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IMPACT OF GULL COLONIES ON THE FLORA OF THE RIOU ARCHIPELAGO (MEDITERRANEAN ISLANDS OF SOUTH-EAST FRANCE)

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Abstract
The effects of an increasingly large yellow-legged gull Larus cachinnans *colony on the flora of a Mediterranean limestone archipelago (south-east France) were studied through the analysis of floristical changes which have occurred in the past 36 years. Island plant lists can be distinguished first according to the island area, but all the islands show a common pattern of historical changes in flora. This floristical change appears to be correlated with the gull density and the percentage of ruderal plant species. Disturbance by gulls favours the massive establishment of non-native plant species which has led to the extinction of some endangered taxa through this plant species 'enrichment'. Small islets appear to be more affected than large islands. Some preliminary conservation measures are presented. © 1998 Elsevier Science Ltd. All rights reserved*

Keywords: *Larus cachinnans*, disturbance, south-east France, floristic turn over, Mediterranean islands, biological invasions.

INTRODUCTION

With almost 5000 islands and islets, the Mediterranean basin comprises one of the largest groups of islands in the world (Delanoë *et al.*, 1996). The flora on Mediterranean islands represents an important part of the Mediterranean plant diversity and the largest islands show a rate of endemism between 7 and 13% (Médail and Quézel, 1997). The role of disturbance in natural communities has received a great deal of attention, especially on island ecosystems (e.g. Mueller-Dombois, 1995). Small natural disturbances maintain or increase plant species richness in many natural and agricultural ecosystems (Pickett and White, 1985; Lavorel *et al.*, 1994), but, under this scheme, a severe drop in species diversity can occur when perturbations are intense or frequent. Thus, the high floristic richness of Mediterranean islands might be partly explained by the intermediate disturbance hypothesis (Levin and Pain, 1974). Nevertheless, islands are very vulnerable to human activities (e.g. Moore, 1983), aggravated by the reduced genetic exchanges between these isolated populations (Barret, 1996). This frequently results in ecological imbalances and a high degree of invisibility (D'Antonio and Dudley, 1995).

Islands often house large sea-bird colonies which benefit from the tranquillity necessary to accomplish their nesting cycle (Jouventin and Mougin, 1981). The high disturbances induced by these colonies on vegetation have been studied on several islands, notably in the Atlantic Ocean (e.g. Gillham, 1956, 1961; Bioret *et al.*, 1991; Dean *et al.*, 1994) and sub-Antarctic archipelagos (e.g. Smith, 1979; Joly *et al.*, 1987; Chapuis *et al.*, 1989). The impact of seabirds on the vegetation is varied (e.g. Sobey and Kenworthy, 1979; Hogg and Morton, 1983): physical disturbance (pulling-up, treading, collecting of nest materials), chemical disturbance (soil manuring, salt deposition), alteration of competitive processes (dispersal of allochtonous seeds, expansion of annual or ruderal species). Gillham (1961) studied the alteration in the breeding habitat caused by gulls, terns, cormorants and shearwaters in Mediterranean-type south-western Australian islands. To the best of our knowledge, the effects of sea-birds on the vegetation of Mediterranean basin islands, although occasionally mentioned in the literature (e.g. Beaubrun, 1988, in Morocco; Laguna and Jimenez-Pérez, 1995, on Columbretes islands, Spain) have not been thoroughly studied, apart from the Corsican islets, by Paradis and Lorenzoni (1996).

The yellow-legged gull *Larus cachinnans* is the most common and widespread seabird of the western part of the Mediterranean basin. This gull species, whose breeding range extends from the Azores to the Aral sea, is represented in the western part of the Mediterranean

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basin by an endemic subspecies, *Larus cachinnans michahellis* (Yésou and Beaubrun, 1995). The western Mediterranean yellow-legged gull population has undergone a very high demographic increase over the past 30 years, reaching now 120,000 nesting pairs (Perennou *et al.*, 1996).

The aims of this study are to analyse the effects of a large yellow-legged gull colony on the flora of a small limestone north-Mediterranean archipelago and to examine the consequences of these disturbances from the point of view of plant conservation.

