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Does El Niño Affect Survival Rate of Mediterranean Populations of Cory's Shearwater?

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Abstract.—Cory's Shearwater (*Calonectris diomedea diomedea*) survival rates were analyzed by means of capture histories of a small population of breeding birds banded from 1988 to 1998 in two caves on the Tremiti Islands, South Italy, to test the hypothesis that El Niño has a negative effect on Cory's survival rates. We tested the hypothesis of a relationship between Cory's survival rates and the ENSO cycle, modeling the survival and recapture probabilities by means of the program SURGE. After allowing for temporal variation in capture probabilities, we found that the variation of survival rates during our study period was in accordance with the ENSO cycle. We found no evidence of a negative effect of the warm episodes (El Niño) on the survival rates of Cory's Shearwater; instead, a lowering of survival rates were detected in connection with the cold episodes (La Niña). The main effect of La Niña over the range of Cory's Shearwater is cooler and wetter conditions along the Atlantic coasts and in South Africa, where the birds winter, but La Niña conditions may also strengthen the Atlantic hurricane season. We then constrained the survival rate by the number of intense hurricane days, producing a second, better-fitted model. The effects of the greater numbers of Atlantic hurricanes and storms may be a possible explanation of the lowering of Cory's survival rate observed during La Niña years. Received 25 November 1999, accepted 2 February 2000.

Key words.—Cory's Shearwater, *Calonectris diomedea*, population, survival, Italy, El Niño, La Niña, ENSO, hurricane.

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El Niño is the name Peruvian fishermen gave to coastal sea-temperature warming usually appearing around Christmas. More generally, El Niño refers to the warming of the eastern and central Pacific that roughly occurs every three to seven years, in association with a weakening of the trade winds. The flip side of El Niño, La Niña, is characterized by stronger than normal trade winds and unusually cold sea-surface temperatures in the tropical Pacific. Both El Niño and La Niña are accompanied by swings in atmospheric pressure between the eastern and western Pacific, known as the Southern Oscillation. These phenomena are collectively referred to as El Niño/Southern Oscillation, or ENSO, which also includes periods of near-normal conditions (Trenberth 1997).

The impact of ENSO on food chains and fisheries along the Pacific coast of South America are well known, as are the devastating effects on sea-bird populations (Duffy *et al.* 1988; Schreiber and Schreiber 1989). During the 1982-1983 ENSO event, up to 85% of the seabird population in Peru was killed (Schreiber and Schreiber 1984). Some factors which may negatively affect seabird population during ENSO include: flooding of nesting sites, changing atmospheric circulation patterns, increasing sea surface temperatures and migration or even deaths of their prey (Schreiber and Schreiber 1984).

Moreover, ENSO is now known to have global effects (teleconnections) on temperature, precipitation patterns and storms fre-

quencies in many regions of the world (Cane 1983; Ropolewski and Halpert 1987; Tremberth *et al.* 1998).

Cory's Shearwater (*Calonectris diomedea diomedea*) has a large breeding population in the Mediterranean Sea, probably exceeding 65,000 pairs, that overwinters mainly in the Southern Atlantic Ocean (Thibault 1997). Their breeding sites coincide with a heavily populated area and, at least until recently, many colonies have suffered heavy exploitation for food or fish bait, predation and competition by introduced mammals like rats, cats and rabbits (Thibault 1995) and habitat modification. As with other Procellariiforms, Cory's Shearwaters are long-lived birds with a low reproduction rate. A single egg is laid each year and sexual maturity is reached only after several years (Del Hoyo *et al.* 1992); therefore, their populations may be very susceptible to adult mortality. Because the species in many places is difficult to census, population trends are poorly known (Del Nevo in Tucker and Heath 1994).

The high survival rates of many Procellariiformes are now relatively well known from analyses based on modern capture-recapture models (Dunnet and Ollason 1978; Weimerskirch *et al.* 1987), but few such studies have been examined yearly variations in survival rates and their causes.

In 1988, we started a long-term banding project at the Tremiti Islands in the Southern Adriatic Sea, to monitor survival rate and breeding success, and to examine population trends and their possible causes.

