

# Estimating the Sizes of Large Gull Colonies Taking into Account Nest Detection Probability

CHRISTOPHE BARBRAUD<sup>1</sup> AND GUILLAUME GÉLINAUD<sup>2</sup>

<sup>1</sup>Centre d'Etudes Biologiques de Chizé—CNRS, UPR 1934, F-79360 Villiers en Bois, France  
Internet: barbraud@cebc.cnrs.fr

<sup>2</sup>Bretagne Vivante—SEPNB, Réserve Naturelle des Marais de Séné, Brouel-Kerbihan, F-56860 Séné, France

**Abstract.**—A double-observer approach was used during colony surveys of large gulls to estimate nest detection probabilities and unbiased estimates of abundance. Several models were developed that incorporate different assumptions about the sources of variation in detection probabilities (observer, colony, vegetation height). Nine colonies were surveyed in which a total of 137 transects were conducted. Although the most likely model was a one with a constant nest detection probability, a constrained model with observer dependent nest detection probability had substantial support. Overall detection probability (probability that a nest was detected by at least one of the two observers) was 0.943 (SE  $\pm$  0.008). Detection probability for a single observer was lower (0.761, SE  $\pm$  0.016). These estimates indicate a relatively high underestimation of the population sizes of large gull species when not taking into account nest detectability. Received 26 April 2004, accepted 12 September 2004.

**Keywords.**—Abundance, detection probability, double observer, gulls, *Larus* sp., population size, census.

Waterbirds 28(1): 53-60, 2005

Gulls (family Laridae) are widespread and abundant across both north and south hemispheres. They are highly adaptable, with a wide natural breeding habitat tolerance ranging from pack ice, sea cliffs to deserts, although they also breed in artificial habitats such as buildings (del Hoyo *et al.* 1996). Long-term changes in gull numbers may indicate changes in the food supply, pollution, inter-specific interactions or other environmental problems (Hand *et al.* 1985; Furness and Greenwood 1993; Pons and Migot 1995; Newton 1998). For example, several species partly rely on Man's waste such as fishing ships or garbage dumps and have dramatically increased (Pons and Migot 1995; Oro *et al.* 1996), and have been considered as problematic, sometimes resulting in the development of control programs in several countries (Bosch *et al.* 2000; Brooks and Lebreton 2001). In addition, since large gull species may compete with smaller seabird species, the increase in the numbers of large gulls may often affect the population dynamics of other smaller gull species (Nisbet 1976; Sadoul 1996) but also of other animal species, as well as habitats (Vidal *et al.* 1998; Orgeas *et al.* in press). Therefore, the gull species constitute a particularly important group to monitor, as their behavior and

population dynamics might reflect both natural and anthropogenic changes in coupled marine-terrestrial ecosystems. Because long-term monitoring is an important component of effective conservation-orientation research and management (Wiens *et al.* 1986; Sadoul 1997), wildlife biologists and conservationists require data on breeding of gulls to understand their population dynamics, in order to guide management actions in order to either favor endangered species or to limit species causing nuisances.

Although some gull species nest on bare ground, in which case the probability to detect a nest when collecting nesting abundance data is =1, many species build their nest in short ground vegetation, and a proportion of the total number of nests in a colony may remain undetected during counts, which can bias the abundance estimates of monitoring programs. The relationship between a count statistic and the quantity of interest (i.e., the number of nests) is:  $E(C) = N \times p$ , where  $C$  denotes the count,  $N$  the true abundance, and  $p$  the detection probability (Barker and Sauer 1992; Nichols 1992; Lancia *et al.* 1994). Several methods have been developed to take into account the detection probability of animals during surveys for accurate estimates of trends in abundance (see

Walsh *et al.* 1995 for seabirds; Pollock *et al.* 2002). However, few studies have used and tested these methods for surveys aiming at collecting nest abundance data (Nichols *et al.* 1986; Buckland *et al.* 1993; Rivera-Milán 2001). Here, we undertook a field study on breeding colonies of large gulls (Herring Gull [*Larus argentatus*], Lesser Black-backed Gull [*L. fuscus*] and Great Black-backed Gull [*L. marinus*]) to estimate the detection probability of nests and to obtain accurate estimates of colony size. Our aim was to test the assumption that all nests are detected, and to estimate the effects of observer and habitat type on nest detection probability.

#### METHODS

Fieldwork was carried out in Brittany, France, between 18 May and 6 June 2002, when a maximum number of nests have eggs in Brittany (Henry and Monnat 1981). To estimate the detection probability of gull's nests, we used the double-observer approach (Nichols *et al.* 2000) on nine breeding colonies. Colonies were situated on the offshore islands of Belle-Ile (47°20'N, 03°10'W) and Ile d'Houat (43°23'30", 02°58'00"W), and were covered by herbaceous vegetation (mainly *Erica* spp. and *Dactylis* spp.) and rocky outcrops. Vegetation height was often short (78% of the colonies), but in some cases reached c.50 cm. All colonies but one were on flat areas, and all were occupied by at least two species breeding together. Nests of Herring and Lesser Black-backed Gulls could not be distinguished. Although nests of Great Black-backed Gulls could be distinguished from nests of other species, nests of all species were pooled together in the analysis, and a non-specific nest detection probability was estimated.

The double-observer approach permits estimation of observer-specific detection probabilities and abundance. The modelling approach and parameter estimators, derived from a method developed by Cook and Jacobson (1979) to estimate abundance from aerial survey data, are detailed in Nichols *et al.* (2000). Briefly, the field methods were as follows. One to three teams of two observers surveyed a fraction of each colony. Each survey consisted of 2 m wide parallel transects throughout the colonies. On each transect, one of the two observers of each team counted and marked, with a brightly colored paper tag, the nests containing eggs (or chicks) as well as recently built nests. The second observer followed the primary observer and recorded any nest with eggs, chicks, or nests not counted and marked by the first observer. Tags were removed from the nests by the secondary observer. Observers alternated primary and secondary roles during the course of the surveys. Since transects when the double-observer approach was used were only conducted on part of each colony, the number of nests on the remaining fraction was counted by a single observer along 2 m wide transects, which can be considered as a primary observer. To minimize disturbance in the colonies pairs of observers and single observers walked synchronously along transects. Nests

were searched by walking slowly (at about one step every two to three seconds) on a straight line, and by looking on, and on each side of the line. Both observers had the same intensity of nest searching.

Then,  $x_{ij}$  was defined as the number of nests counted by observer  $i$  ( $i = 1, 2$ ) on transects when observer  $j$  ( $j = 1, 2$ ) was the primary observer,  $p_i$  was defined as the detection probability for observer  $i$ , which is assumed to be the same whether observer  $i$  is serving as the primary or the secondary observer, and  $p$  was defined as the probability that a nest on a transect was detected by at least one observer [ $p = 1 - (1 - p_1)(1 - p_2)$ ]. The nest detection probabilities can then be estimated as:

$$\hat{p}_1 = \frac{x_{11}x_{22} - x_{12}x_{21}}{x_{11}x_{22} + x_{22}x_{21}}, \hat{p}_2 = \frac{x_{11}x_{22} - x_{12}x_{21}}{x_{11}x_{22} + x_{11}x_{12}}, \text{ and} \quad (1)$$

$$\hat{p} = 1 - \frac{x_{12}x_{21}}{x_{22}x_{11}} = 1 - (1 - \hat{p}_1)(1 - \hat{p}_2)$$

Once estimates of detection probability are obtained, the estimator for abundance is:

$$\hat{N} = \frac{\sum_{ij} x_{ij}}{\hat{p}} = \frac{x_{11} + x_{12} + x_{21} + x_{22}}{\hat{p}} = \frac{x_{..}}{\hat{p}} \quad (2)$$

In our modeling approach, we assumed differences in detection probabilities for the two observers. It was also assumed that there were different detection probabilities for each colony. Consequently, we have a general model, which considers two possible sources of variation in detection probability, observers and colony. From this general model ( $M_{ic}$ , where  $i$  denotes the observer, and  $c$  the colony), we considered models with a variety of parameter constraints. Model  $M_c$  has the constraint that detection probability differs by colony, but is the same for each observer. Model  $M_i$  retains different detection probabilities for the two observers but constrains detection probability for all colonies to be equal. Model  $M$  constrains detection probabilities for all colonies and observers to be equal. Because the height of the vegetation cover differed between colonies, it was suspected this influenced the detection probabilities. Thus, two groups of colonies were identified: one group with short vegetation, and one group with high vegetation. The model  $M_v$  was tested, where  $v$  indicates that colonies within *a priori* defined groups, which retains different detection probabilities for the two observers, but imposes a constraint on detection probabilities of the different colonies. Thus, model  $M_v$  is a particular case of (i.e., nested within) the more general model  $M_{ic}$ .

To fit and obtain parameter estimates under different models, and to select between models, the program DOBSERV (Hines 2000) was used. Model selection was based on the use of the Akaike's Information Criterion (AIC). AIC is an information theoretic measure used to select a parsimonious model that adequately explains the variation in the data using as few parameters as necessary (Burnham and Anderson 2002). Because the sample sizes were not large relative to the number of parameters in our general model, we used AICc, a second-order AIC with small sample bias adjustment. For inference on model selection we also used AICc weights were used, following Burnham and Anderson (2002). All means are given  $\pm 1$  SE.

## RESULTS

The double-observer approach was used on 137 different transects in the nine colonies surveyed (Table 1). The average number of transects per colony was  $15.2 \pm 4.6$ . All the tested models had a good fit to the data (Table 2). Model  $M$  showed the lowest AICc (Table 2). Under this model, the probability that a nest was detected by at least one observer was  $0.943 \pm 0.0078$ , and the probability that only one observer detected a nest was  $0.761 \pm 0.0162$ . Models  $M_p$ ,  $M_{ip}$ , and  $M_{ic}$  had considerably lower support compared to model  $M$ , since their evidence ratios versus model  $M$  were respectively 7.5, 8.3 and 22,471 (Table 2). Therefore, the nest detection probability varied little between colonies. Model selection results indicated that

the distinction between the two observers was relatively important, since model  $M$  was only 1.56 times more likely than model  $M_p$ . The observer effect explained about 9% of the among colony variation in detection probability  $[(31.2-30.7)/(31.2-25.2)]$ . Estimates of nest detection probability for individual observers showed substantial variation with averages on specific transect ranging from 0.61 to 0.91 (Table 3). The weight of evidence about the difference in detection probabilities of colonies with short and long vegetation cover was 2.36. However, vegetation height only explained about 3% of the among colony variation in detection probability. Indeed, the probability that a nest was detected by at least one observer was similar for colonies with long ( $0.937 \pm 0.013$ ) and short vegetation ( $0.946 \pm 0.010$ ).

Table 1. Descriptive information on the transect surveys on the nine gull colonies using the double-observer approach. A and B respectively indicate the primary and secondary observer.

	Colony	A	B	Number of transects	Date/2002
1	Lande du Talut	1	2	5	18 May
1		2	1	5	18 May
2	Lande de Vazen	9	10	3	20 May
2		10	9	2	20 May
3	Ilot de Her Hastellic	5	11	2	19 May
3		11	5	1	19 May
4	Borderun 9	1	7	2	19 May
4		7	1	1	19 May
5	Borderun 10	1	7	2	19 May
5		7	1	2	19 May
6	Bordelane	5	10	4	19 May
6		10	5	4	19 May
6		4	3	3	19 May
6		3	4	5	19 May
7	Lande de Her Hastellic	8	6	4	19 May
7		6	8	4	19 May
7		11	5	4	19 May
7		5	11	4	19 May
7		9	12	4	19 May
7		12	9	4	19 May
8	Koh Kastell	1	2	6	18 May
8		2	1	6	18 May
8		3	4	6	18 May
8		4	3	6	18 May
8		5	6	6	18 May
8		6	5	6	18 May
9	Ile aux Chevaux	1	14	9	6 June
9		14	1	9	6 June
9		10	13	9	6 June
9		13	10	9	6 June

**Table 2.** Likelihood values, number of parameters (#), AICc and  $\Delta$ AICc values, AICc weights, and goodness-of-fit tests (Gof) for the six models of detection probability. The Gof test is the G-test statistic computed by program DOBSERV.

Model	Likelihood	#	AICc	$\Delta$ AICc	AICc weights	Gof
M	-31.23	1	64.45	0.00	0.432	0.849
M <sub>i</sub>	-30.67	2	65.34	0.89	0.277	0.862
M <sub>v</sub>	-31.08	2	66.17	1.72	0.183	0.821
M <sub>c</sub>	-25.19	9	68.51	4.06	0.057	0.999
M <sub>iv</sub>	-30.33	4	68.69	4.24	0.052	0.811
M <sub>ic</sub>	-23.99	18	84.49	20.04	<0.001	1.000

Estimates of nest abundance for all colonies are shown in Table 4. To estimate abundance we used the detection probabilities for a single observer under the more likely model (model *M*) since apart from the fractions of the colonies that were counted on transects, a single observer counted the rest of the colonies. The precision of the estimates was relatively good, but in some cases the abundance estimates were substantially larger than the actual counts. This mainly comes from the fact that the abundance estimates are calculated with the nest detection probability of a single observer, which is lower than the probability that a nest is detected by at least one observer. Indeed, the abundance estimates from the nest counts on transects calculated using the probability that a nest was detected by at least one observer were more precise ( $SE/N = 3.3\%$ ) than abundance estimates for the whole colonies ( $SE/N = 10.3\%$ ).

## DISCUSSION

### Nest Detection Probability

Several authors have identified and sometimes quantified the sources of bias in bird counts (see Thompson *et al.* 1998 and Bibby *et al.* 2000 for reviews). Nest detection probability has, however, received relatively little attention in methods used for counting colonial ground-nesting seabirds. Application of the double-observer approach appears to be a feasible and reliable approach to obtain unbiased estimates of detection probabilities and abundance of nests for colonial species such as Laridae, provided other sources of bias are taken into account (see below). The detection probability of nests was surprisingly low for a species nesting on open ground, particularly if one considers the nest detection probability for a single observer which indicates that on average  $24\% \pm 1.6\%$  of the

**Table 3.** Mean detection probabilities for the different observers based on model *M<sub>i</sub>* for each colony.

Observer	Number of colonies	Number of transects	$\hat{p}$	$SE(\hat{p})$
1	5	47	0.759	0.011
2	2	22	0.701	0.003
3	3	30	0.860	0.002
4	3	30	0.841	0.003
5	5	34	0.783	0.004
6	3	23	0.704	0.006
7	2	7	0.824	0.014
8	1	8	0.610	0.010
9	2	13	0.900	0.007
10	3	31	0.794	0.009
11	2	11	0.691	0.003
12	1	8	0.749	0.005
13	1	18	0.778	0.007
14	1	18	0.877	0.008

Table 4. Numbers of nests counted, and estimated detection probabilities and abundance for large Gulls in Brittany, France. For each colony,  $x_i$  indicates the number of nests counted on transects, as defined in equation (2);  $\hat{p}$  indicates the probability that a nest is detected by at least one of the two observers, as defined in equation (1);  $N_{obs}$  indicates the total number of nests counted by single observers on the whole colony;  $\hat{p}_s$  indicates the probability that a nest is detected by a single observer;  $\hat{N}$  indicates the estimated number of nests on the whole colony.

Colony	$x_i$	$\hat{p}^a$	$\hat{S}E(\hat{p})$	$N_{obs}^b$	$\hat{p}_s^a$	$\hat{S}E(\hat{p}_s)$	$\hat{N}^c$	$\hat{S}E(\hat{N})$	95% CI <sup>d</sup>
1	72	0.9427	0.0078	210	0.7607	0.0162	276	11	257 to 301
2	31	0.9427	0.0078	213	0.7607	0.0162	280	11	261 to 305
3	70	0.9427	0.0078	293	0.7607	0.0162	385	13	361 to 416
4	13	0.9427	0.0078	64	0.7607	0.0162	84	5	75 to 97
5	27	0.9427	0.0078	122	0.7607	0.0162	160	7	147 to 179
6	194	0.9427	0.0078	1270	0.7607	0.0162	1669	42	1594 to 1761
7	366	0.9427	0.0078	1355	0.7607	0.0162	1781	44	1702 to 1878
8	497	0.9427	0.0078	3096	0.7607	0.0162	4069	93	3902 to 4271
9	123	0.9427	0.0078	245	0.7607	0.0162	322	12	301 to 349

<sup>a</sup>Estimated from model M.

<sup>b</sup>Transects to estimate detection probabilities were conducted on part of each colony. The number of nests on the remaining part ( $x_i$ ) was counted by a single observer, which can be considered as a primary observer. Consequently, the total number of nests counted on the whole colony was  $N_{obs} = x_i + x_i$ , where  $x_{i1}$  is the number of nests counted on transects by the primary observer.

<sup>c</sup> $\hat{N} = N_{obs} / \hat{p}_s$ .

<sup>d</sup>Confidence intervals for  $\hat{N}$  were approximated by  $(N_{obs} + \hat{f}_0 / C, N_{obs} + \hat{f}_0 C)$ , where  $\hat{f}_0 = \hat{N} - N_{obs}$  and  $C = \exp\left(1.96 \sqrt{1 + \frac{\text{var}(\hat{N})}{\hat{f}_0^2}}\right)$ , and

$$\text{var}(\hat{N}) = \frac{N_{obs}^2 \text{var}(\hat{p}_s)}{\hat{p}_s^4} + \frac{N_{obs}^2 (1 - \hat{p}_s)}{\hat{p}_s^2} \quad (\text{Nichols et al. 2000}).$$

nests were missed, whereas only 6% of the nests were missed if two observers conducted the transects. Ferns and Mudge (1981) using counts of marked nests of Herring Gulls and Lesser Black-backed Gulls estimated that an average of  $16.9\% \pm 3.3\%$  (range 5% to 27%) of nests were missed in colonies of the UK, irrespective of the area counted, observer experience or vegetation type. Wanless and Harris (1984) overlooked 5%-20% of nests on the Isle of May using a team of counters and marking each nest counted. Similarly, Erwin (1980) using marked nests of several species of terns and gulls found that an average of  $12\% \pm 2.4\%$  (range 4% to 22%) of nest were missed in colonies of Massachusetts.

Although the lowest AICc model was a model with a constant nest detection probability, models incorporating the effects of observer or vegetation height had some support, given the data. Most of the variability in detection probabilities came from the observers. Different observers had different detection probabilities, but the same observer may also have different detection probabilities depending on the colony surveyed. The largest variation in detection probabilities for a given observer was 0.65 to 0.92 depending on the colony surveyed. Similarly, Nichols *et al.* (1986) found important variability in nest detection probability between observers. Such differences in detection probabilities partly due to observers and habitat type raise some concern for detecting trends in numbers, since between two surveys conducted several years apart different observers are involved and habitat characteristics may change, thereby affecting the number of nests that are de-

tected. Estimating nest detection probability and incorporating observer and habitat effect into the models would permit avoiding bias in abundance estimates (Nichols *et al.* 2000), and consequently would increase the statistical power for detecting trends.

Relatively few monitoring programs have incorporated nest detection probabilities when estimating abundance of breeding birds. Nest detection probabilities obtained for more cryptic species than the Herring Gull are on average lower than our estimates [from 0.67 to 0.87 for the White-winged Dove *Zenaida asiatica* (Nichols *et al.* 1986); from 0.60 to 0.85 for five duck species (Buckland *et al.* 1993); from 0.17 to 0.62 for nine tropical Columbidae species (Rivera-Milán 2001)].

Methods other than the double-observer approach may be used to estimate nest detection probabilities. Nichols *et al.* (1986) used a capture-recapture method with five recapture occasions and estimated detectability parameters using closed population estimators. Buckland *et al.* (1993) and Rivera-Milán (2001) used line transect methods. These methods require different assumptions that may or may not be fulfilled depending on the ecology of the studied species (Table 5). For example, the main assumption of the distance method that all nests on the line transect are detected, may not be fulfilled when nests are situated in dense vegetation structures such as trees. The allocation of effort (i.e., number of observers) also varies between methods and has to be taken into account before applying field protocols. Other methods, such as removal models (Farnsworth *et al.* 2002), can probably be used to estimate detection prob-

**Table 5. Methods used to estimate nest detection probabilities.**

Method	Assumptions	Effort
Double-observer approach*	<ul style="list-style-type: none"> <li>• no heterogeneity in detection probabilities between nests</li> <li>• primary observer independent of secondary observer</li> <li>• same probability of recording a nest regardless of primary or secondary role</li> </ul>	Two observers
Capture-recapture models*	<ul style="list-style-type: none"> <li>• closed population (no nest appears or disappears) between capture sessions</li> </ul>	At least five observers
Distance methods	<ul style="list-style-type: none"> <li>• complete detection of nests on line or point</li> <li>• no distance measurement error</li> </ul>	One observer

\*Indicates the methods for which it is required to mark the nests.

abilities and abundance, but to our knowledge this method has not been used for estimating nest detection probabilities.

#### Other Sources of Error

Despite efforts to take into account the source of error due to nest detectability, there are a number of other potentially significant sources of error that might affect colony size estimates of large gulls. First, our estimates are based upon one visit to the colonies, at which time we estimated that the maximum numbers of nests were present. A factor leading to underestimation of the colony sizes is the effect of asynchronous nesting and nest failure. The accuracy of counts of unmarked nests may be strongly affected by nests missed because they had started and failed prior to or after surveys, or during the inter-visit interval (P. C. Frederick, pers. comm.). This bias cannot be corrected by increasing the number of surveys during the breeding season, since the bias stems from the fact that nests are not individually identified, a problem that cannot be addressed by increasing count frequency (P. C. Frederick, pers. comm.). Nesting asynchrony may also affect the nest detection probability and consequently bias the estimates, since for example nests with chicks may be more easily detected than nests with eggs. For highly asynchronous species, it should be easy to take into account this potential source of variability by classifying nests into stages (e.g., egg, chick), and by testing for a nesting stage effect on detection probabilities during the modeling process. Second, it has been shown that some pairs of Lesser Black-backed Gulls build more than one nest, and that a proportion of nests built do not receive eggs (O'Connell *et al.* 1997). These authors showed that, for colonies in Lancashire, UK, counts of nests have to be multiplied by 0.61 to obtain a realistic estimate of the number of pairs. Finally, as for other seabird species, intermittent breeding has been documented for the Herring Gull and the Lesser Black-backed Gull (Calladine and Harris 1997). During a two years study, Calladine and Harris (1997) found that between 33% and 40%

of adults failed to breed in these species, although they were present at the colonies.

Monitoring programs of nesting Laridae (but also of many other colonial bird species) are often conducted without taking into account these sources of bias. In future efforts to estimate the number of nests in colonial species such as gulls, it may be desirable to take into account nesting asynchrony, non-breeders (and nests without eggs), and nest detection probability for different observers and for variables such as vegetation cover. We are aware of the higher allocation of effort needed to obtain unbiased estimates. However, the effort may be optimized by using a double sampling approach (Bart and Earnst 2002), in which a correction factor taking into account nesting asynchrony and empty nests (for example using a sample of marked or mapped nests), and nest detection probability (for example using a double observe approach) can be estimated on part of the colonies surveyed, and used to correct more naïve abundance estimates obtained on the remaining part. Finally, since the detectability may vary as a function of time between each survey, it may be useful to estimate it during each survey in order to avoid bias when trying to detect trends in abundance.

These sources of bias may have effects on the detection of trends from monitoring programs involving many colonies and observers because of heterogeneity between colonies and observers. For example, present estimates obtained from standard surveys indicate 90,000 breeding pairs of Herring Gulls and 23,000 breeding pairs of Lesser Black-backed Gulls in France (Cadiou *et al.* in press). Given our estimates of nest detection probability for a single observer, and assuming, for example, a correction factor of 0.61 to take into account empty nests (O'Connell *et al.* 1997), the breeding population size may well be between 68,900 and 75,700 breeding pairs of Herring Gulls, and between 17,700 and 19,200 breeding pairs of Lesser Black-backed Gulls.

#### ACKNOWLEDGMENTS

Special thanks to J. Gallen and A. Loiret for organizing the censuses. We also wish to thank J. Cabelguen, A. Clément, B. Cocardon, B. Demont, C. Dumas, E. Even-

Jones, M. Fortin, J. Gallen, R. Gallais, A. Loiret, N. La Magourou, A. Le Nevé, G. Perrin, A. Le Roch, H. Le Roy, P. Le Roy, and D. Masci for assistance in counting nests. We are grateful to Morten Frederiksen, John Coulson and an anonymous referee for criticisms of the manuscript.

## LITERATURE CITED

- Barker, R. J. and J. R. Sauer. 1992. Modelling population change from time series data. Pages 182-194 in *Wildlife 2001: Populations* (D. R. McCullough and R. H. Barrett, Eds.). Elsevier, New York.
- Bart, J. and S. Earnst. 2002. Double sampling to estimate density and population trends in birds. *Auk* 119: 36-45.
- Bibby, C. J., N. D. Burgess, D. A. Hill and S. Mustoe. 2000. *Bird census techniques*. Academic Press, London.
- Bosch, M., D. Oro, F. J. Cantos and M. Zabala. 2000. Short term effects of culling on the ecology and population dynamics of a Yellow-legged Gull colony. *Journal of Applied Ecology* 37: 369-385.
- Brooks, E. N. and J.-D. Lebreton. 2001. Optimizing removals to control a metapopulation: application to the Yellow-legged Gull (*Larus cachinnans*). *Ecological Modelling* 136: 269-284.
- Buckland, S. T., D. R. Anderson, K. P. Burnham and J. L. Laake. 1993. *Distance sampling: estimating abundance of biological populations*. Chapman and Hall, London.
- Burnham, K. P. and D. R. Anderson. 2002. *Model selection and multimodel inference: a practical information-theoretic approach*. 2nd ed. Springer, New York.
- Cadiou, B., J.-M. Pons and P. Yesou (Eds.). In press. *Oiseaux marins nicheurs de France métropolitaine (1960-2000)*. Groupe d'Intérêt Scientifique pour les Oiseaux Marins.
- Calladine, J. and M. P. Harris. 1997. Intermittent breeding in the Herring Gull *Larus argentatus* and the Lesser Black-backed Gull *Larus fuscus*. *Ibis* 139: 259-263.
- Cook, R. D. and J. O. Jacobson. 1979. A design for estimating visibility bias in aerial surveys. *Biometrics* 35: 735-742.
- del Hoyo, J., A. Elliott and J. Sargatal. 1996. *Handbook of the Birds of the World*, Vol. 3. Lynx edicions, Barcelona.
- Erwin, R. M. 1980. Censusing waterbird colonies: some sampling experiments. *Transactions of the Linnean Society New York* 9: 77-86.
- Farnsworth, G. L., K. H. Pollock, J. D. Nichols, T. R. Simons, J. E. Hines and J. R. Sauer 2002. A removal model for estimating detection probabilities from point-count surveys. *Auk* 119: 414-425.
- Ferns, P. N. and G. P. Mudge. 1981. Accuracy of nest counts at a mixed colony of Herring and Lesser black-backed Gulls. *Bird Study* 28: 244-246.
- Furness, R. W. and J. J. D. Greenwood (Eds.). 1993. *Birds as Monitors of Environmental Change*. Chapman and Hall, London.
- Hand, J. L., W. E. Southern and K. Vermeer (Eds.). 1985. *Ecology and Behavior of Gulls*. Studies in Avian Biology 10. Cooper Ornithological Society, Camarillo, USA.
- Henry, J. and J. Y. Monnat. 1981. *Oiseaux marins de la façade atlantique française*. Unpublished report Société pour l'Etude et la Protection de la Nature en Bretagne.
- Hines, J. E. 2000. Program DOBSERV: user's instructions. <http://www.mbr-wrc.usgs.gov/software.html#dobserv>.
- Lancia, R. A., J. D. Nichols and K. H. Pollock. 1994. Estimating the number of animals in wildlife populations. Pages 215-253 in *Research and management techniques for wildlife and habitats* (T. Bookhout, Ed.). The Wildlife Society Publications, Bethesda, MD.
- Newton, I. 1998. *Population limitation in birds*. Academic Press, London.
- Nichols, J. D. 1992. Capture-recapture models: using marked animals to study population dynamics. *BioScience* 42: 94-102.
- Nichols, J. D., R. E. Tomlinson and G. Waggerman. 1986. Estimating nest detection probabilities for White-winged Dove nest transects in Tamaulipas, Mexico. *Auk* 103: 825-828.
- Nichols, J. D., J. E. Hines, J. R. Sauer, F. W. Fallon, J. E. Fallon and P. J. Heglund. 2000. A double-observer approach for estimating detection probability and abundance from point counts. *Auk* 117: 393-408.
- Nisbet, I. C. T. 1976. Selective effects of predation in a tern colony. *Condor* 77: 221-226.
- O'Connell, M. J., J. C. Coulson, S. Raven and S. Joyce. 1997. Nonbreeding and nests without eggs in the Lesser Black-backed Gull *Larus fuscus*. *Ibis* 139: 252-258.
- Orgeas, J., E. Vidal and P. Poneil, P. In press. Colonial seabirds change beetle assemblage on a Mediterranean island. *Ecoscience*.
- Oro, D., L. Jover and X. Ruiz. 1996. Influence of trawling activity on the breeding ecology of a threatened seabird, Audouin's Gull *Larus audouinii*. *Marine Ecology Progress Series* 139: 19-29.
- Pollock, K. H., J. D. Nichols, T. R. Simons, G. L. Farnsworth, L. L. Bailey and J. R. Sauer. 2002. Large scale wildlife monitoring studies: statistical methods for design and analysis. *Environmetrics* 13: 105-119.
- Pons, J. M. and P. Migot. 1995. Life history strategy of the Herring Gull: variations of the survival and the fecundity parameters of a population under different feeding conditions. *Journal of Animal Ecology* 64: 592-599.
- Rivera-Milán, F. F. 2001. Transect surveys of Columbidae nests on Puerto Rico, Vieques, and Culebra islands. *Condor* 103: 332-342.
- Sadoul, N. 1996. *Dynamique spatiale et temporelle des colonies de Charadriiformes dans les salins de Camargue: implications pour la conservation*. Unpublished Ph.D. thesis, University of Montpellier II, France.
- Sadoul, N. 1997. The importance of spatial scales in long-term monitoring of colonial Charadriiformes in southern France. *Waterbirds* 20: 330-338.
- Thompson, W. L., G. C. White and C. Gowan. 1998. *Monitoring vertebrate populations*. Academic Press, San Diego.
- Vidal, E., F. Médail and T. Taton. 1998. Is the Yellow-legged Gull a superabundant bird species in the Mediterranean? Impact on fauna and flora, conservation measures and research priorities. *Biodiversity and Conservation* 7: 1013-1026.
- Walsh, P. M., D. J. Halley, M. P. Harris, A. del Nevo, I. M. W. Sim and M. L. Tasker. 1995. *Seabird monitoring handbook for Britain and Ireland*. A compilation of methods for survey and monitoring of breeding seabirds. JNCC/RSPB/ITE/Seabird Group, Peterborough.
- Wanless, S. and M. P. Harris. 1984. Effect of date on counts of nests of Herring and Lesser Black-backed Gulls. *Ornis Scandinavica* 15: 89-94.
- Wiens, J. A., J. F. Addicott, T. J. Case and J. Diamond. 1986. Overview: the importance of spatial and temporal scale in ecological investigations. Pages 145-153 in *Community ecology* (J. Diamond and T. J. Case, Eds.). Harper and Row, New York.