STUDY AREA AND METHODS

This study was conducted on the Riou archipelago (43°12′ N, 5°20′E), off the coast of Marseille (Provence coast). This archipelago, which has been uninhabitated, comprises seven main islands and represents *c.* 160 ha (Fig. 1). The relief is very uneven: Riou Island (90 ha) is 191 m at its highest point and Maïre Island (27 ha) is 141 m a.s.l. Distance from the coast varies from 50 to 3525 m. This archipelago was isolated from the continent during the last transgression, around 8000–9000 BP (Sartoretto *et al.*, 1996). The Mediterranean climate on the archipelago is harsh: rainfall is about 350 mm per year with more than 180 sunny days and 200 days of high wind per year (Knoerr, 1960).

Gull monitoring

The first yellow-legged gull breeding records in France were made in the Riou archipelago (Jaubert and Lapommeraye, 1859). Since 1920, ornithologists have monitored gull breeding (Launay, 1983; Vidal *et al.*, 1997*a*). In addition, in 1996, a set of 100 500 m^2 plots were set up according to a systematic sampling (on a 100×100 m grid). The counting of breeding pairs on each plot has made it possible to assess the distribution of gull density throughout the archipelago.

Flora changes

Flora and vegetation studies of Knoerr (1960) provide detailed and complete archipelago plant species inventories made when gull disturbance was still mild and recent. In 1995 and 1996, new plant inventories were taken on every island in order to assess the floristical changes which had occurred over the past 36 years.

The floristical changes between 1960 and 1996 were analysed using canonical correspondence analysis (CCA) (Ter Braak, 1986; Chessel, 1995). This allows island environment information to be combined with plant species list. Ordination of plant species was constraining so that the axes are linear combinations of the value of five island variables (gull density, island area, distance to the continent, island shape index (length/width) and percentage of ruderal plant species). Plant strategies were examined according to the Grime classification (1977). Based on this model, each plant species can be associated with a strategy resulting from a combination of interspecific competition (C), disturbance (R) and stress (S). Moreover, seven intermediate strategies were analysed separately: CR, RC, CS, SC, SR, RS, followed by the CSR strategy. According to Grime (1977), the main plant characteristics studied in the CSR model are life-form, shoot morphology, phenology, seed production and leaf longevity. These plant attributes are based on the Mediterranean Institute for Ecology and Paleoecology floristic databank (Médail, 1996), along with additional published data, such as regional plant monographies (e.g. Molinier, 1981; Pignatti, 1982). Plants with special patrimonial interest (protection status, IUCN. categories, biogeographical interest) are labelled according to French Red Data Book for plant conservation (Olivier *et al.*, 1995). Plant nomenclature is based on Kerguélen (1993).

RESULTS

The Riou archipelago yellow-legged gull colony

In 1995, Vidal *et al.* (1997*b*) counted 14000 nesting pairs on the Riou archipelago. Thus, the breeding strength has increased at an annual rate of *c.* 7% since 1923 (Fig. 2). The growth rate differed from one island to another. For example, on Plane Island, 15 pairs nested in 1949, while 2300 pairs were recorded in 1995 (*c.* 13% of annual growth rate). Currently the nesting population of Riou Island only increases at a rate of *c.* 5% per year (Vidal *et al.*, 1997*b*). In the study plots, gull density was generally higher on the smaller islands (Fig. 3), varying from a mean of 4·5 pairs 500 m^{-2} on Maïre Island to a mean of *c.* 11 pairs 500 m^{-2} on the Grand Congloué islet. Even on Riou Island, gull distribution is not uniform. At the initial colony location (Caramassagne plateau, east Riou), density is very high (about 180 pairs ha^{-1}), while density is < 100 pairs ha^{-1} on the north-western foreland.

Floristic drift and native flora

The biplot based on CCA of plant communities in relation to the five island variables (Fig. 4) shows the extent of the floristic changes which have occurred over the past 36 years. The explanatory variables accounted for 49% of the floristic variability and the axis/axis correlations between the inner CA of floristic data and the CCA are fairly high (Table 1). The first axis of the CCA (eigenvalue: 0·289; % inertia: 29·3) expresses a gradient correlated with island area ($r = 0{\cdot}506$). The second axis (eigenvalue: 0·216; % inertia: 22·8) represents the historical changes of flora between 1960 and 1996.

All the islands show a common pattern of changes correlated with the gull density ($r = -0{\cdot}395$), the percentage of ruderals ($r = -0{\cdot}405$), and to a lesser extent, to the distance from the continent ($r = 0{\cdot}300$). Larger islands (Riou and Maïre) show a pronounced decline in plant species diversity (Table 2) whereas the three islets

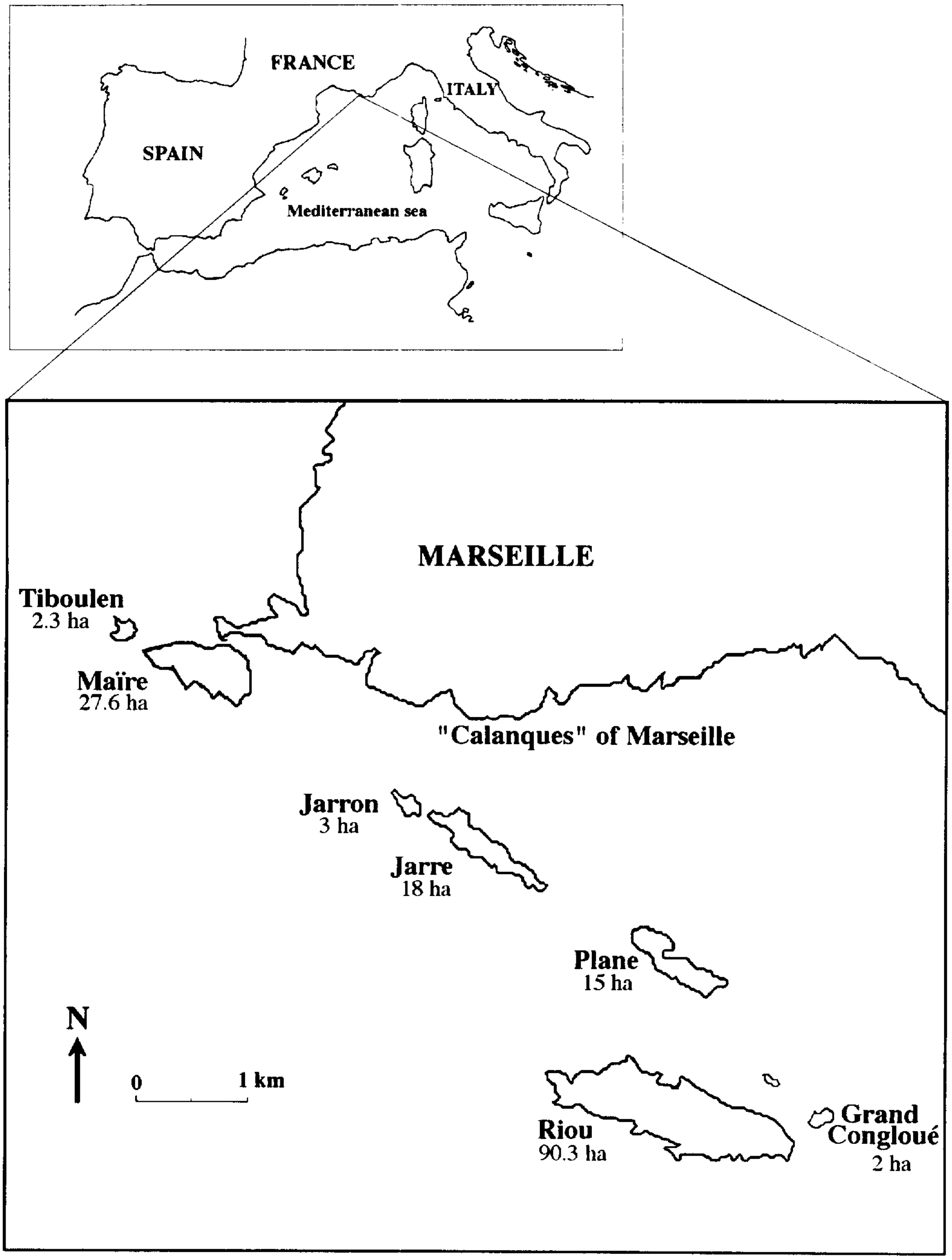

Fig. 1. Location of the Riou archipelago in the Mediterranean basin.

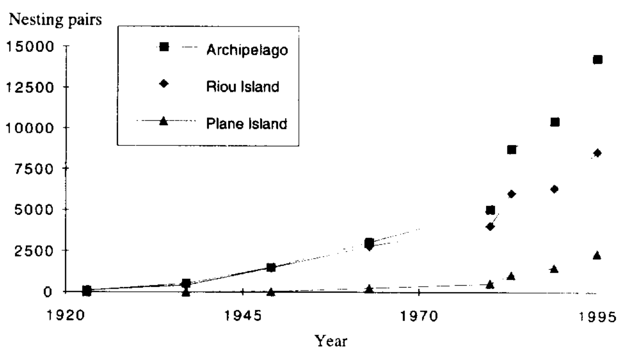

Fig. 2. Increase of yellow-legged gull nesting pairs on the Riou archipelago colony. From Vidal *et al.* (1997).

(Jarron, Tiboulen and Grand Congloue) show a strong species enrichment. This suggests a massive establishment of immigrant plant species. Currently (Fig. 5), the proportion of newly established plant species is high especially on the small islands (from 19·5% for Maïre to 52·5% for Jarron).

The comparison of the 1960 and 1996 floristic compositions for Riou, Plane and Tiboulen according to the Grime model (Fig. 6) shows that species adopting the stress strategy *s.l.* (S + SR + SC) have markedly decreased in favour of those with ruderal strategy *s.l.* (R + RS + RC), the latter increasing by 63% at Riou to nearly nine times at Tiboulen, although the stress

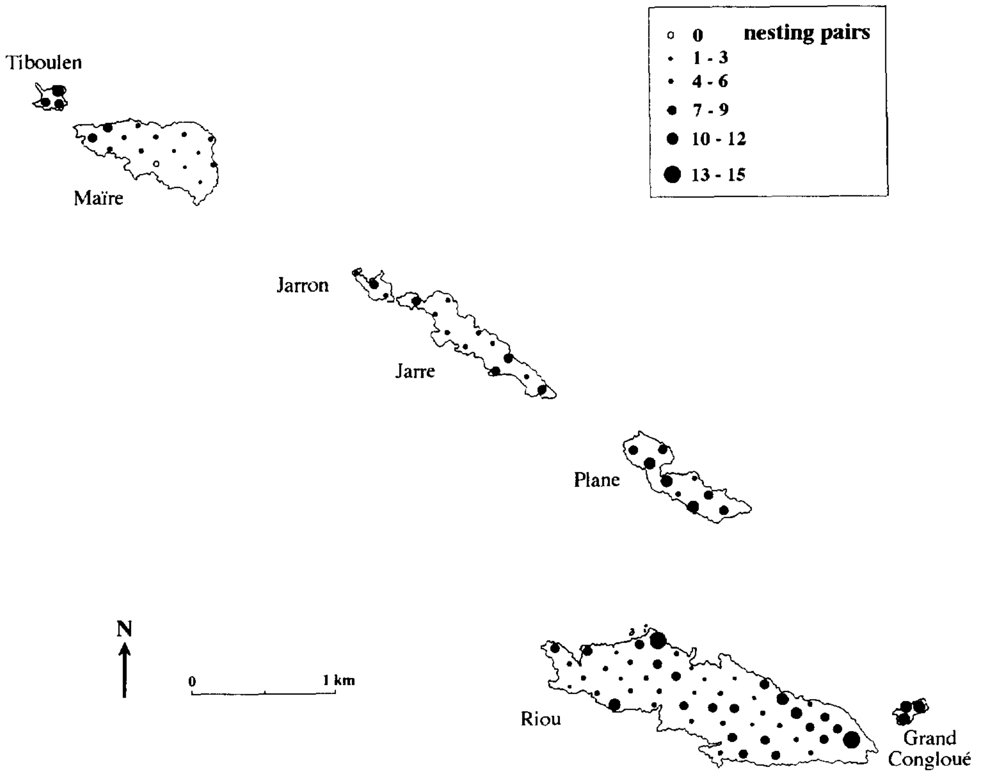

Fig. 3. Distribution of gull nesting pairs number on 500 m² sampling plots in the Riou archipelago.

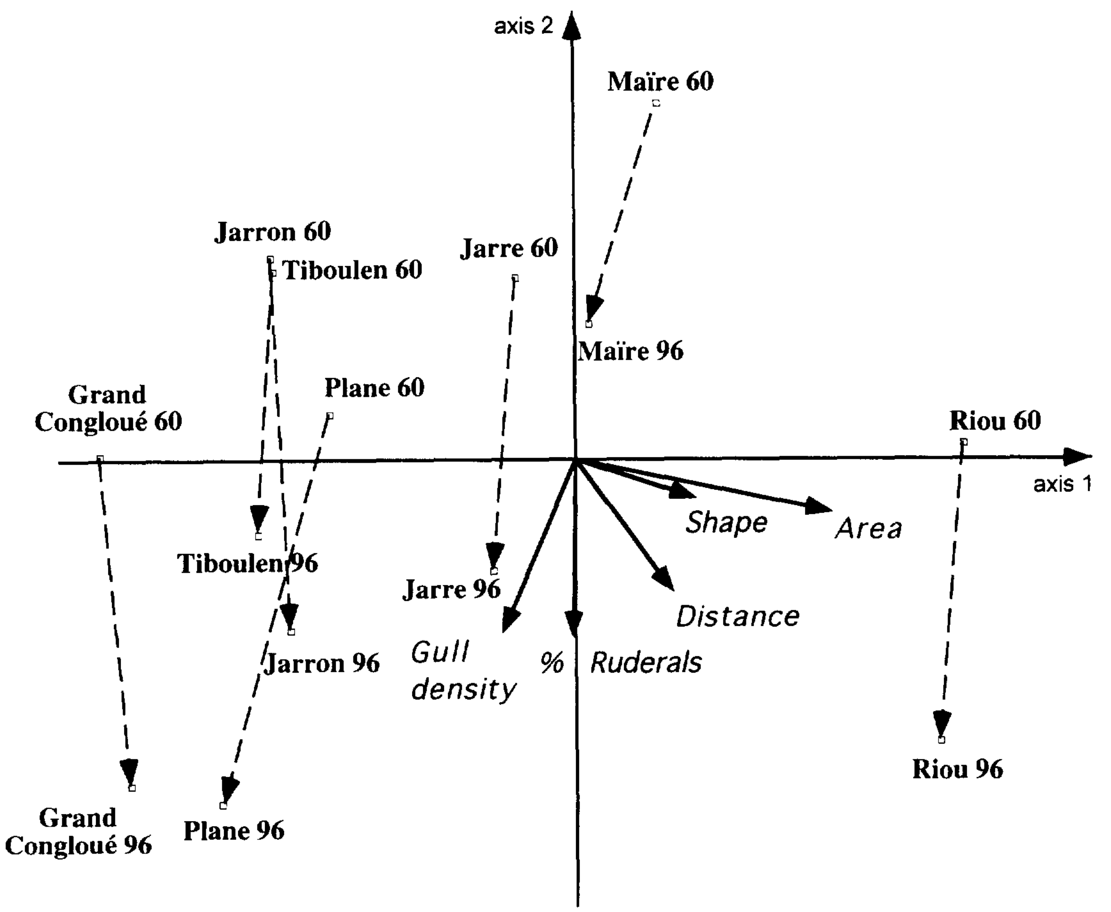

Fig. 4. Biplot based on CCA of island plant species composition in relation to 5 island variables.

Table 1. Eigenvalues, species island variables correlations, percentage variance explained using CCA, and correlation coefficients with axes 1 to 5

Axes	1	2	3	4	5
Eigenvalues	0·289	0·216	0·160	0·134	0·079
Species–island data correlations	0·987	0·945	0·969	0·964	0·740
Cumulative % variance					
of species–island variables relation	29·3	52·1	68·6	82·7	93·4
of species data	16·8	27·0	35·3	42·3	48·2
% Ruderals	−0·000	−0·405	0·170	0·046	−0·057
Island area	0·506	−0·119	−0·082	−0·014	0·018
Distance to the continent	0·193	−0·300	−0·259	0·039	0·040
Island shape index	0·239	−0·093	0·072	0·314	−0·005
Gull density	−0·141	−0·395	0·157	−0·038	0·058

Table 2. Floristic changes that have occurred on the Riou archipelago during the last 36 years (plant species diversity, local status of plants with special interest). N–1960: number of plant species present in 1960; N–1996: number of plant species present in 1996

		Riou	Maïre	Jarre	Plane	Jarron	Tiboulen	Congloue
	N–1960	191	154	116	82	42	38	31
	N–1996	179	131	125	80	61	47	39
Plant species	Stable	14	14	7	6	4	3	3
with	Extinct	6	2	3	3	1	1	1
special interest	Declining	2	1	0	1	0	0	0
	Expanding	3	2	4	3	3	1	1

strategy was still more prevalent (from 51% for Plane to 57% for Tiboulen). Tiboulen is the most affected by these changes: the proportion of strictly ruderal species has increased from 0 to 13%, while the proportion of stress tolerant species has decreased from 24 to 13%.

The severe impact by gulls has led to the local extinction of some endangered plants (Table 2) as a result of this plant species 'enrichment'. Despite its small area, the flora of Riou archipelago contains at least 28 special interest taxa (Table 3): 21 protected species and nine species mentioned in the French Red Data Book for plant conservation (Olivier *et al.*, 1995), some of which have a high biogeographical interest (*Galium minutulum, Stachys brachyclada, Teucrium polium* sp. *purpurascens*). Moreover, the presence of plant communities close to the Greek phryganic ecosystems reinforces the value of this site and justifies classifying these phytocenoses as 'Directive habitats' of the European Community. Four special interest species now appear to be extinct (*Artemisia caerulescens, Calystegia soldanella, Eryngium maritimum* and *Polypogon maritimus*) and seven have declined over the past 35 years (in particular, *Coronilla valentina* and *Stachys brachyclada* which are now nearly extinct). Moreover 15 special interest plant species seem to be stable while two appear to be expanding (*Sedum litoreum* and *Senecio leucanthemifolius*).

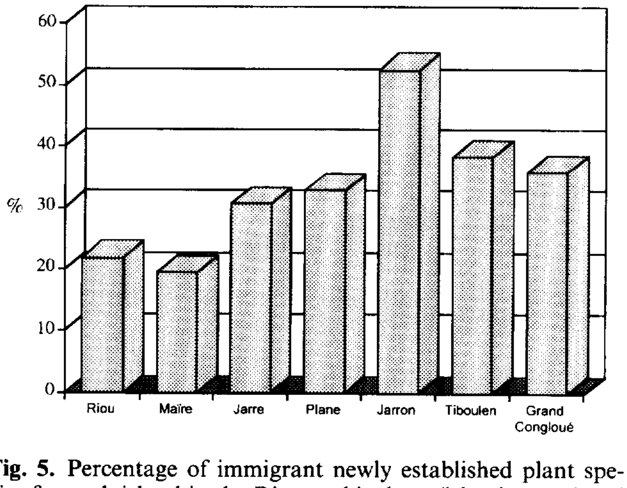

Fig. 5. Percentage of immigrant newly established plant species for each island in the Riou archipelago (islands are placed by decreasing area).

DISCUSSION

The yellow-legged gull colony of the Riou archipelago, which is one of the largest French sea-bird colonies, represents a third of the whole French population of this species. The population explosion is due to several factors. The most important one is due to the accessibility of a new and abundant food supply from a large number of open-air refuse dumps (Isenmann, 1976, 1978) and discards from increasing commercial fishing activities (Isenmann, 1976; Beaubrun, 1988; Oro *et al.*, 1995). Landfills seem to be primarily visited during the inter-breeding period (Launay, 1983) and improve the survival rate of immature birds, while discarded fish represents the greatest part of the chick diet (Beaubrun, 1988). Gulls of the Riou archipelago benefit particularly

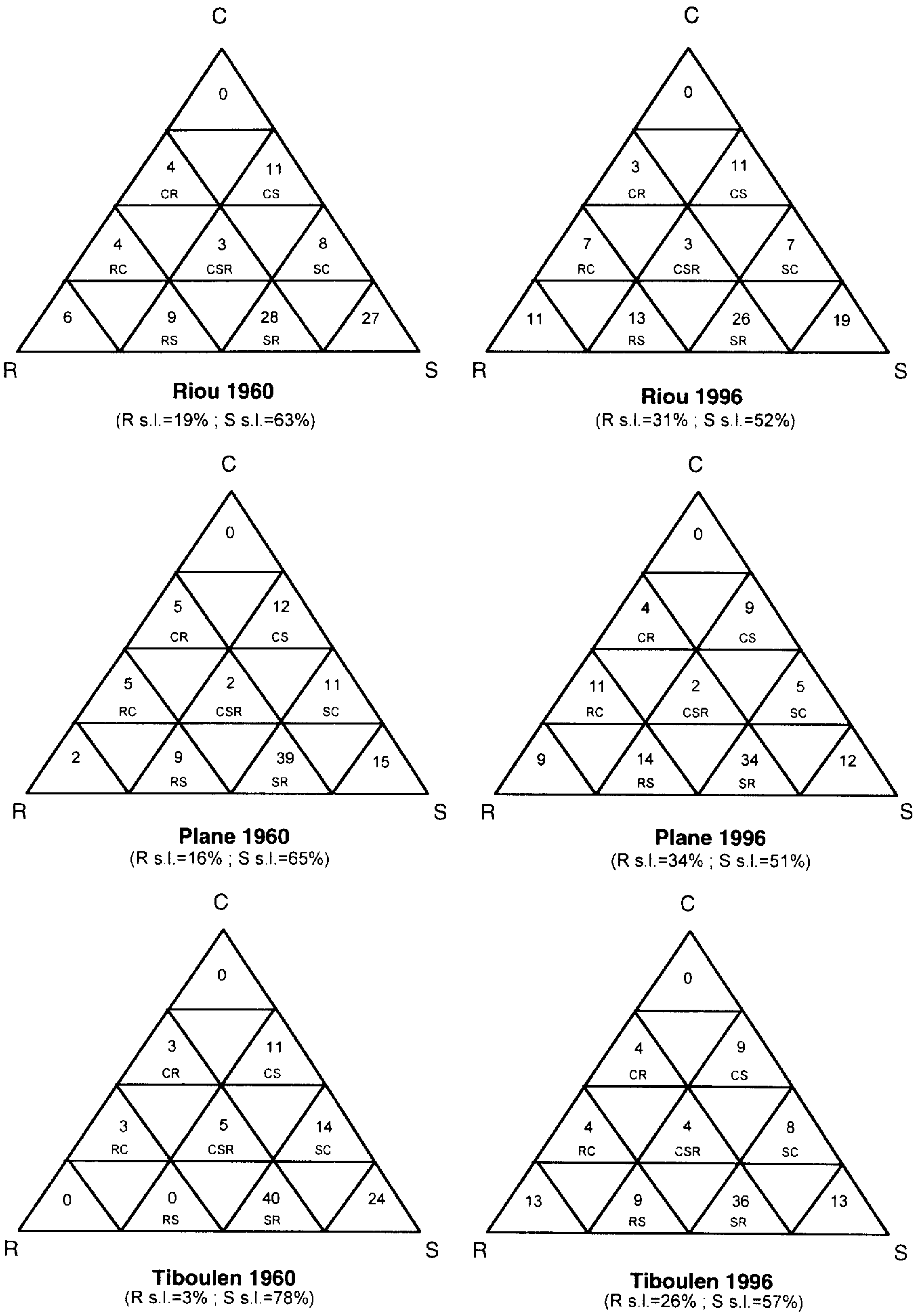

Fig. 6. Floristical changes between 1960 and 1996, on three Riou archipelago islands, examined according to Grime strategies model. Data are expressed in %. C: competition; S: stress-tolerant; R: ruderal.

from the large food supply provided by several landfills on the outskirts of Marseille, notably in the plain of 'la Crau' (Entressen, 60 km north-west Riou). Since 1960, refuse has been spread out by bulldozers which makes 80–90% of the total food accessible to gulls, i.e. about 18 tons day^{-1} (Isenmann, 1978). The attractiveness of the site is further augmented by the presence of nearby meadows and lakes. Owing to its relatively ancient origin, this colony shows a growth rate slightly less than the French national average (Yésou and Beaubrun,

Table 3. Overall status of Riou archipelago special interest plants. Question mark indicates that the average conservation status is only assumed. V = Vulnerable

	Protection		French Red Data Book	IUCN category	Biogeogr. interest	Overall status
	National level	Regional level				
Allium acutiflorum	—	—	—	—	Subendemic	Stable
Anthemis secundiramea	—	Yes	Yes	V	Range limit	Stable
Artemisia caerulescens subsp. *gallica*	—	—	—	—	Subendemic	Extinct
Asplenium sagittatum	Yes	—	Yes	V	—	Stable
Asteriscus maritimus	—	—	—	—	Range limit	Stable
Astragalus tragacantha	Yes	—	Yes	V	Range limit	Declining
Calystegia soldanella	—	Yes	—	—	—	Extinct
Cheirolophus inthybaceus	—	—	—	—	Range limit	Stable
Coronilla valentina subsp. *valentina*	—	Yes	—	—	—	Near extinct
Crepis leontodontoides	—	—	—	—	Range limit	Stable
Ephedra distachya	—	Yes	—	—	—	Stable
Eryngium maritimum	—	Yes	—	—	—	Extinct
Galium minutulum	—	Yes	Yes	V	Range limit	Stable?
Hymenolobus procumbens subsp. *revelieri*	—	—	Yes	V	Subendemic	Stable
Limonium echioides	—	—	—	—	Range limit	Declining?
Limonium pseudominutum	Yes	—	—	—	Endemic	Stable
Limonium virgatum	Yes	—	—	—	Subendemic	Stable
Myosotis pusilla	Yes	—	—	—	—	Declining
Pancratium maritimum	—	Yes	—	—	—	Stable
Plantago subulata	—	Yes	—	—	—	Declining
Polypogon maritimus	—	Yes	—	—	—	Extinct
Sedum litoreum	—	Yes	Yes	V	—	Expanding?
Senecio leucanthemifolius	—	Yes	—	—	—	Expanding
Silene sedoides	—	Yes	—	—	—	Stable
Stachys brachyclada	Yes	—	Yes	V	Range limit	Near extinct
Teucrium polium subsp. *purpurascens*	—	Yes	Yes	V	Subendemic	Stable?
Thymelaea hirsuta	—	Yes	—	—	—	Declining
Thymelaea tartonraira subsp. *tartonraira*	Yes	—	Yes	V	—	Stable

1995). Some parts of the Riou archipelago appear to have reached a saturation point for nesting gulls which has led to the development of new colonies in the surroundings, notably on the Frioul archipelago 10 km north west of Riou (Aillaud and Bayle, 1996).

The results of this study suggest that the gull demographic explosion has induced some very significant floristic changes on the archipelago. Island plant lists can be distinguished first on the biplot according to the island area. This illustrates the classical pattern of impoverishment of islets flora when compared to larger islands. Moreover, islets are more severely affected than large islands by the harsh disturbance and stress (Whitehead and Jones, 1969). Below a certain threshold area, islets are vulnerable to a high environmental stochasticity which can completely destroy their phytocenosis. The original dynamics and ecological structure, sometimes referred to as 'small-island effects' (MacArthur and Wilson, 1967) have already been described on some Provence islands (Médail and Vidal, in press). On the Riou archipelago, the vulnerability of islets is further increased by the gull colonies. Thus, > 50% of the current plant species on Jarron were not present 36 years ago. The floristic drift (i.e. the floristical changes which have occurred during the last 36 years) is clearly perceptible along axis 2 (Fig. 4). These historical changes in the flora correspond mainly to the increase of ruderal plant species along with the expansion of non-indigenous species particularly therophytes and hemicryptophytes, some of which have recently become abundant (notably *Urtica urens, Geranium molle, Heliotropium europaeum*) (Médail and Vidal, in press). Similar results have been reported elsewhere (Gillham, 1956, 1961; Hogg and Morton, 1983; Hogg *et al.*, 1988). The high amount of guano and organic matter, along with physical disturbances (pulling-up, treading) exert a strong pressure which favours the most resistant plants and excludes the indigenous species which are generally not sufficiently adaptable. This impact on the flora is also strongly correlated with gull density, which is higher on islets (because of the low degree of human disturbance), on the eastern part of Riou (initial colony location, low accessibility, long distance from the continent), and on Plane island whose very flat and uniform topography (only 22 m a.s.l.) is very appealing. The apparent importance, on the biplot of CCA, of the distance from the continent in the distribution of island flora is an indirect correlation, resulting from the se-nw alignment of the islands (Fig. 1). The geographical extension of the colony during the 20th century roughly follows a north-western direction since the initial colony location on the east of Riou island. Thus, the distance from the continent corresponds, in fact, to the duration of colony establishment on an island.

The flora of Riou archipelago is thus currently undergoing an ecological transformation which leads to uniformity; the vegetation is gradually changing from matorrals and coastal phryganic ecosystems to ruderal plant communities, and is losing progressively its ecological specificity. Of particular conservation concern is the extinction of several native plants, including some special interest species which seem to be very affected by the increase in organic matter in the soil and by the competition with ruderal species.

Due to its duration, intensity and the multiplicity of its effects, the disturbance caused by gull colonies undeniably represents the major alteration factor for the flora and vegetation of the Riou archipelago. Measures for the preservation of severely endangered plant species (*Coronilla valentina* sp. *valentina*, *Astragalus tragacantha* and *Stachys brachyclada*), such as population reinforcement and lifting and mowing of ruderal and invasive plant species (*Carpobrotus, Heliotropium, Carduus, Ecballium*) have been carried out since 1995 (Vidal *et al.*, 1997). However, conservation and management efforts must focus on limiting sea-bird pressure. On the Frioul islands, near Riou, the yearly sterilisation of a thousand clutches by the 'Direction Departementale de l'Agriculture et de la Forêt' is not sufficient to check the population explosion (Aillaud and Bayle, 1996; Vidal *et al.*, 1997). In Camargue (Rhône delta), the yellow-legged gull continues to increase despite many years of culling (Sadoul *et al.*, 1996). For the moment, the lack of sufficient manpower and material resources, and the persistence of the main food supply (refuse dumps), make culling impracticable as a sustainable population management technique.

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