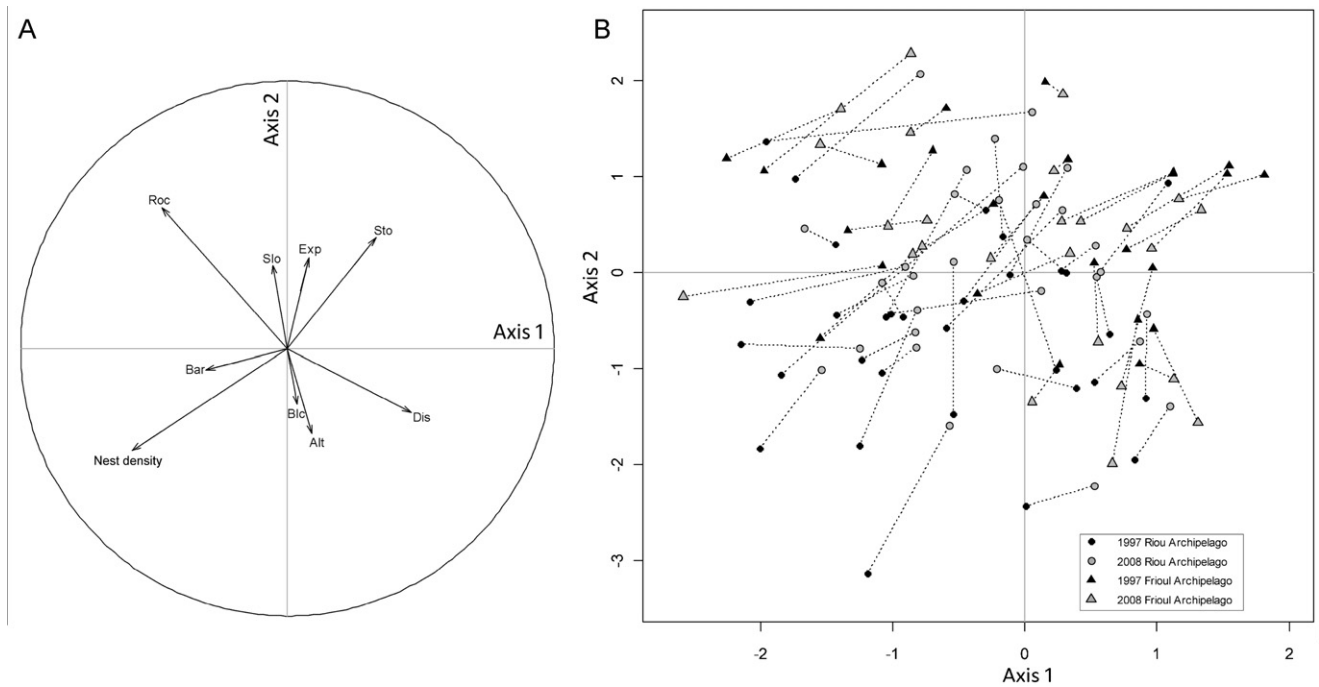
Fig. 2. Results from STATICO analysis of environmental patterns and the patterns of change in plots along environmental gradient between 1997 and 2008. (A) Correlation circle of the compromise of environmental factors and gull density recorded in 1997 and 2008, i.e. "Nest density". For environmental variables: "Roc" = rock cover, "Blc" = bloc cover, "Sto" = stone cover, "Bar" = bare ground cover, "Exp" = exposure, "Slo" = slope, "Alt" = altitude above sea level, "Dis" = distance to seashore. (B) Biplot based on STATICO analysis representing island plot patterns of change (dashed lines) regarding environmental variables between 1997 (black symbols) and 2008 (grey symbols). Each plot is clustered into one of the archipelagoes (dots for Riou and triangles Frioul archipelagoes).

plots in the Frioul archipelago in 1997 (black triangles) showed low nest density values. However, they showed an increase in nest density between 1997 and 2008 (grey triangles, Fig. 2B). This observation was confirmed by the strong negative correlation between changes in gull nest density and initial nest density recorded in 1997 ($r = 0.67$, beta = 0.76, $p < 0.001$). Hence, plots with high gull nest density in 1997 showed a marked decrease of nest density and inversely, plots with low nest density in 1997 showed an increase in nest density. Regarding vegetation structure, the STATICO analysis discriminated four main groups of plant species (Fig. 3). The first axis of the STATICO diagram (Fig. 3A) corresponded to the salinity gradient inducing a floristic gradient from shrub species far from the seashore (e.g. *Thymus vulgaris*: "Thyvul", *Helichrysum stoechas*: "Helsto", and *Teucrium flavum*: "Teufla" on the positive side of axis
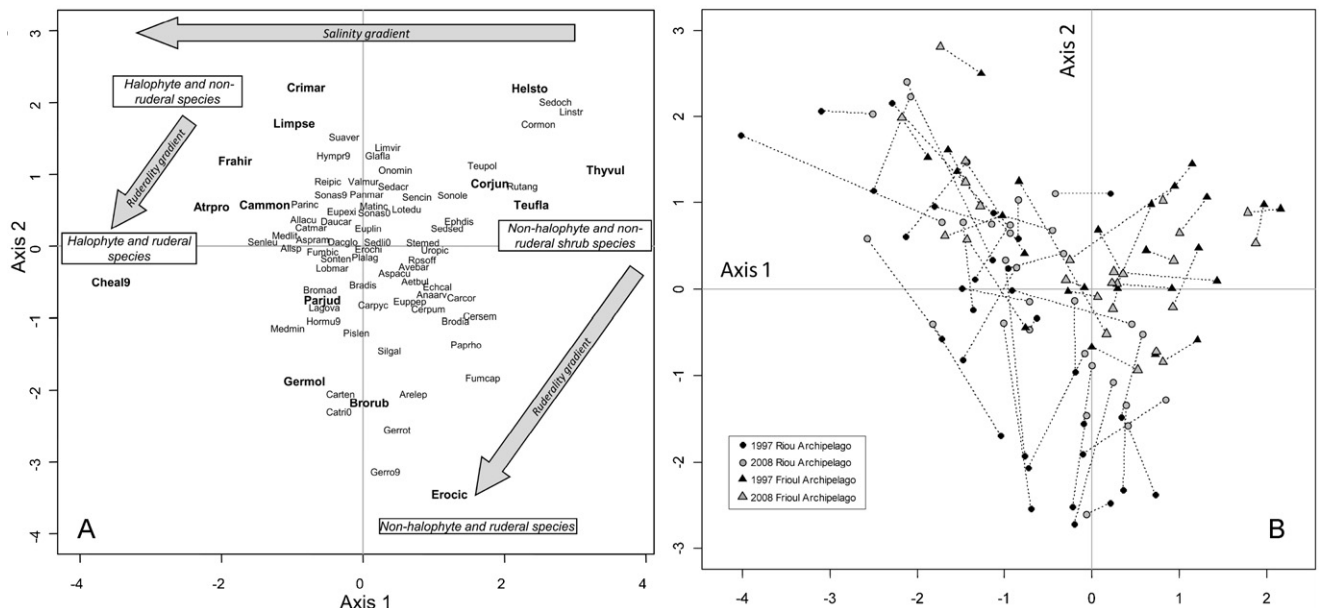

Fig. 3. Results from STATICO analysis of vegetation patterns affected by environmental variables. (A) Positions of plant species on the two first axes of STATICO analysis based on compromise, i.e. the position of each species corresponds to its mean position between 1997 and 2008 (bold species are quoted in the text, for species not quoted in the text, see Appendix A). (B) Biplot based on STATICO analysis representing island plot patterns of change (dashed lines) regarding plant species composition between 1997 (black symbols) and 2008 (grey symbols). Each plot is clustered into one of the archipelagoes (dots for Riou and triangles for Frioul archipelagoes).

1) to halophytes species (e.g. *Atriplex prostrata*: "Atrpro", *Frankenia hirsute*: "Frahir", and *Limonium pseudominutum*: "Limpse" on the negative side of axis 1) growing under salty and dry conditions. However, vegetation was also structured along a ruderal gradient from non-ruderal species (e.g. *Coronilla juncea*: "Corjun" and *T. vulgaris*: "Thyvul") or non-ruderal halophyte species (e.g. *L. pseudominutum*: "Limpse" and *Crithmum maritimum*: "Crimar") to non-halophyte ruderal shrub species (e.g. *Geranium molle*: "Germol", and *Parietaria judaica*: "Parjud") or ruderal halophyte species (e.g. *Chenopodium album*: "Cheal9", and *A. prostrata*: "Atrpro") (Fig. 3A). We noted that this ruderal gradient had the same orientation as the gull nest density gradient previously cited (see Fig. 2A). In contrast to changes in nest density values between 1997 and 2008 (Fig. 2A and B), patterns of vegetation shift were not as clearly marked (Fig. 3A and B). However, there was a strong shift in vegetation composition concerning Frioul archipelago plots, especially on the positive side of the first axis (Fig. 3B). Frioul archipelago 1997 plots (black triangles) that correspond to non-ruderal shrub-like vegetation, shifted toward more ruderal plant communities (grey triangles). This is not the case for the Riou archipelago (black dots, Fig. 3B) for which the direction is perpendicular to the ruderal gradient.

3.2. Quantification of vegetation changes

Results showed a statistically significant increase regarding change of species number within plots (Table 2). Concerning the dynamics of Grime life strategies, ruderal species had significantly increased between 1997 and 2008, especially for stress-ruderal species "SR". Likewise, the Raunkiaer growth forms showed a statistically significant increase in annual, hemicryptophyte and geophyte species (Table 2). We observed a decrease in species number only for chamaephytes species. Hence, our results showed that shrub or arboreal perennial species ("NP" and "H"), generally stress-competitive or competitive species, do not show any statistically significant change between 1997 and 2008.

3.3. Effects of gull nest density on vegetation changes

Results showed that only gull nest density recorded in 1997 has a statistically significant effect on turnover, species richness recorded in both years, and changes in the proportion of plant functional types except for ruderal species "R" and stress tolerant species "S" (Table 3). We choose here to present only statistically significant and relevant correlations between vegetation changes and gull density (Table 3). We did not take into account changes in the gull nest density since there is a strong negative correlation with gull nest density measured in 1997 ($r = -0.67$, beta = 0.76, p-value < 0.001) and we assumed that the first causal variable responsible for vegetation changes is the initial gull nest density recorded in 1997. Gull nest density in 1997 had a positive effect on turnover, in contrast to the number of species within plots in 1997 and 2008 that significantly decreased when gull nest density increased. Concerning plant functional types, high gull nest density favored ruderal species "RC" and "R" in contrast to stress tolerant species "CS" and "S" (Table 3). We note that gull nest density recorded in 2008 had an effect on the proportion of plant functional traits recorded in 2008, i.e. ruderal species and stress tolerant species ("R" and "S" Grime life strategies), which corresponds to non-competitive species. Furthermore, gull nest density recorded in 1997 had an effect on the proportion of Grime life strategies measured in 1997: competitive-stress tolerant species "CS" and ruderal-competitive species "RC" (Table 3). Finally, regarding the changes in plant functional types, gull nest density in 1997 only

Table 2

Results of comparisons of number of plant species into plot, Grime life strategies and Raunkiaer growth forms between 1997 and 2008. One sided paired samples Student test, $\alpha = 0.05$. ***p-value < 0.001; **p-value < 0.01; *p-value < 0.05; ns: non-significant, Sd: standard deviation; Df: degree of freedom. For student test, numbers are square-rooted. Raunkiaer growth forms (T: therophyte, H: hémicryptophyte, G: geophyte, CH: chamaephyte and NP: nanophanerophyte). Grime life strategies (S: stress tolerant species, R: ruderal species, RS: ruderal-stress tolerant species, SR: stress tolerant-ruderal species, SC: stress tolerant-competitive species and CS: competitive-stress tolerant species).

		Total species number in 1997 and 2008	Dynamics	T	p-Value	Mean plot species number in 1997 ± Sd	Mean plot species number in 2008 ± Sd	Df
Species number		163/176	+	5.70	<0.001	18.57 ± 10.67	24.02 ± 12.68	55
		Species number	Dynamics	T	p-Value	Mean plot number in 1997 ± Sd	Mean plot number in 2008 ± Sd	Df
Grime life strategies	SR	73	+	7.69	<0.001	6.48 ± 4.06	9.75 ± 4.68	55
	R	21	+	4.04	<0.001	0.67 ± 0.79	1.32 ± 1.05	55
	RS	31	+	2.53	0.007	3.36 ± 2.45	4.61 ± 3.63	55
	SC	34	±	0.71	ns	2.80 ± 2.73	3.00 ± 2.70	55
	S	56	±	0.20	ns	2.77 ± 2.50	2.75 ± 2.21	55
	CS	16	±	−0.98	ns	0.86 ± 1.02	0.80 ± 1.10	55
Raunkiaer growth forms	T	92	+	5.80	<0.001	5.86 ± 4.11	10.34 ± 6.53	55
	G	20	+	2.87	0.003	0.93 ± 1.16	1.45 ± 1.44	55
	CH	53	−	−2.26	0.014	5.11 ± 3.13	4.41 ± 2.85	55
	H	30	±	1.12	ns	1.75 ± 1.42	2.02 ± 1.48	55
	NP	12	±	0.94	ns	1.04 ± 1.13	1.11 ± 1.09	55

Table 3
Results of simple regressions of the effect of gull colonies on vegetation changes. Grime life strategies (SR: stress tolerant-ruderal species, CS: competitive and stress tolerant species, RC: ruderal and competitive species, R: ruderal species, S: stress tolerant species).

Response variables		Predictors	Beta	Standard error	t-Value	p-Value	Adjusted R^2
Turnover (Sr)		Gull nest density in 1997	0.193	0.050	3.884	<0.001	0.204
Species richness	Number of species in 1997	Gull nest density in 1997	−2.034	0.335	−6.069	<0.001	0.395
	Number of species in 2008	Gull nest density in 1997	−2.082	0.432	−4.817	<0.001	0.288
Proportion of plant	Proportion of CS species in 1997	Gull nest density in 1997	−0.508	0.167	−3.038	0.004	0.130
functional types in	Proportion of RC species in 1997	Gull nest density in 1997	0.724	0.222	3.256	0.002	0.149
1997 and 2008	Proportion of R species in 2008	Gull nest density in 2008	1.272	0.386	3.301	0.002	0.153
	Proportion of S species in 2008	Gull nest density in 2008	−1.341	0.498	−2.694	0.009	0.102
Change of plant functional types	Change of the proportion of SR species	Gull nest density in 1997	20.203	6.039	3.346	0.002	0.156

had a positive effect on changes in the proportion of stress tolerant-ruderal species "SR" (Table 3).

4. Discussion

4.1. Gull colonies drive vegetation structure and plant community shifts

STATICO analysis showed that gull nest density is among the most strongly structuring factors with distance to seashore, which constitutes a gradient of salinity stress and substratum type. The results of this multivariate analysis showed that gull colonies structured the plant communities of Riou and Frioul archipelagoes even if they were not exposed to the same gull colonies pressure over time. *L. michahellis* first colonized Riou archipelago where 100 breeding pairs in eastern Riou islands were recorded in 1920. In contrast, Frioul archipelago had about 300 breeding pairs in 1980 (Vidal, 1998). Moreover, the nest-density distribution pattern is quite variable among islands because it was demonstrated that as distance from the first colony location increases, gull density significantly decreases (Vidal et al., 2001). Hence, Riou and Frioul archipelagoes did not undergo the same gull pressure since the appearance of the first gull breeding pairs on the islands. The gull population growth rate in Riou archipelago is lower than that of Frioul archipelago which suggests that Riou archipelago gull colonies are saturated in contrast to Frioul archipelago. STATICO analysis showed a decrease in gull nest density for most plots on the islands of Riou archipelago in contrast to Frioul archipelago plots where gull nest density increases (Fig. 2). Vidal et al. (1998b) show that, among other nitrophilous species, gulls favor the development of *Lavatera arborea*. Borboroglu and Yorio (2004) demonstrated that gulls avoid habitats with vegetation cover too high for breeding. Hence, on Riou archipelago, vegetation changes reached such a level that locally abundant *L. arborea* was so high that it constrained gulls to move their breeding sites to Frioul archipelago.

According to previous studies (see Ellis, 2005), our results showed that seabird colonies have a strong impact on various ecological compartments, including island vegetation structure. Investigations of the pattern of vegetation changes using STATICO analysis is more difficult to interpret because surprisingly, vegetation communities in plots where nest density decreased did not necessarily return to less gull-impacted vegetation communities. Vegetation within plots with high nest density in 1997 shifted along a salinity gradient rather than a ruderal gradient due to expansion of gull colonies. In contrast, plots with low gull nest density in 1997 shifted toward more ruderal vegetation communities linked to a recent increase in nest density.

4.2. Species enrichment and ruderalization of island plant communities

The results of the comparisons of plot species number and plant functional types showed an increase in the number of species between 1997 and 2008. We recorded 34 plant extinctions and 47 plant immigrations. Species enrichment is mainly due to the increase of ruderal and stress ruderal species such as of therophyte and geophytes species. Hence, it seems that species with high tolerance to disturbances occurring in harsh habitat have been favored since 1997. In contrast, chamaephyte species showed a significant decrease between 1997 and 2008. This statement is important for conservation as patrimonial and/or protected plant species on the Marseille archipelagoes are chamaephytes and specialists (e.g. *Astragalus tragacantha*, *Plantago subulata*, *L. pseudominutum*, *Helianthemum syriacum*, *Euphorbia pithyusa*).

4.3. Gull colonies affecting vegetation turnover, species enrichment and plant functional type proportions and dynamics

Gull nest density has a positive effect on species turnover and species richness. When initial vegetation under oligotrophic conditions undergoes soil enrichment, we observed an increase in species number. This confirms that an alteration of a biotic variable can lead to species enrichment (Ellis, 2005). Gull nest density favors species turnover as the presence of breeding pairs induces changes in environmental conditions, in particular by removing the original vegetation or soil conditions (Bancroft et al., 2005; Wait et al., 2005). This local environmental change leads to the establishment of new species that may have already colonized the island but are not yet established everywhere. Our results underline the inertial nature of the impact of gull presence on vegetation changes and functional composition.

4.4. Conclusion

Our work shows the relevance of the use of plant functional types as an indicator of changes occurring at community level within the context of global change. Although Oro and Martínez Abraín (2007) showed that the effects of yellow-legged gulls on other syntopic bird species are limited, our work reveals their negative impact on the island vegetation. Gull colonies have become one of the most strongly structuring factors of island vegetation and its patterns of change. Typical island Mediterranean seabirds are hypogeous (Zotier et al., 1999) while *Larus* species are typical of coastal habitats such as estuarine marshes. Hence shearwaters and storm-petrels have little impact on the vegetation cover (Gillham, 1961), especially for limestone islands where they breed in rocky cliff cavities and cannot have an strong impact on vegetation. On the contrary, *L. michahellis* builds its nest directly on the soil surface and alters soil conditions and vegetation.

Classical methods used on the Marseille islands to reduce the rapid demographic expansion of gulls have not been effective (Bosch et al., 2000). Nevertheless, one of the biggest open-air refuse dumps close to Marseille was closed in 2010 and recent surveys of gull demography indicate a decrease in gull number. It has been assumed that the closing of the Marseille open air refuse dump would induce a dramatic decrease in the gull population, as shown

by Cadiou and Yésou (2006) for *Larus* spp. colonies of the French Brittany islands.

We showed that using a local scale and short time method makes it possible to observe changes that could not have been detectable at island scale. We also highlighted the inertial aspect of ecological processes and the fact that even if the disturbing factor decreases in intensity, ecosystem changes do not necessarily return to the initial state. Finally, in the context of global change and biodiversity erosion, garbage management policy can have a profound impact on remote ecosystems presenting high ecological value in terms of biodiversity.

Appendix A. Species codes and their complete names according to Brisse and Kerguélen (1994)

Code	Species complete name	Code	Species complete name	Code	Species complete name	Code	Species complete name
Aegova	*Aegilops ovata*	Daucar	*Daucus carota*	Limvir	*Limonium virgatum*	Solnig	*Solanum nigrum*
Aetbul	*Aetheorhiza bulbosa*	Diasyl	*Dianthus sylvestris*	Linstr	*Linum strictum*	Sonas0	*Sonchus asper* subsp. *asper*
Allacu	*Allium acutiflorum*	Dipmur	*Diplotaxis muralis*	Linsup	*Linaria supina*	Sonas9	*Sonchus asper* subsp. *glaucescens*
Allcom	*Allium commutatum*	Ditvis	*Dittrichia viscosa*	Lobmar	*Lobularia maritima*	Sonole	*Sonchus oleraceus*
Allole	*Allium oleraceum*	Dorpen	*Dorycnium pentaphyllum*	Lonimp	*Lonicera implexa*	Sonten	*Sonchus tenerrimus*
Allsp	*Allium sp.*	Ecbela	*Ecballium elaterium*	Lotcyt	*Lotus cytisoides*	Sperub	*Spergularia rubra*
Allsph	*Allium sphaerocephalon*	Echasp	*Echium asperimum*	Lotedu	*Lotus edulis*	Stabra	*Stachys brachyclada*
Ameova	*Amelanchier ovalis*	Echcal	*Echium calycinum*	Malpar	*Malva parviflora*	Stadub	*Staehelina dubia*
Anaarv	*Anagallis arvensis*	Echrit	*Echinops ritro*	Malsyl	*Malva sylvestris*	Stemed	*Stellaria media*
Antsec	*Anthemis secundiramea*	Echvu9	*Echium vulgare* subsp. *pustulatum*	Matinc	*Matthiola incana*	Stioff	*Stipa offneri*
Antvul	*Anthyllis vulneraria*	Ephdis	*Ephedra distachya*	Medarb	*Medicago arborea*	Suaspi	*Suaeda spicata*
Aphmon	*Aphyllantes monspeliensis*	Erimul	*Erica multiflora*	Medlit	*Medicago littoralis*	Suaver	*Suaeda vera*
Arelep	*Arenaria leptoclados*	Erochi	*Erodium chium*	Medmin	*Medicago minima*	Tamcom	*Tamus communis*
Argzan	*Argyrolobium zanonii*	Erocic	*Erodium ciconium*	Nardub	*Narcissus dubius*	Teuaur	*Teucrium aureum*
Aripis	*Aristolochia pistolochia*	Eromal	*Erodium malacoides*	Odolut	*Odontites luteus*	Teucha	*Teucrium chamaedrys*
Arivul	*Arisarum vulgare*	Erover	*Erophila verna*	Onomin	*Ononis minutissima*	Teufla	*Teucrium flavum*
Arrela	*Arrhenatherum elatius*	Erycam	*Eryngium campestre*	Onorec	*Ononis reclinata*	Teupol	*Teucrium polium*
Artca9	*Artemisia caerulescens* subsp. *gallica*	Eupcha	*Euphorbia characias*	Ophfus	*Ophrys fusca*	Thyta0	*Thymelaea tartonraira* subsp. *tartonraira*
Artmac	*Arthrocnemum macrostachyum*	Eupexi	*Euphorbia exigua*	Orovar	*Orobanche variegata*	Thyvul	*Thymus vulgaris*
Aspacu	*Asparagus acutifolius*	Euphel	*Euphorbia helioscopia*	Panmar	*Pancratium maritimum*	Trapo9	*Tragopogon porrifolius* subsp. *australis*
Aspaes	*Asphodelus aestivus*	Euplin	*Euphorbia linifolia*	Paprho	*Papaver rhoeas*	Triglc	*Trinia glauca*
Aspfis	*Asphodelus fistulosus*	Euppep	*Euphorbia peplus*	Papsom	*Papaver somniferum*	Trimon	*Trigonella monspeliaca*
Aspram	*Asphodelus ramosus*	Euppit	*Euphorbia pithyusa*	Parinc	*Parapholis incurva*	Trisca	*Trifolium scabrum*
Asprut	*Asplenium ruta-muraria*	Eupsul	*Euphorbia sulcata*	Parjud	*Parietaria judaica*	Triste	*Trifolium stellatum*
Asptri	*Asplenium trichomanes*	Eupten	*Euphorbia tenufolia*	Phamin	*Phalaris minor*	Umbrup	*Umbelicus rupestris*
Astaqu	*Nauplius aquaticus*	Evapyg	*Evax pygmea*	Phasor	*Phagnalon sordidum*	Urodal	*Urospermum daleschampii*
Astlin	*Asterolinon linum-stellatum*	Fesovi	*Festuca ovina*	Phiang	*Phillyrea angustifolia*	Uropic	*Urospermum picroides*
Astmar	*Asteriscus maritimus*	Foevu9	*Foeniculum vulgare* subsp. *piperitum*	Philat	*Phillyrea latifolia*	Urture	*Urtica urens*
Asttra	*Astragalus tragacantha*	Frahir	*Frankenia hirsuta*	Pinhal	*Pinus halepensis*	Valmur	*Valantia muralis*
Atrhal	*Atriplex halimus*	Frapul	*Frankenia pulverulenta*	Pipcae	*Piptatherum* subsp. *caerulescens*	Vinhir	*Vincetoxicum hirundinaria*
Atrpro	*Atriplex prostrata*	Fumbic	*Fumaria bicolor*	Pipmil	*Piptatherum miliaceum*		
Avebar	*Avena barbata*	Fumcap	*Fumaria capreolata*	Pislen	*Pistacia lentiscus*		
Avebro	*Avenula bromoides*	Fumer9	*Fumana ericoides* subsp. *montana*	Pister	*Pistacia terebinthus*		
Betvul	*Beta vulgaris*	Fumlae	*Fumana laevipes*	Placor	*Plantago coronopus*		
Bislae	*Biscutella laevigata*	Fumsp	*Fumana sp.*	Plalag	*Plantago lagopus*		
Bradis	*Brachypodium distachyon*	Fumthy	*Fumana thymifolia*	Plasub	*Plantago subulata*		
Braret	*Brachypodium retusum*	Galapa	*Galium aparine*	Poaann	*Poa annua*		
Brodia	*Bromus diandrus*	Galcor	*Galium corrudifolium*	Poainf	*Poa infirma*		
Bromad	*Bromus madritensis*	Galgr	*Galium gr.*	Poltet	*Polycarpon tetraphyllum*		
Brorub	*Bromus rubens*	Galmur	*Galium murale*	Porole	*Portulaca oleracea*		
Broste	*Bromus sterilis*	Gaufra	*Gaudinia fragilis*	Quecoc	*Quercus coccifera*		
Bupbal	*Bupleurum baldense*	Germol	*Geranium molle*	Queile	*Quercus ilex*		

Code	Species complete name	Code	Species complete name	Code	Species complete name	Code	Species complete name
Calarv	*Calendula arvensis*	Gerro9	*Geranium robertianum* subsp. *purpureum*	Raprug	*Rapistrum rugosum*		
Cammon	*Camphorosma monspeliaca*	Gerrot	*Geranium rotundifolium*	Reipic	*Reichardia picroides*		
Capbur	*Capsella bursa-pastoris*	Glafla	*Glaucium flavum*	Resalb	*Reseda alba*		
Carcor	*Carlina corymbosa*	Gloaly	*Globularia alypum*	Rhaala	*Rhamnus alaternus*		
Cardis	*Carex distachya*	Gouare	*Gouffeia arenarioides*	Rhaste	*Rhagadiolus stellatus*		
Cardra	*Cardaria draba*	Halpor	*Halimione portulaccoides*	Rhucor	*Rhus coriaria*		
Carha0	*Carex halleriana* subsp. *halleriana*	Hedcre	*Hedypnois cretica*	Rosoff	*Rosmarinus officinalis*		
Carlan	*Carthamus lanatus*	Hedrha	*Hedypnois rhagadioloides*	Rubper	*Rubia peregrina*		
Carpyc	*Carduus pycnocephalus*	Helape	*Helianthemum apenninum*	Rumint	*Rumex intermedius*		
Carten	*Carduus tenuiflorus*	Heleur	*Heliotropium europaeum*	Rusacu	*Ruscus aculeatus*		
Catmar	*Catapodium marinum*	Heloel	*Helianthemum oelandicum*	Rutang	*Ruta angustifolia*		
Catri0	*Catapodium rigidum* subsp. *rigidum*	Helpil	*Helianthemum pilosum*	Sagmar	*Sagina maritima*		
Cencal	*Centaurea calcitrapa*	Helsto	*Helichrysum stoechas*	Sarfru	*Sarcocornia fructicosa*		
Cenmel	*Centaurea melitensis*	Helsyr	*Helianthemum syriacum*	Scomur	*Scorpiurus muricatus*		
Cenrub	*Centranthus ruber*	Hormu9	*Hordeum murinum* subsp. *leporinum*	Sedacr	*Sedum acre*		
Cepleu	*Cephalaria leucantha*	Horpet	*Hornungia petraea*	Sedalb	*Sedum album*		
Cerarv	*Cerastium arvense*	Hympr9	*Hymenolobus procumbens* subsp. *revelieri*	Sedcae	*Sedum caespitosum*		
Cerpum	*Cerastium pumilum*	Hyoalb	*Hyoscyamus albus*	Seddas	*Sedum dasyphyllum*		
Cersem	*Cerastium semidecandrum*	Hyorad	*Hyoseris radiata*	Sedli0	*Sedum litoreum litoreum*		
Cheal9	*Chenopodium album* subsp. *opulifolium*	Ibestr	*Iberis stricta*	Sedoch	*Sedum ochroleucum*		
Cheint	*Cheirolophus intybaceus*	Inucr9	*Inula crithmoides* subsp. *mediterranea*	Sedsed	*Sedum sediforme*		
Chemur	*Chenopodium murale*	Irilut	*Iris lutescens*	Sencin	*Senecio cineraria*		
Cherub	*Chenopodium rubrum*	Junoxy	*Juniperus oxycedrus*	Senleu	*Senecio leucanthemifolius*		
Cisalb	*Cistus albidus*	Junpho	*Juniperus phoenicea*	Senvul	*Senecio vulgaris*		
Cismon	*Cistus monspeliensis*	Lacper	*Lactuca perennis*	Sidrom	*Sideritis romana*		
Cissal	*Cistus salviifolius*	Lagova	*Lagurus ovatus*	Silgal	*Silene gallica*		
Clefla	*Clematis flammula*	Lamamp	*Lamium amplexicaule*	Silita	*Silene italica*		
Corjun	*Coronilla juncea*	Lampur	*Lamium purpureum*	Silmar	*Silybum marianum*		
Cormon	*Coris monspeliensis*	Lasgal	*Laserpitium gallicum*	Silsed	*Silene sedoides*		
Cresan	*Crepis sancta*	Lavarb	*Lavatera arborea*	Sisiri	*Sisymbrium irio*		
Crimar	*Crithmum maritimum*	Lavlat	*Lavandula latifolia*	Sisrun	*Sisymbrium runcinatum*		

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