This paper estimates survival rates of a study population of Cory's Shearwater and tests the hypothesis of a negative effect on this population of El Niño/Southern Oscillation (ENSO) climatic anomalies (Ristow *et al.* 1990). These authors observed irregularities in the return rate of banded juveniles and in the number of an adult breeding population on a small Aegean Island, and they suggested that when these Mediterranean seabirds overwinter in the Southern Atlantic Ocean, anomalous climatic phenomena linked to ENSO could affect their survival rates.

STUDY SITE AND METHODS

Our study site was located in the Tremiti Islands (S. Italy, 42°8'N, 15°30'E), the *locus typicus* of Cory's Shearwater described by Scopoli (1769). About 250-350 pairs of Cory's, and 100-150 pairs of Yelkouan Shearwaters (*Puffinus yelkouan*) have bred in recent years (Bricchetti 1988; Lo Valvo e Massa 1992), in three different nesting sites typologies: a) burrows occupied by single breeding pairs, b) little caves with 1-4 pairs, c) large caves with tens of pairs. We worked in two caves of the third type.

From 1988 to 1998, from the second half of May to the first half of June, about forty nest cavities of Cory's Shearwater were inspected regularly once annually, after egg laying. Birds in the nests were captured by hand and immediately released after banding and measurements (wing, bill, tarsus, weight). The ring numbers of previously-banded birds were recorded. We were able to sex most birds by biometry and vocalizations when handled (Ristow and Wink 1980).

Since the incubation shifts of the partners last about 4-8 days (Thibault 1997) and our banding sessions usually lasted 1-4 days, we expected each year to mark about 50% of the breeding adults. During our day-time visits, we found usually only incubating bird, but during a single visit at night we found other birds, perhaps not all breeders. Some exceptions to our visit protocol occurred in 1997 and 1998, when not all the burrows could be inspected.

Cohorts of marked birds were composed of birds marked as breeding in the same year, but probably not hatched in the same year. After several years of banding, it was possible that unmarked birds were in their first breeding attempt, but we detected only four birds previously banded by us as nestlings at this colony.

Data analysis

In the last two decades, the problem of estimating survival rates from recaptures of marked birds has received increased attention, and an array of open-population models and associated model-selection criteria (e.g., Nichols 1994; Lebreton 1995) have been developed from the earlier work of Cormack (1964), Jolly (1965) and Seber (1965). Consequently, a growing number of field studies have successfully made use of this methodology.

Survival estimates based on these models are better than estimates based on return rates only, because return-rate methodology, to yield unbiased estimates, requires the very unlikely assumption that capture probability is one, i.e., that every marked animal still in the population is actually caught (Nichols and Pollock 1983). As shown by theoretical and empirical studies, the lower the capture probabilities, the larger the disparity between return rates and good survival estimates (Martin *et al.* 1995).

A major drawback in estimating mortality from capture-recapture studies at a single site (as opposed to recoveries from a large geographic area) is the possibility of permanent emigration. If a significant part of the population, although alive, does not return to the sampling site in subsequent sampling periods, then the mortality estimate will be positively biased. As a result, strongly philopatric species are better for investigations with capture-recapture methods. Breeding procellariiforms are remarkably faithful to their nest sites year after year, quite fearless of humans and easy to capture. Such characteris-

tics make these birds ideal subjects for long-term demographic studies with capture-mark-recapture methods.

Survival rates and recapture probabilities of our Cory's Shearwaters were estimated, following Cormack-Jolly-Seber and related models. Survival probability (Φ) is the probability that a live bird at period i is still alive and in the area exposed to sampling efforts at period $i + 1$. As with all capture-recapture sampling, the complement of the survival probability estimate includes both mortality and permanent emigration from the study site. Capture probability (P_i) is the conditional probability that an individual is caught in period i , given that the individual is alive and in the area exposed to sampling effort at the time of sampling.

The basic Cormack-Jolly-Seber (CJS) model allows for variability of Φ_i and P_i among different periods (e.g., successive years), but to obtain unbiased estimates of the parameters of interest, the assumptions of the model must be met (Seber 1982). The most important assumptions are: 1) every bird present in the population at the time of sampling in period i has the same capture probability; 2) every marked bird present in the population immediately after sampling period i has the same survival probability until period $i + 1$; 3) marks are not lost or overlooked; 4) all emigration is permanent; 5) sampling is instantaneous (i.e., sampling time is negligible in relation to the inter-sample period). Some of these assumptions may be abandoned with more general models; on the contrary, reduced-parameter models make more restrictive assumptions (e.g., survival and/or capture probabilities are forced to be constant in the time).

We started the analysis using the program RELEASE (Burnham *et al.* 1987) to compute the goodness-of-fit test of the most general model, then we fitted models making further restrictions, using the program SURGE (Pradel and Lebreton 1991; Cooch *et al.* 1997). Because of SURGE's ability to handle constrained models, we fitted models where temporal variation in survival is modeled as a logit-link function of specific climatic events and compared them with the fit of the more general model where survival varies simply with time. Such an approach increases the overall precision of estimates because time-dependence is expressed in a parsimonious way and the effect of the external variable can be tested by comparing between models. This procedure is better than an ordinary regression analysis of the CJS estimates over the variable, because it avoids the pitfall of the autocorrelation of estimates (Lebreton *et al.* 1992).

We categorized the climate variables with 0 (years without the anomaly) and 1 (years with the anomaly). The years mark the start of each episode (warm or cold) that usually lasts through the winter of that year and into the spring of the next year. During the study period, cold episodes (La Niña) started in 1988 and in 1995, while warm episodes (El Niño) were especially strong in 1991, 1993, 1994 and 1997 (Tremberth 1997). Finally, we also tested in the same way the number of Atlantic intense hurricane days (Landsea *et al.* 1996, 1997), assuming that this might be the proximal cause affecting bird survival.

Selection of the most appropriate model for our purposes was finally based on Akaike's Information Criterion (AIC) (Akaike 1973; Lebreton *et al.* 1992; Anderson *et al.* 1994). Akaike's procedure allows comparison of models that are not necessarily nested and, as it gives a penalty to models with too many parameters, it retains the most parsimonious model. The lower the AIC value,

the more appropriate the model is for the experimental data. AIC can be viewed as an objective function to adequately describe the data, employing the model with fewest parameters, even in presence of heterogeneity of capture and/or survival probabilities (Burnham *et al.* 1995). The idea is to select a model that contains sufficient parameters to avoid bias, yet not so many that precision is unnecessarily lost (Burnham and Anderson 1992; Lebreton *et al.* 1992).

RESULTS

From 1988 to 1998 we banded 112 adult Cory's Shearwaters, and many of them were recaptured for several years, for a total of 345 captures (Table 1). We computed the goodness-of-fit test (Test 2 + Test 3, program RELEASE) of the general model including time (CJS model) and sex effects for both survival and capture probabilities. The usual notation for this model is (Φ_{s^*t}, P_{s^*t}) where s stands for sex and t for time. The overall results ($X^2 = 39.569$, $P = 0.700$) and all the components of the test suggest that the basic assumptions of the Cormack-Jolly-Seber model are nicely met. The RELEASE test for differences between groups (sexes) failed to find any differences in survival or capture rates ($X^2 = 11.686$, $P = 0.899$), allowing the pooling of male and female data for further analysis.

To investigate the effects of climate anomalies, we further fitted models with time constraints on survival and capture rates, using the program SURGE. The output provides the deviance of the model fitted to an additive constant that depends on the data set but not on the model. This relative deviance may be used to compute likelihood-ratio tests (LRT) and the AIC of the models.

We first tested for a time-effect alternatively on recapture and survival rate. We found, at this level of analysis, the lowest AIC for the model with constant survival, time-dependent capture probabilities and no sex differences (ΦPt).

To further test the hypothesis that climate anomalies affect the survival of shearwaters, we then added constraints to force the survival probabilities over the years, warm or cold anomalies having one value, and normal years, another. We categorized

Table 1. Data summarized in "B-Table" format (see Leslie *et al.* 1953).

Year of last capture	Year of recapture										
	88	89	90	91	92	93	94	95	96	97	98
1988	—	19	4	2	0	0	0	1	0	0	0
1989	—	—	19	6	2	0	0	1	1	0	0
1990	—	—	—	27	1	2	1	2	0	0	0
1991	—	—	—	—	20	10	2	4	2	1	1
1992	—	—	—	—	—	11	13	2	2	1	0
1993	—	—	—	—	—	—	6	12	3	2	0
1994	—	—	—	—	—	—	—	10	6	1	1
1995	—	—	—	—	—	—	—	—	10	4	2
1996	—	—	—	—	—	—	—	—	—	8	4
1997	—	—	—	—	—	—	—	—	—	—	7
1998	—	—	—	—	—	—	—	—	—	—	—
Total Recaptures	0	19	23	35	23	23	22	32	24	17	15
New birds captured	38	15	15	15	15	10	4	0	0	0	0
Total birds captured	38	34	38	50	38	33	26	32	24	17	15
% of new birds	100	44	39	30	39	30	15	0	0	0	0

the effect of El Niño years with (n) and that of La Niña years with (v). We used an additive model ($\Phi_{n+v,Pt}$), because there is no interaction between cold and warm episodes and found a better fit to the data than models not depending on these anomalies. We then compared models that depend only on warm (El Niño) or on cold (La Niña) episodes, to determine which of these two climatic anomalies has the greatest effect on Cory's Shearwaters survival.

The lowest AIC value (897.166) among the models studied was reached with the $\Phi_{v,Pt}$ model (Table 2), in which the survival rate depends on La Niña years and the capture rates are time dependent. Besides the

Table 2. Models selection criteria.

N. progr.	Model	Np	Deviance (-2 Ln L)	AIC
1	Φ_{S^*t,Ps^*t}	38	855.145	931.145
2	$\Phi_{t,Pt}$	19	871.877	909.877
3	$\Phi_{,Pt}$	11	883.067	905.067
4	$\Phi_{t,P}$	11	902.135	924.135
5	$\Phi_{,P}$	2	912.456	916.456
6	$\Phi_{n+v,Pt}$	13	873.065	899.065
7	$\Phi_{n,Pt}$	12	880.461	904.461
8	$\Phi_{v,Pt}$	12	873.166	897.166
9	$\Phi_{h',Pt}$	12	875.556	899.556
10	$\Phi_{h,Pt}$	12	876.337	900.337

models shown in Table 2, we also tested additive models (i.e., models without interaction between time and sex on survival and/or capture probabilities), but found no significant improvement in the AIC criterion.

The difference in survival between La Niña years and non-La Niña years was significant, as shown by the large difference between AIC ($\Phi_{v,Pt}$) and AIC($\Phi_{,Pt}$) in Table 2 and also by the result of the likelihood ratio test between them ($X^2 = 9.901$, $P = 0.002$). Therefore the estimated survival rates yielded by the $\Phi_{v,Pt}$ model are shown in Table 3.

In contrast, we found no evidence supporting the hypothesis of a negative effect of El Niño on Cory's survival rates, not only on the basis of the AIC values, but also because the estimated survival rates of the $\Phi_{v,Pt}$ mod-

Table 3. Adult survival rates of Cory's Shearwater (all birds) according to models.

$\Phi_{,Pt}$	$\Phi = 0.885$; s.e. = 0.018; conf. int. = 0.850 - 0.921
$\Phi_{u,Pt}$	Φ (1988, 1995) = 0.694; s.e. = 0.067; 95% conf. int. = 0.550-0.808
	Φ (all other years) = 0.923; s.e. = 0.019; 95% conf. int. = 0.874-0.954

el during the years with strong El Niño were greater, the inverse of what we expected.

During La Niña years, the Atlantic coasts and specially the South Africa coast are wetter and cooler than usual, but probably the most prominent weather feature of these years is the greater frequency of Atlantic tropical cyclones and the greater intensity of each storm (Gray 1984; Pielke and Landsea 1999) than in El Niño or "neutral" years. This increased "storminess" could be the proximal link with the observed Cory's survival pattern, so we explored this possibility by testing the effect of the Atlantic hurricane season on survival by means of two new constrained models: the first used the actual number of intense hurricane days (h) as covariates, while on the second (h') we categorized the year with a number of intense hurricane days greater (1) or lower (0) than average (Landsea *et al.* 1996, 1997) (see Table 4). The AIC's of these last models were among the lowest after that of the best model (Φ_v , Pt).

DISCUSSION

On the basis of methodological and biological considerations, we retained our model-based estimates as good approximations of the actual survival. We expected our data to meet assumptions (1) and (2), because we studied only birds banded as breeding adults. Moreover, because in Cory's Shearwaters the age of first breeding averages 7.3 years for males (interval 5-9) and 7.6 for females (interval 7-9) (Ristow *et al.* 1990, confirmed by four observations at our study site), a significantly lower survival rate of first breeders would be surprising. More likely would be a lower philopatry, specially after a breeding failure, by the new breeders than by the experienced breeders (Thibault 1997). If this was the case, the survival rate

estimate could be biased, representing a weighted mean of two different survival rates. Looking at each component of the RELEASE goodness-of-fit test, we noticed no structural problem; the results of Test 3.SR suggest no significant differences in survival probabilities of newly-marked and previously-marked animals (Burnham *et al.* 1987; Pradel *et al.* 1997). The third assumption is probably very nicely met because of the moderate number of animals handled on each capture occasion, as is assumption (5), since the sample period was limited to a few days every year in May.

Some problems may instead be generated by possible violation of the fourth assumption, birds undertaking temporary emigration. Sabbatical years (Mougin *et al.* 1984) are known in Cory's Shearwater, implying that in certain years some individuals, although alive, are not in the sampled area. This behavior affects 4-10% (Mougin *et al.* 1984, 1985; Thibault 1997) of both sexes in breeding *C. d. diomedea borealis* each year at Selvagem Grande, mainly inexperienced breeders, but was not observed on Crete with *C. d. diomedea* by Ristow *et al.* (1992). Fortunately, survival estimates are unbiased if the temporary emigration is completely random, although the precision of the estimates is reduced (Kendall *et al.* 1997). Even if Markovian emigration occurs (i.e., the probability of being a temporary emigrant depends on the temporary emigration status of the preceding periods), the survival rate estimates should show only minor bias if the rate of emigration affects <10% of the population (see Spendelow and Nichols 1989; Kendall *et al.* 1997). Moreover a higher rate of temporary emigration should be detected by the goodness-of-fit test to the Cormack-Jolly-Seber model.

Previous studies of Cory's Shearwater found a survival rate of 89-90% in an Aegean

Table 4. Number of intense hurricane days (after Landsea *et al.* 1996, 1997).

Years	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997
h—Intense hurricane days	8.0	10.8	1.0	1.2	3.2	0.8	0.0	11.50	13.0	1.0?
h'—Years above (1) or below (0) the mean	1	1	0	0	0	0	0	1	1	0

(eastern Mediterranean) population (Ristow *et al.* 1990) and of 93% (86-96%) at Lavezzi Island, Corsica (Thibault 1997). Our results are more or less similar to these values, depending on the model chosen (Φ ,Pt or Φ ,Pt), and the bigger estimate for the Atlantic race (*C. d. borealis*) that breeds in the Azores and Canaries (95%; after Mougin *et al.* 1987) may be expected (Saether 1989) as a consequence of its larger size (817-953 g versus 560-730 g of *C. d. diomedea*).

Our best model, according to AIC, allows us to retain the hypothesis of an influence of climatic anomalies on survival, focusing on cold (La Niña) and not on warm (El Niño) episodes; in other words, strong cold episodes are negatively correlated with survival rate of adult Cory's Shearwaters. The biological meaning of this pattern flows from the global effect of climatic anomalies in the main wintering area of Mediterranean Cory's Shearwater.

Global climate anomalies associated with La Niña tend to be opposite to those of El Niño; in particular, El Niño conditions may suppress the development of tropical storms and hurricanes in the Atlantic and La Niña favors hurricane formation there (Pielke and Landsea 1999).

Most Mediterranean Cory's Shearwaters at the end of their breeding season enter the Atlantic through the Straits of Gibraltar (Teileira 1980), then move rapidly south and become abundant during the northern winter along the South African coast (Mougin *et al.* 1988; del Hoyo *et al.* 1992; Thibault 1997). Detailed indications about the movement and winter quarters of Mediterranean birds are scanty, because of the identification problems posed by the presence of the Atlantic races *borealis* and *edwardsii*. However, recent observations along the Senegalese coasts showed that in late October and early November, Cory's Shearwaters begin their southward migration and most of the 4,585 *Calonectris* shearwaters seen going south between 29 October-4 November 1997 were identified as *C. d. diomedea* (Marr *et al.* 1998).

We suspect that the more frequent Atlantic hurricanes in La Niña years were responsible for the observed reduction in survival rates of the birds released in 1988 and 1995,

compared to the normal value. This hypothesis is also acceptable in view of the AIC results of the models constrained by intense hurricane days (h and h').

Storm condition, with gale-force winds, can influence mortality by causing increased heat loss, displacing birds to areas with less food, or making foraging more difficult, especially for birds that feed mainly from the sea surface, as do Cory's Shearwaters (Underwood and Stowe 1984; Elkins 1988), since common fish prey species may move deeper into the water column in response to sea condition (Nikolski 1963; Lo Valvo and Massa 1992). Due to autumn and northern-winter storms, wrecks of large numbers of seabirds of many species, including shearwaters, petrels and auks, are well documented for both North Atlantic coasts (e.g., Fisher and Lockley 1954; Texeira 1987; Elkins 1988; Post 1998) and the west coast of South Africa, where albatrosses also are involved (Ryan and Avery 1987).

The Atlantic hurricane season (July through November) ^{is going} occurs toward the end ^{at} of the time the birds reach the Atlantic Ocean, and we have no direct evidence of winter mortality of Cory's Shearwaters. Therefore, analysis of other marked colonies and longer series of data, including more La Niña years, are badly needed to test our hypothesis.

In contrast, we found no evidence supporting the hypothesis of a negative effect on survival during warm episodes (El Niño) (Ristow *et al.* 1990), not only on the basis of the results of the model selection criteria, but also because, constraining the survival during El Niño years, we obtained a positive rather than a negative effect on survival. In this case, we stress that we are in a very good position to judge the effects of El Niño, because the study period was distinguished by large warm anomalies, the 1997 event being the largest on record (McPhaden 1999).

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LITERATURE CITED

- Akaike, H. 1973. Information theory and an extension of the maximum likelihood principle. Pages 267-281 in International symposium on information theory (B. N. Petran and F. Csaki, Eds.). Akademiai Kiado, Budapest, Hungary.
- Anderson, D. R., K. P. Burnham and G. C. White. 1994. AIC model selection in overdispersed capture-recapture data. *Ecology* 75: 1780-1793.
- Brichetti, P. 1988. Distribuzione geografica degli uccelli nidificanti in Italia, Corsica e Isole Maltesi. 5. Aggiunte e Rettifiche. *Natura Bresciana* 14: 110-126.
- Brownie, C. and D. S. Robson. 1983. Estimation of time-specific survival rates from tag-resighting samples: a generalization of the Jolly-Seber model. *Biometrics* 39: 437-453.
- Burnham, K. P. and D. R. Anderson. 1992. Data-based selection of an appropriate biological model: the key to modern data analysis. Pages 16-30 in *Wildlife 2001: Populations* (D. R. McCullough and R. H. Barrett, Eds.). Elsevier, London.
- Burnham, K. P., D. R. Anderson, G. C. White, C. Brownie and K. H. Pollock. 1987. Design and analysis methods for fish survival experiments based on release-recapture. *American Fisheries Society Monograph* 5: 1-437.
- Burnham, K. P., D. R. Anderson and G. C. White. 1995. Selection among open population capture-recapture models when capture probabilities are heterogeneous. *Journal of Applied Statistics* 22: 611-624.
- Cane, M. A. 1983. Oceanographic events during El Niño. *Science* 222: 1189-1195.
- Clobert, J., J.-D. Lebreton and D. Allaine. 1987. A general approach to survival rate estimation by recaptures or resightings of marked birds. *Ardea* 75: 133-142.
- Cooch, E. G., R. Pradel and N. Nur. 1996. A practical guide to mark-recapture analysis using SURGE. Centre d'écologie Fonctionnelle et Evolutive. CNRS, Montpellier, France.
- Cormack, R. M. 1964. Estimates of survival from the sighting of marked animals. *Biometrika* 51: 429-438.
- Del Hoyo, J., A. Elliott and J. Sargatal (Eds.). 1992. *Handbook of the birds of the world*. Vol. I. Lynx Ed., Barcelona.
- Del Nevo, A. 1994. Cory's Shearwater. Pages 66-67 in *Birds in Europe: their conservation status* (G. M. Tucker and M. F. Heath, Eds.). BirdLife International, Cambridge, U.K.
- Duffy, D. C., W. E. Arntz, H. T. Serpa, P. D. Boersma and R. L. Norton. 1988. A comparison of the effects of El Niño and the Southern Oscillation on birds in Peru and the Atlantic Ocean. Pages 1740-1746 in *Acta 19 Congressus Internationalis Ornithologici*, Ottawa.
- Dunnet, G. M. and J. C. Ollason. 1978. The estimation of survival rate in the fulmar, *Fulmarus glacialis*. *Journal of Animal Ecology* 47: 507-532.
- Elkins, N. 1988. Weather and bird behavior. Poyser, Calton, U.K.
- Fisher, J. and R. M. Lockley. 1954. *Sea-birds*. Collins, London.
- Granadeiro, J. P., B. Massa and M. Lo Valvo. 1997. Cory's Shearwater. Page 20 in *The EBCC atlas of European birds: Their distribution and abundance* (E. J. M. Hagemeyer and M. J. Blair, Eds.). T. & A. Poyser, London.
- Gray, W. 1984. Atlantic seasonal hurricane frequency: Part I. El Niño and 30 mb quasi-biennial oscillation influence. *Monthly Weather Review* 112: 1649-1668.
- Jolly, G. M. 1965. Explicit estimates from capture-recapture data with both death and immigration-stochastic model. *Biometrika* 52: 225-247.
- Kendall, W. L., J. D. Nichols and J. E. Hines. 1997. Estimating temporary emigration using capture-recapture data with Pollock's robust design. *Ecology* 78: 563-578.
- Landsea C. W., W. M. Gray, P. W. Mielke Jr., K. J. Berry and R. K. Taft. 1996. June to September rainfall in North Africa: verification of our 1996 forecasts and an extended range forecast for 1997. Paper released on 6 December, 1996. Department of Atmospheric Science, Colorado State University, Fort Collins, CO.
- Landsea C. W., W. M. Gray, P. W. Mielke Jr., K. J. Berry and R. K. Taft. 1997. June to September rainfall in North Africa: verification of our 1997 forecasts and an extended range forecast for 1998. Paper released on 5 December 1997. Department of Atmospheric Science, Colorado State University, Fort Collins, CO.
- Lebreton, J. D. 1995. The future of population dynamics studies using marked individuals: a statistician's perspective. *Journal of Applied Statistics* 22: 1009-1030.
- Lebreton, J. D., K. P. Burnham, J. Clobert and D. R. Anderson. 1992. Modeling survival and testing hypotheses using marked animals: a unified approach with case studies. *Ecological Monograph* 62: 67-118.
- Leslie, P. H., D. Chitty and H. Chitty. 1953. The estimation of population parameters from data obtained by means of the capture-recapture method: III. An example of the practical applications of the method. *Biometrika* 40: 137-169.
- Lloyd, C. S. and C. M. Perrins 1977. Survival and age at first breeding in the Razorbill (*Alca torda*). *Bird Banding* 48: 239-252.
- Loery, G., J. D. Nichols and J. E. Hines. 1997. Capture-recapture analysis of a wintering Black-capped Chickadee population in Connecticut, 1958-1993. *Auk* 114: 431-442.
- Lo Valvo, M. and B. Massa. 1992. Berta maggiore. Pages 63-70 in *Fauna d'Italia: Uccelli*. Vol. I (P. Brichetti, P. De Franceschi and N. Baccetti, Eds.). Calderini, Bologna, Italy.
- Marr, T., D. Newell and R. Porter. 1998. Seabirds of Senegal, West Africa. *Bulletin of African Bird Club*, 5.
- Martin, T. E., J. Clobert and D. R. Anderson. 1995. Return rates in studies of life history evolution: are biases large? *Journal of Applied Statistics* 22: 863-875.
- McPhaden M. J. 1999. El Niño: The child prodigy of 1997-98. *Nature* 398: 559-562.
- Mougin, J. L., B. Despin, C. Jouanin and F. Roux. 1987. La fidélité au partenaire et au nid chez le Puffin cendré, *Calonectris diomedea borealis*, de l'île Selvagem Grande. *Gerfaut* 77: 353-369.
- Mougin, J. L., C. Jouanin and F. Roux. 1985. Données complémentaires sur les années sabbatiques du Puffin Cendré *Calonectris diomedea borealis* de l'île Selvagem Grande. *Bocagiana* 86: 1-12.
- Mougin, J. L., C. Jouanin and F. Roux. 1988. Les migrations du Puffin cendré *Calonectris diomedea*. *L'Oiseau et Revue Française d'Ornithologie* 58: 303-319.
- Mougin, J. L., F. Roux, C. Jouanin and J.-C. Stahl. 1984. Quelques aspects de la biologie de reproduction du

- Puffin cendré *Calonectris diomedea borealis* des îles Selvagens (30°09'N, 15°52'W). Oiseau et Revue Française d'Ornithologie 54: 229-246.
- Nichols, J. D. 1994. Capture-recapture methods for bird population studies. 6^e Convegno Italiano di Ornithologia, Torino, October 1991. Torino, Italy.
- Nichols, J. D. and H. Pollock. 1983. Estimation methodology in contemporary small mammal capture-recapture studies. Journal of Mammalogy 64: 253-260.
- Nikolski G. V. 1963. The ecology of fishes. Academic Press, London.
- Perrins, C. M., M. P. Harris and C. K. Britton. 1973. Survival of the Manx Shearwater *Puffinus puffinus*. Ibis 115: 535-548.
- Pielke, R. A. and C. W. Landsea. 1999. La Niña, El Niño, and Atlantic hurricane damages in the United States. Bulletin of the American Meteorological Society (in press).
- Pollock, K. H., J. D. Nichols, C. Brownie and J.-E. Hines. 1990. Statistical inference for capture-recapture experiments. Wildlife Monographs 107: 1-97.
- Post, J. N. J. 1998. Biometrics of 35 specimens of the Leach's storm-petrel *Oceanodroma leucorhoa* from a wreck in southern Portugal. Deinsea 4: 77-89.
- Pradel, R., J.-E. Hines, J.-D. Lebreton and J. D. Nichols. 1997. Capture-recapture survival models taking account of transients. Biometrics 53: 60-72.
- Pradel, R. and J.-D. Lebreton. 1991. User's manual for Program Surge, Version 4.2. CEFE/CNRS, Montpellier, France.
- Ristow, D. and M. Wink. 1980. Sexual Dimorphism of Cory's Shearwater. II Merrill 21: 9-12.
- Ristow, D., F. Feldmann, W. Scharlau and M. Wink. 1990. Population structure, philopatry and mortality of Cory's Shearwater *Calonectris d. diomedea*. Die Vogelwarte 111: 172-181.
- Ristow, D., I. Swatschek and M. Wink. 1992. Does Cory's Shearwater breed every year or is there evidence for a sabbatical? Avocetta 16: 105-107.
- Ryan, P. G. and G. Avery 1987. Wreck of juvenile Black-browed Albatrosses on the west coast of South Africa during storm weather. Ostrich 58: 139-140.
- Ropolewski, C. C. and M. S. Halpert. 1997. Global and regional scale precipitation patterns associated with the El Niño/Southern Oscillation. Monthly Weather Review 115: 1606-1626.
- Saether B.-E. 1989. Survival rates in relation to body weight in European birds. Ornis Scandinavica 20: 13-21.
- Schreiber, E. A. and R. W. Schreiber 1989. Insights into seabird ecology from a global "natural experiment". National Geographic Research Report 5: 64-79.
- Schreiber, R. W. and E. A. Schreiber. 1984. Central Pacific seabirds and the El Niño Southern Oscillation: 1982 to 1983 perspectives. