Seabirds of the Southern Lagoon of New Caledonia; Distribution, Abundance and Threats

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Abstract.—We present the first detailed information on breeding marine birds from the southern Lagoon of New Caledonia, southwest Pacific. The area under consideration, 5,000 km^2, hosts 74 islets varying in size from ca. 0.05 to 30 ha. We found 13 breeding seabird species, of the 23 known to breed in the New Caledonian region. The most significant seabird numbers included large colonies of Black Noddy *(Anous minutus,* 50,000-100,000 pairs) and especially Wedge-tailed Shearwaters *(Puffinus pacificus);* the latter species totaling half a million pairs and probably the largest colony in the world. About 5,000 pairs of Roseate Tern *(Sterna dougalli)* have been found. Several species of conservation concern are also breeding in appreciable numbers, e.g., Fairy Tern *(Sterna nereis)* and Tahiti Petrel *(Pseudobulweria rostrata);* both New Caledonian endemic subspecies. However, some species are now very rare (e.g., Red-footed Booby *Sula sula),* and others have appreciably declined over the last eight years (Fairy Tern, Black-naped Tern *Sterna sumatrana* and Crested Tern *S. bergii).* The recent increase in the frequency of visits to islets by people from Nouméa (ca. 100,000 inhabitants), resulting from the increase in the number of leisure boats, may be the principal factor responsible for the current trends and threats. Human disturbance seems to be a major threat that may lead to desertion of seabirds on islets, or reduced breeding success. *Received 18 August 2001, accepted 20 November 2001.*

Keywords.—Seabird community, New Caledonia, distribution, abundance, conservation, human disturbance.

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The breeding status of seabirds throughout the Pacific Ocean, apart from Australia, has been poorly studied, especially on islands such as Vanuatu, Samoa, Tonga and New Caledonia (reviews in van Tets and Fullagar 1984; Garnett 1984; Higgins and Davies 1996). New Caledonia is a French overseas territory situated in the southwestern Pacific Ocean (Fig. 1). The biological richness of seabirds in New Caledonia remains unexplored. There are several remote offshore islands, as well as islands within the lagoon of New Caledonia, that support large marine bird colonies with several endemic subspecies of petrels and terns (Hannecart 1988). Delacour (1966) published the first monograph on New Caledonian birds. More recently, Rancurel (1974), Naurois and Rancurel (1978a, 1978b), Hannecart and Letocart (1980, 1983), Hannecart (1988), Robinet *et al*. (1997) and Bretagnolle and Pandolfi (1997) added information on breeding seabirds within New Caledonia waters.

Over the last five years, we have carried out intensive fieldwork on New Caledonian seabirds, leading to the discovery of many seabird colonies. Our aim in this paper is to provide new information with regard to seabirds that breed in southern New Caledonia, and to present data on their distribution and numbers. We also investigate the potential impact of human disturbance on seabirds in this lagoon.

STUDY AREA AND METHODS

Study Locality

New Caledonia (ca. 16,500 km^2) is of ancient origin and part of Gondwanaland that split away about 80 million years ago from what is now Australia (Mathieu-Daudé 1989; Fig. 1). The climate is tropical, tempered by trade winds. The main island is situated in tropical waters (Nouméa is in 22°l7'S, 166°26'E; see Fig. 1), and is surrounded by numerous islets, particularly in the southwestern part, which is a very large lagoon. The average depth of the lagoon is between 20 and 80 m. It is enclosed by a barrier reef which extends up to 70 km from the mainland (at its southern extremity), and is up to 30 km wide. Beyond the southern end of the mainland, the lagoon splits into two tips, one southward enclosing many islets and the other extending to Île des Pins (Fig. 1). The area under consideration ranges from 22°18'S to 23°S, and contains 74 islets, including dead coral and sand banks. Most of the Southern Lagoon islets are low, flat, and small (the largest is 30 ha). According to their topography, geomorphology and vegetation, it is possible to distinguish five types of islets in the study area. (1) The southernmost islets are flat, low, of white sand, and are uniformly covered by a ring of *Suriana maritima* surrounding *Pisonia grandis* shrubs.

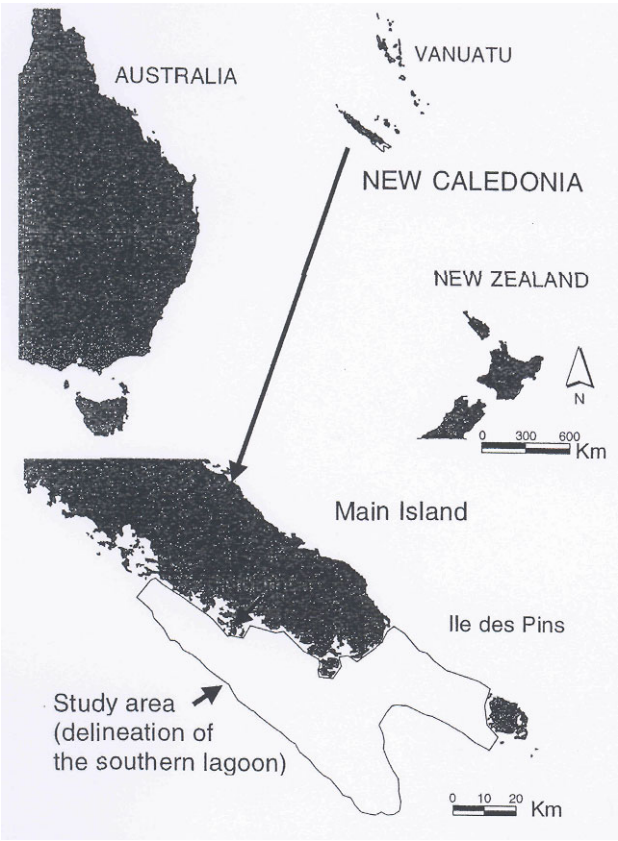

Figure 1. Map of western Pacific Ocean, showing the position of New Caledonia, and the study area. The coastline of the main island, and islets less than 1 km from the main island, were excluded from the study area.

The presence of herbaceous plants is limited to five islets, and to a few patches of *Sesuvium portulacastrum.* Overall, the ground is soft. These eleven islets are also the farthest from human habitation. (2) This type of islet is also flat and low, with yellow sand and short stretches of rocky coastline. There is a larger diversity of tree species. In addition to a ring of *S. maritima* and patches of *S. portulacastrum,* there are a variety of herbaceous plants among the shrubs. In the study area, 32 such islets were visited. (3) A few islets (N = 10) are rocky, one rising up to 40 m. The tree and herbaceous vegetation and cover is dense and varied. (4) The fourth category of islets includes very small and low islets (N = 4). They are covered only with *S. portulacastrum.* (5) Lastly, 17 islets are dead coral and sand banks, devoid of vegetation. All of these islets have recently been seriously affected by three years of drought (1995-1997) in New Caledonia. Many trees have died but, with the return of rain, herbaceous plants and *P. grandis* have recovered. Each islet is surrounded by a fringing coral reef, more or less awash at low tide. Using three satellite photographs, we were able to estimate precisely land surface areas as well as fringing coral reef surface areas for 19 islets (S. Dupont, pers. comm.). Overall, the reef area of these 19 islets varies from 1.8 to 10. ha. Rat presence was noted initially, but they were successfully eradicated from most islets in 1997.

Visits to Islets and Seabird Census

Fieldwork was carried out between 1993 and 1999, during each summer breeding season, although 1993-1994, 1997-1998 and 1998-1999 breeding seasons provided only incomplete surveys, with less than half of the islets were visited. Islets in the lagoon were visited irregularly, but particularly intense fieldwork was conducted in February 1994, March 1995, December 1995 and January 1996. Moreover, in January 1996, 53 islets were visited in one week in order to assess total numbers of seabirds during a short period. Other surveys, two to five days in length and spread out over the whole year, were undertaken in 1996 and 1997. A total of 229 trips within the lagoon were made during the study period, totaling 618 visits to islets throughout the study area (137 in 1996 and 213 in 1997). A total of 74 islets were visited 1-34 times, with an average of eight visits per islet.

On each visit, the islet was completely surveyed for diurnal seabirds. According to islet size, the survey took between 30 minutes and 3 hours (dead coral banks were surveyed by boat, and we generally did not land if no birds were seen). A survey consisted of a complete circuit of the islet coastline, and, according to islet topography and heterogeneity, one to several transects. For each islet except sand and coral banks, at least one night (but usually several) were spent looking for nocturnal petrels and Bridled Terns *(Sterna anaethetus)* (see Bretagnolle and Pandolfi 1997).

Abundance Estimates

Different methods of census were used according to the species, i.e., line transects, flush counts and direct counts (see Bibby *et al.* (1992) for general descriptions of these methods and Robinet *et al.* (1997) for a discussion on their application to some tropical seabirds). Basically, large colonies of terns and shearwaters were counted by line transects, while small colonies were evaluated through direct counts of nests. Flush counts were used for two species. The line transect technique is efficient in terms of data gathering per unit effort (Bibby *et al.* 1992). Transects were chosen to cover the maximum range of the different habitats, and generally crossed the islet at its longest axis. When multiple transects were carried out, these were spaced more than 100 m apart to maintain independence. Transects were walked slowly (0.5-1 km/h), and birds, burrows or nests counted within a band 2 m wide. Transect width was determined to minimize both non-detection of nests/burrows and differences in detectability according to species (see Bibby *et al.* 1992). For the Wedge-tailed Shearwater *(Puffinus pacificus),* we counted burrow entrances: transects were made on 27 out of the 43 islets where this species was present in large numbers, otherwise we used direct counts. On four islets, large colonies were detected, but transects were not made, and we estimated abundance on the basis of area. In order to convert the number of burrows into breeding pairs, we evaluated burrow occupancy rate (see Dyer *et al.* 1995). In 1994 and 1995, the percentage of burrow entrances with signs of occupation (calling adults or chicks, feathers, etc.) was estimated on 30 transects in January, March and April. Occupancy rate was 90.4% on average (N = 1,168 entrances checked, range 78-97%). We thus assume that the count of burrow entrances is a good indicator of numbers, and did not use a correction index. Transects were also used in very large Roseate Tern *(Sterna dougallii)* colonies, in which we counted the number of nests or the number of chicks.

Flush counts method was used for Black Noddy *(Anous minutus)* and Silver Gull *(Larus novaehollandiae);* one observer walked through the colonies around the

island and flushed the birds, the other stayed on the shore or in the boat. We also counted when the birds were disturbed by other humans, or by Peregrine Falcons *(Falco peregrinus)*.

Direct counts were used for the remaining species. The two other burrowing petrels, Black-winged Petrel *(Pterodroma nigripenis)* and Tahiti Petrel *(Pseudobulweria rostrata),* breed within shearwater colonies (and so burrows were difficult to separate), and were counted on the basis of nocturnal counts of calling birds. Black-winged Petrels were counted in the late afternoon, as this petrel uses aerial displays by day. Brown Noddy *(Anous stolidus)* could be counted directly by walking on the beach surrounding the islets, where they gather for breeding. Red-footed Boobies *(Sula sula)* were counted directly on their nests. In moderately large colonies of white terns, we divided the area into transects of 2-5 m, and walked all transects counting the clutches or nests. The colony size was the total numbers counted. For smaller colonies, we counted incubating birds or nests directly.

Species Richness and Biomass

Some seabird species remain faithful to their breeding sites (see below). For these species, we used data from any of the visits in order to draw distribution maps. Abundance data are means over the whole study period if multiple counts were available; otherwise a single count was used. For other species, breeding localities vary, at least partly, each year. We used data from all years with complete coverage (1995, 1996, and 1997) in order to draw distribution maps, or when analyzing species richness (S) per islet. For population estimates and biomass calculations, we used only one year's data, and chose the January 1996 complete coverage, when all islets were visited within a single week.

Seabird live biomass was calculated for each islet, using average body masses given in Marchant and Higgins (1990) and Higgins and Davies (1996). The diversity of seabird assemblage on islets was measured by the Shannon-Weaver index ($H = -(p_i \text{ Log } p_i$, where $p_i = X_i/X$, X_i = number of pairs from species *i* on the islet; X = total number of pairs of seabirds on the islet). Diversity (D) is defined as Exp (H) and equitability (E) as D/S (see Zotier *et al.* 1999). As the Wedge-tailed Shearwater outnumbered by far any other species, D and E were also calculated excluding this species.

Breeding Success in Relation to Human Disturbance

In 1996-1997, breeding success of the Brown Noddy was measured accurately on four islets that differed in their distance to Nouméa, in order to assess the potential effect of human disturbance on this species. The Brown Noddy was chosen because it nests on the edges of islets, in low vegetation, and thus is presumably particularly sensitive to human visits on islets. All nests of Brown Noddy were marked with small colored marks. Visits to these four islets were regularly spaced, every three weeks from November to March.

Statistical Analysis

All tests were performed using SAS 6.13 (SAS 1988). In order to identify parameters that may influence size and distribution of colonies, we used multiple regression analysis (PROG REG), non-parametric Analysis of Variance (PROG NPAR1WAY) and logistic regression (PROG CATMOD). Islet area, type of islet, coral fringe area, distance from mainland, and distance from Nouméa were used as dependent variables, while probability of presence, density and abundance per species, species richness, biomass, diversity, and equitability on islets were the independent variables. A first analysis investigated the potential effects of islet characteristics (islet type and area, and for a subset, coral fringe area). A second set of analyses investigated the potential impact of human activities, in which we used distances to the coast and to Nouméa, and an estimated index of the frequency of visits to islets by tourists, as explanatory variables. The index was coded into three classes, and was subjectively derived from the frequency and number of boats encountered on each visit to each islet.

Data are presented as mean ± SD. When multiple tests were performed on the same data sets, a sequential Bonferoni correction was applied.

RESULTS

Seabird Distribution in the Southern Lagoon of New Caledonia

Figure 2 summarizes the distribution ranges of ten of the 13 seabird species that have been found breeding in the southern lagoon of New Caledonia during the study period (1993-1999). Of these, nine species bred on the same islet every year and thus showed strong site-fidelity. The commonest petrel was the Wedge-tailed Shearwater, found on 43 of the 74 islets (58%; Fig. 2), followed by the Black-winged Petrel which was found on 29 islets and the Tahiti Petrel, restricted to twelve islets (Fig. 2). Boobies are now rare in the southern lagoon, although fishermen mention colonies that were deserted some 20 years ago. Masked Booby *(Sula dactylatra)* and Brown Booby *(S. leucogaster)* were commonly observed, and roost-ed on a single sand bank, but only the Red-footed Booby was still breeding, and restrict-ed to a single islet. The Silver Gull *(Larus novahallandiae)* was breeding on 28 islets (39%; Fig. 2). The Bridled Tern was a common breeder, found on 21 islets (see also Bretagnolle and Pandolfi 1997; Fig. 2), but Sooty Terns *(Sterna fuscata)* were rare and occurred in three small colonies, and only two of these were used regularly. The Brown Noddy was breeding on nine islets. The Black Noddy, though it was found on only seven islets, had a slightly wider distribution than the Brown Noddy (Fig. 2).

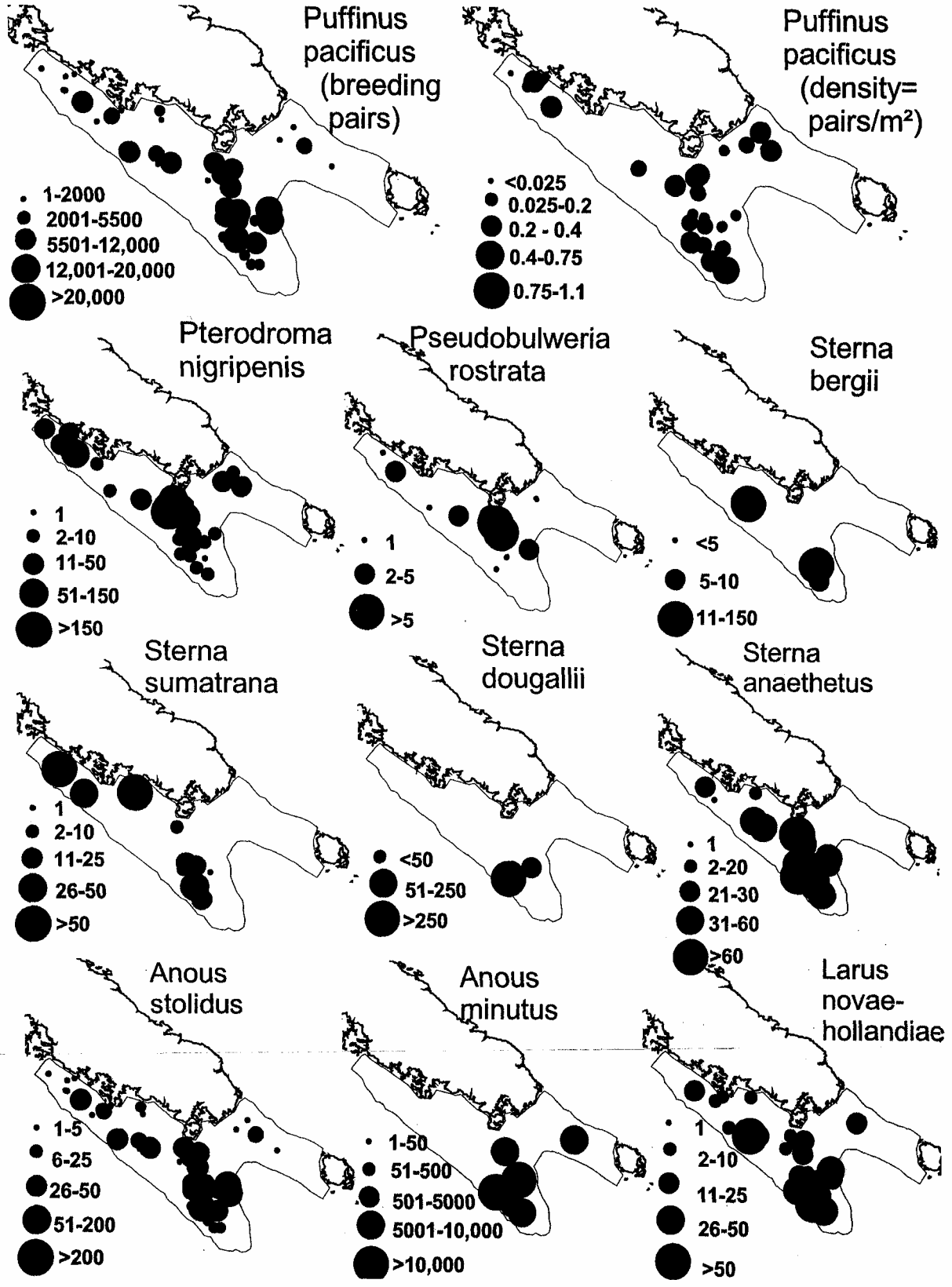

Figure 2. Abundance and distribution of ten of the 13 seabird species found breeding in the southern lagoon of New Caledonia. Species not shown include Red-footed Booby (a single breeding locality), Sooty Tern (two regular and one irregular breeding localities) and the Fairy Tern (no breeding record *in* 1995-1997). Abundance data are derived from a single census carried out in January 1996 for all seabirds except petrels (see methods for further details). Two abundance indices are provided for the Wedge-tailed Shearwater, the most abundant seabird: an estimate of breeding pairs (or burrows) per islet, and the average density (burrow entrances per square meter) found on line transects.

The four remaining species did not show site tenacity, and usually changed breeding sites every year. Among them, the Crested Tern *(Sterna bergii)* bred in five colonies, but did so regularly on only three islets. The Roseate Tern has bred on at least 21 localities since 1994/1995; among these, only four were used for two years consecutively and none for three years consecutively. In a given year, the maximum number of colonies ranged between four and twelve (average: 5 colonies). The Black-naped Tern *(S. sumatrana)* has bred on at least 24 localities, of which two were used in two consecutive years, and one, a dead coral bank which has been a nature reserve since 1994, five consecutive years. The number of colonies ranged from one to eleven (average: 6 colonies). A breeding colony of ca. 20 pairs of the Fairy Tern *(S. nereis)* was found in 1992. Between 1993 and 1996, this species apparently deserted the lagoon. In 1997, two sites with one and two pairs were found, but in 1998, up to seven small colonies were located, and in September 1999, three colonies were found.

Seabird Abundance

Abundance varied from a few nests (Red-footed Booby, Fairy Tern), to hundreds of thousands of pairs, with the Wedge-tailed Shearwater totaling about a half million pairs in the southern lagoon. Although it was present on most islets, it was most abundant in the southern part of the lagoon, farthest from Nouméa, and the main island (Fig. 2). Numbers of the other two petrels were much smaller; Tahiti Petrels were rare, with the largest numbers on a single islet of only ca. 20 pairs. The Black-winged Petrel was commoner, with up to 250 pairs on a single islet, for a total number estimated at around 1,000 pairs. The Red-footed Booby, present on a single islet, is on the verge of local extinction, with less than 20 pairs, as is the Fairy Tern. The other terns varied in numbers between years (see Table 1 for values for each year). The most abundant was the Roseate Tern, with nearly 5,000 pairs in some years. Among the "black" terns, the Black Noddy was the most abundant, with probably more than 60,000 pairs. Counts were particularly difficult for this species, as we could only rely on the flush and count method (see also Robinet *et al.* 1997).

Biomass, Richness and Diversity

The total biomass of seabirds (breeders only) in the southern lagoon reached ca. 400,000 kg, i.e., ca.160 g/m^2 for the total islet surface, and 0.08 g/m^2 for the entire southern lagoon. The Wedge-tailed Shearwater alone accounted for over 95% of the total biomass, followed by the Black Noddy (<4%; see Table 1). As the Wedge-tailed Shearwater was distributed heterogeneously, the distribution of total biomass was also non-random, with higher values in the southern part of the Lagoon (Fig. 3). Biomass on individual islets varied from zero to over 30,000 kg, with an average of 5,100 ± 800 (N = 74). Species richness (Fig. 3) on the islets varied from zero (on 26% of the 74 islets) to ten seabird species, averaging 2.76 ± 2.81. Again, there was a regional trend in seabird richness, values being on average higher in the southern part of the lagoon (Fig. 3). These trends were less clear when considering diversity indices, especially when the Wedge-tailed Shearwater was excluded from the calculation (Fig. 3).

The effects of islet category (five categories, see methods), distances to mainland and to Nouméa, frequency of tourist visits, islet surface area, and coral area around the islet, were assessed on parameters predicting seabird diversity (either with or without the Wedge-tailed Shearwater), species richness, and presence or abundance of the main seabird species (Table 2). Islet category had a significant effect on most parameters tested, either at the community or species levels (Table 2; see also Fig. 4 for some examples). The "Pisonia islets" were the richest islets, presumably due to their large size and because of the presence of tall (10 m) trees. At the other extreme, coral and sand banks were, in general, poor (Fig. 4). Surface area of the islet also played a significant role on Shearwater abundance (and thus total biomass), and on the probability of the pres-

Table 1. Abundance of breeding seabirds of the Southern Lagoon of New Caledonia (1994-1998). Numbers are given in pairs. See methods section for estimates of abundance. For the species that show a different distribution each year, we present data for each year when available. For the white terns, the number of colonies located and counted is given within brackets for each year. The number in parentheses in the last column of the table refers to the number of islets where the presence/absence of a given species could not be fully ascertained (e.g., no night visit, or no winter visit).

Species	Method of census	Number of pairs/year				Number of pairs counted	Estimated numbers (pairs)	% biomass	Number of islets with presence
		1994-95	1995-96	1996-97	1997-98				
Black-winged Petrel	Counts of calling pairs	—	—	—	—	986	c. 1,000	0.08	29 (13)
Tahiti Petrel	Counts of calling pairs	—	—	—	—	63	c. 100	0.01	12 (18)
Wedge-tailed Shearwater	Transects (burrow entrances)	—	—	—	—	474,000	c. 500,000	96.0	43 (1)
Red-footed Booby	Direct counts of nests	13	18	>10	11	18	10-30	0.01	1
Silver Gull	Direct and flush counts	—	—	—	—	643	1,000-1,500	0.10	29 (4)
Crested Tern	Direct counts of nests	846 (2)	650 (3)	670 (5)	31 (1)†	846	c. 1,000	0.13	5 (4)
Roseate Tern	Direct counts and transects	4,600 (4)†	2,830 (11)	1,500 (4)	3,070 (5)	4,600	2,000-5,000	0.10	21 (4)
Black-naped Tern	Direct counts and transects	130 (2)†	281 (8)	354 (9)	56 (l)†	354	500-1,000	0.03	24 (4)
Fairy Tern	Direct counts of nests	0	0	0	3 (2)	3	<10	0.00	3 (4)
Bridled Tern	Direct counts of adults/nests	—	786 (18)	250 (18)	390 (16)	786	500-1,000	0.05	21 (4)
Sooty Tern	Direct counts of adults/nests	—	300 (2)	200 (2)	15 (l)†	300	200-300	0.03	3 (2)
Brown Noddy	Direct counts and transects	—	800 (9)	924 (8)	65 (6)†	924	c. 1,000	0.10	9 (1)
Black Noddy	Flush counts of adults	—	—	—	—	60,450	>60,000	3.36	7

†In 1994-95 and 1997-98, surveys were not complete.

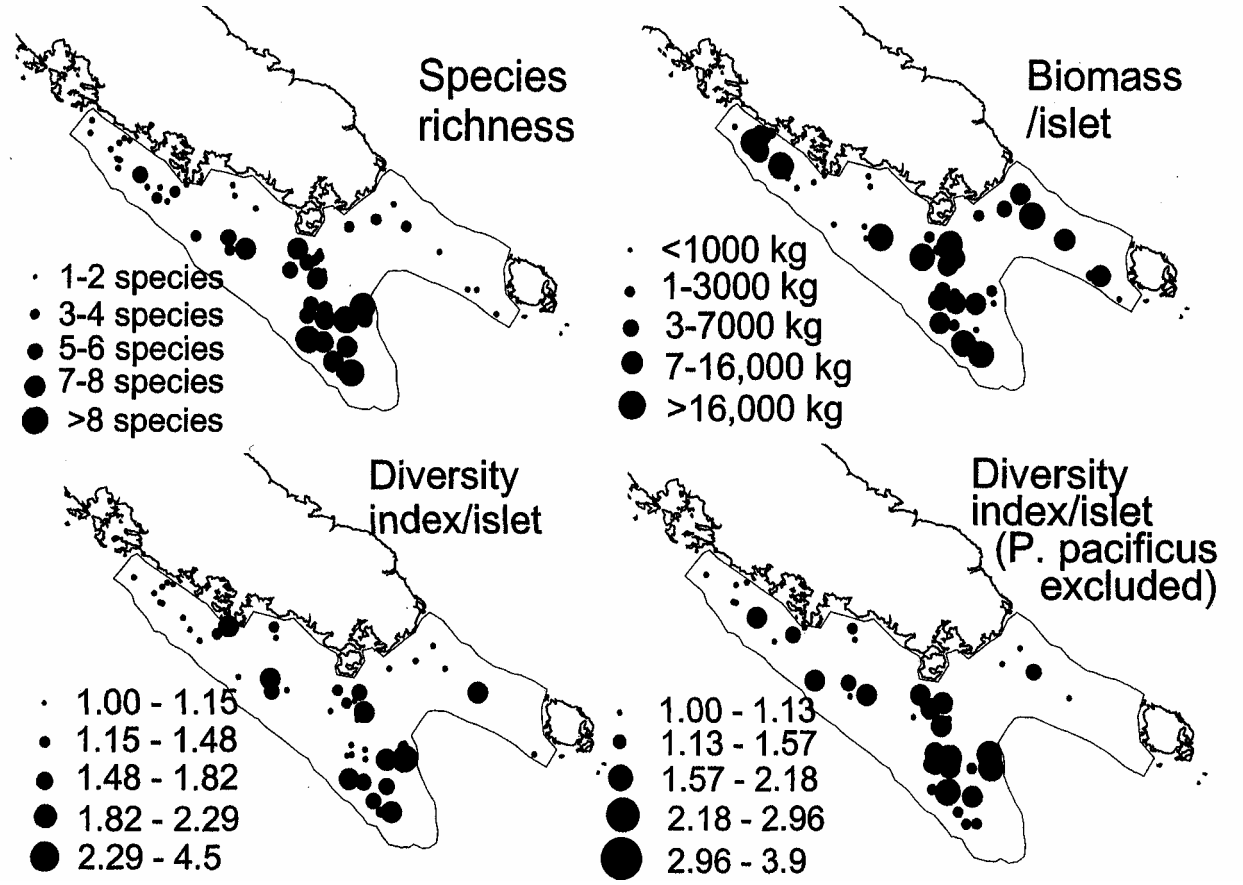

Figure 3. Species richness, biomass, diversity index either including, or excluding Wedge-tailed Shearwater from calculations, according to islets. The Wedge-tailed Shearwater was excluded from some analyses because it was by far the most abundant seabird on the islets, and thus strongly affects the value of the Shannon Index.

ence of all species tested (and thus, species richness; see Table 2). No significant effect of coral fringe area was found on any of the tested parameters, although this may result from limited sample size (19 islets). Only a few of the seabirds feed close to their breeding colony (pers. obs.), so the absence of a relationship was not surprising. The seabird community appeared to be significantly and negatively affected by the indices of human disturbance that we tested, either distance to mainland (7 cases), or frequency of tourist visits (one case). Distance from Nouméa was never significant after a Bonferroni correction (Table 2). However, all three parameters are, to some extent, correlated with each other, so they are difficult to separate. Overall, one of these three parameters significantly affected all species except the Tahiti and Black-winged Petrels (Table 2). Diversity and equitability indices were more difficult to interpret, but increasing distance from the mainland tended to increase overall diversity (when excluding Wedge-tailed Shearwater) and decreased equitability (Table 2).

Trends in Seabird Numbers

Roseate Terns declined from 5,000 pairs in 1994 to a low of 1,500 pairs in 1997, though numbers increased again in 1997-98 and reached 4,000 pairs in 2000. Similarly, the Black-naped Tern has declined, although the number of colonies, the widespread breeding season (unpubl. data) and the laying of replacement clutches made interpretation more difficult. Fairy Terns are on the verge of local extinction, with no more than a few tens of pairs currently breeding. They used to breed in large numbers just off Nouméa in the 1960s (F. Hanecart, pers. comm.), and were still breeding there in the 1970s and early 1980s (Naurois and Rancurel 1978a, pers. obs.). The species is also exhibiting

Table 2. Factors affecting distribution and abundance of breeding seabirds of southern lagoon of New Caledonia. A first analysis investigated the effect of islet type on presence / absence (Kruskall-Wallis test), density and abundance of each species, and the five community parameters (One-way AN OVA). A second set investigated the effect of coral fringe area (logistic regression for presence/absence data, and linear regression for other parameters) on these parameters. A third set investigated the effects of human disturbance and islet surface (multiple logistic regression for presence/absence, and multiple regression for other parameters; intercept and slope values are given). Due to the number of tests performed, Bonferoni correction was applied (totaling all analyses performed for a given species, e.g., eight analyses for the Wedge-tailed Shearwater). Analyses were performed on log-transformed values. No analyses was performed when sample size was <20.

		Islet type				Coral area[†]					Islet characteristics (slope)			
Species	Parameter	N	df	H or F	P<	N	Slope	P	N	Intercept	Distance of islet	Distance to Nouméa	Tourist to mainland	frequenta-tion
Wedge-tailed	Presence	73	4	52.6	<0.001	·	·	·	73	-1.96	2.46 (<0.001)	0.60 (n.s.)	2.87 (<0.005)	-0.1 (n.s.)
Shearwater	Density	24	3	1.43	n.s.	17	-0.41	n.s.	24	Model n.s.				
	Abundance	42	3	1.36	n.s.	19	-0.70	n.s.	42	1.51	2.44 (<0.001)	0.001 (n.s.)	0.31 (n.s.)	0.33 (n.s.)
	Presence	61	4	31.5	<0.001	·	·	·	61	-3.72	3.56 (<0.01)	2.86 (0.02)	2.85 (n.s.)	-1.26 (n.s.)
Black-winged Petrel	Abundance	29	3	7.4	<0.001	18	1.1	0.01	29	0.97	0.81 (n.s.)	0.25 (n.s.)	-0.53 (n.s.)	-0.06 (n.s.)
Tahiti Petrel	Presence	56	4	12.5	<0.01	15	3.7	n.s.	56	-3.35	2.15 (0.04)	4.51 (n.s.)	0.91 (n.s.)	-2.49 (0.04)
Bridled Tern	Presence	70	4	18.5	<0.001	19	0.25	n.s.	70	-4.97	2.60 (0.002)	-3.28 (n.s.)	5.35 (<0.001)	1.69 (n.s.)
	Abundance	21	4	12.9	<0.001	15	0.055	n.s.	21	0.76	0.25 (n.s.)	0.77 (n.s.)	0.07 (n.s.)	-0.23 (n.s.)
Roseate Tern	Presence	70	4	22.4	<0.001	19	-2.9	n.s.	70	-4.16	1.04 (0.03)	-1.9 (n.s.)	4.08 (<0.005)	1.09 (n.s.)
Black-naped Tern	Presence	70	4	8.9	n.s.	19	-1.9	n.s.	70	-3.02	0.18 (n.s.)	0.24 (n.s.)	2.07 (<0.02)	0.22 (n.s.)
Silver Gull	Presence	70	4	24.4	<0.001	19	-0.94	n.s.	70	-1.56	2.38 (<0.001)	-2.71 (n.s.)	4.91 (<0.001)	0.41 (n.s.)
	Abundance	29	3	4.5	<0.02	16	-0.31	n.s.	29	0.35	0.13 (n.s.)	-0.62 (n.s.)	0.85 (0.05)	0.33 (n.s.)
Species richness		74	4	11.7	<0.001	19	-3.1	n.s.	74	0.21	1.73 (<0.001)	-1.1 (n.s.)	3.91 (<0.001)	0.62 (n.s.)
Total biomass		74	4	9.4	<0.001	19	-0.75	0.05	74	-5.27	3.68 (<0.001)	4.01 (n.s.)	5.25 (<0.001)	1.18 (n.s.)
Diversity		47	4	7.6	<0.001	19	-0.45	n.s.	47	0.92	-0.01 (n.s.)	-0.39 (n.s.)	0.48 (n.s.)	0.27 (n.s.)
Diversity (*P. pacif.* excluded)		40	4	0.67	n.s.	18	1.0	n.s.	40	1.41	0.26 (n.s.)	-0.24 (n.s.)	1.19 (0.01)	-0.15 (n.s.)
Equitability		47	4	1.7	n.s.	19	0.04	n.s.	47	0.73	-0.17 (<0.01)	-0.05 (n.s.)	-0.33 (0.01)	0.06 (n.s.)

[†]Could not be performed for two petrels, as they were present on all 19 islets.

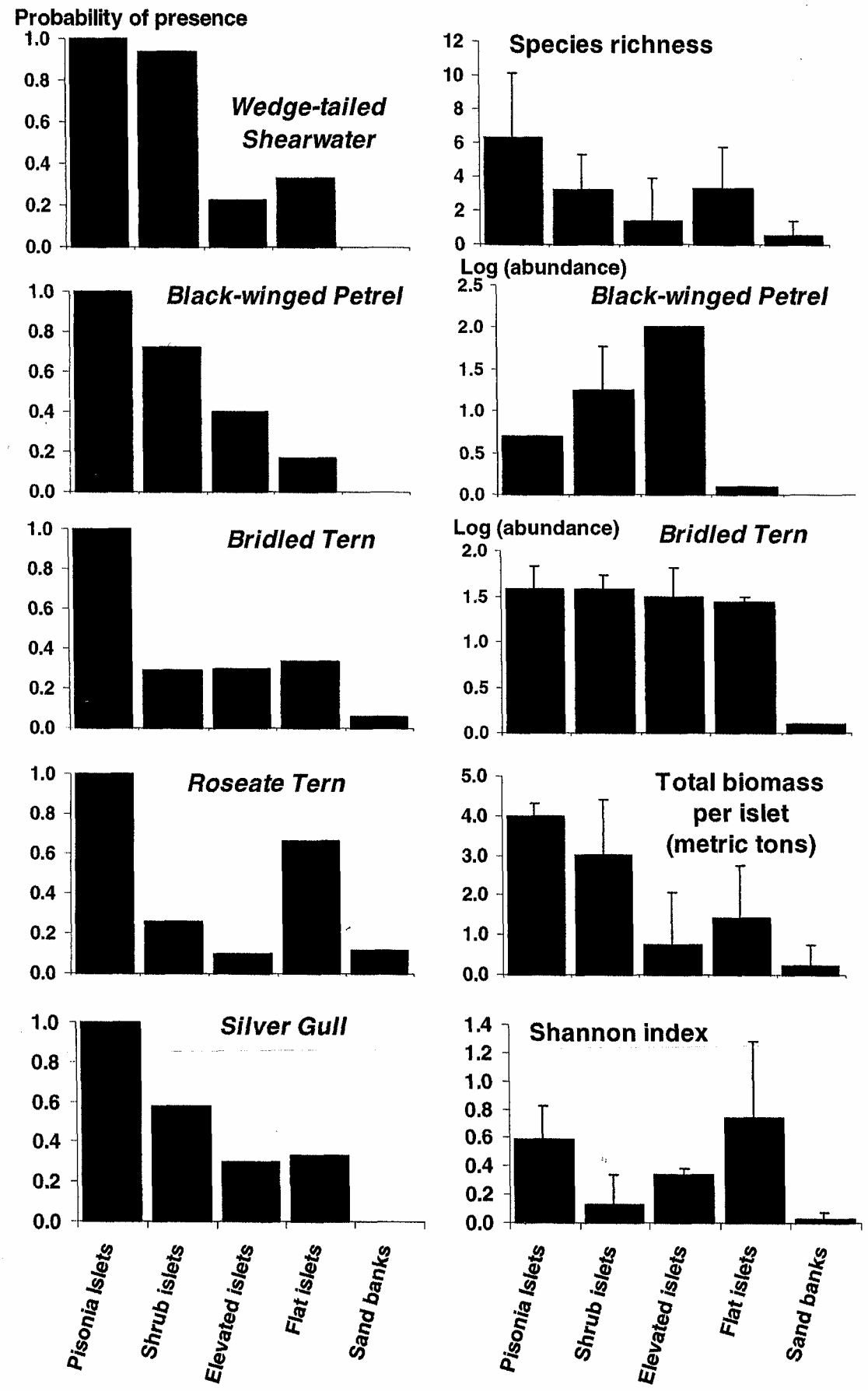

Figure 4. Effects of islet type (five categories) on the probability of presence and abundance (when present) in selected species of seabirds from the southern lagoon of new Caledonia. See Table 2 for statistical significance of results.

alarming decline in Australia (where there are thought to be ca. 2000 pairs) and New Zealand (30 birds; Collar *et al.* 1994; Higgins and Davies 1996). The Crested Tern currently nests on very few sites (and two of these are virtually deserted), which are tiny and very low islets, therefore highly vulnerable to adverse meteorological conditions. This species is also declining: one islet held 200 nests in 1995, 33 in 1996, ten in 1997 and only three in 1998, another one held 500 pairs in 1994, and none in 1997 nor 1998, while they completely disappeared from a third. Sooty Terns are probably more or less stable, but their numbers are very low.

Breeding success of the Brown Noddy was monitored on four islets in 1997, with varying degrees of human disturbance (i.e., distances from Nouméa). The first clutch (November) completely failed on the two islets that were most frequented by humans, while on the other two there was >20% breeding success. The second clutch (December) was strongly affected by the cyclone Drena, and overall, breeding failure due to the cyclone was 61.9% (N = 507 nests monitored), and ranged from 56% to 74% on three islands. On the fourth island (which was also the smallest), the cyclone had the highest impact with 78% failure. This can be compared to a failure of only 15% during the third clutch (February).

DISCUSSION

Seabirds of the Southern Lagoon of New Caledonia

In terms of species richness, the breeding seabird community of the southern lagoon of New Caledonia has 13 species, and is therefore rich, given the total surface of the area (ca.5,000 km^2). The Great Barrier Reef (Queensland, Australia: 9-25°S), which is the closest seabird area to New Caledonia, has more species overall (data from Marchant and Higgins 1990; Higgins and Davies 1996), but the area is considerably larger both in size and latitude amplitude. When restricted to smaller latitude ranges, data become similar to the lagoon of New Caledonia (e.g., 12 species recorded in Blaber *et al.* 1998, between 9°S and 16°S; see also Hulsman 1987). The community composition of the southern lagoon of New Caledonia is nonetheless different compared to its Australian counterpart. Several species are missing from the New Caledonian lagoon: Caspian Tern *(Sterna caspia,* known from 13°S to 24°S in the Great Barrier Reef), Lesser-crested Tern *(Sterna bengalensis,* 11°S to 23°S), Red-tailed Tropicbird *(Phaeton rubricauda,* 10°S to 25°S), Brown Booby (from 9°S to 28°S) and Masked Booby (9°S to 23°S), Great Frigatebird (10°S to 22°S), Least Frigatebird (10°S to 22°S), and Herald Petrel *(Pterodroma arminjoniana,* a single breeding locality in Queensland). Apart from the terns, all of the six remaining species are present in other parts of New Caledonia (unpubl. data), so their absence from the southern lagoon may be attributable to human disturbance. The two tern species are totally absent from New Caledonian waters. However, these are not pelagic terns, and are restricted to Australia within the southern Pacific region. Lastly, only the Tahiti Petrel is present in New Caledonia, but absent from Queensland. Overall therefore, the seabird community of the southern lagoon of New Caledonia is rich in terms of species number when compared to similar areas (geographic location and ecological characteristics).

Abundance of seabirds in the southern lagoon of New Caledonia can also be compared to Great Barrier Reef, at least its northern part (data from Blaber *et al.* 1998). Their study area was about ten times larger than the southern lagoon of New Caledonia, so presumably would be expected to hold numbers about ten times larger. This was effectively the case for Crested, Bridled and Sooty Terns, as well as Brown Noddy. However, numbers were similar for Black-naped Tern and possibly the Roseate Tern, and half for Black Noddy. Abundance of seabirds in the southern lagoon of New Caledonia is thus comparable to those reported for the northern tip of the Great Barrier Reef.

The seabird community of the southern lagoon of New Caledonia, in terms of numbers and biomass, is dominated by the Wedge-tailed Shearwater, and to a much less-

er extent, the Black Noddy. Nowhere else have such high numbers of Wedge-tailed Shearwaters been reported. For instance, the total figure for Hawaiian Islands is ca. 250,000 pairs (Harrison *et al.* 1984). The world population of the species is considered to be over a million pairs (del Hoyo *et al.* 1992), but this could be the figure for New Caledonia alone, as major colonies are also found on offshore islets (unpubl. data). We have no explanations for such high numbers of shearwaters, but availability of islets (both in terms of number and distance from human settlements) cannot account alone for such abundance.

Trends and the Future of New Caledonian Seabirds

Population trends cannot easily be assessed for tropical seabirds (see, e.g., Robinet *et al.* 1997), especially when data are available for only a short period of time. However, it appears that several species have declined over the last years in the southern lagoon, particularly the terns. Trends could not be assessed for any of the petrels or the noddies. Although cyclone effects on tropical seabirds have been repeatedly documented (e.g., King *et al.* 1992; Surman and Wooller 1995; but see Ogden 1993), we believe that neither cyclones nor ENSO can explain current trends (see also Blaber *et al.* 1998). Similarly, rats or cats cannot account for observed trends, although in a sample of 26 islets, the Polynesian Rat *(Rattus exulans)* was found on eleven islets, and Ship Rat *(Rattus rattus)* on one more. The rats were eradicated in 1997 (B. Bell, unpublished data).

Human disturbance was not quantified directly during this study. However, using several indirect measures of human disturbance, such as distance to human settlements, distance to the coast of the main island, and an index related to the number of boats visiting the islets, we found that these factors could be affecting population sizes and/or the probability of presence on an islet for several seabird species. Contrary to Hill and Barnes (1989), we detected a potential effect of human disturbance on the presence of Wedge-tailed Shearwaters, though these authors used burrow density rather than the probability of presence. They also failed to find any effect on Black Noddy. With only seven islets colonized by this species in our study area, we could not perform statistical tests, but these seven islets are among the farthest from human settlement (and thus disturbance). Therefore, it is likely that in New Caledonia, this species could be affected by human disturbance. We believe that human disturbance is currently a major threat to the seabirds, either through humans walking on the islets, or of boats approaching and landing. Both flushed seabirds, even at considerable distances (e.g., Least Tern, from 20 to 100 m from walking human; Rodgers and Smith 1995). Although not precisely quantified during the present study, we found that the smallest terns usually flushed at 20-50 m (Fairy, Roseate and Black-napped Terns), and for the larger ones (Crested and Sooty Terns) at 50-100 m. Seabirds, mainly because they are colonial, are known to be potentially sensitive to human disturbance, either in terms of breeding success or colony desertion (see review by Rodgers and Smith 1995; Carney and Sydeman 1999). For tern colonies, recommended safe distances for human visits are 50 to 200 m (Erwin 1989). Erwin (1980) also showed that recreational activities could preclude terns nesting on beaches. Moreover, seabirds and particularly terns are highly visible because of their animated behavior, and tend to attract visitors (Carney and Sydeman 1999). The recent increase in the frequency of visits to islets by people, resulting from the increase in the number of leisure boats (on average, ca. 1,000 new boats per year in Nouméa harbor during the 1990s), may be the principal factor responsible for the current seabird trends observed in the southern lagoon of New Caledonia.

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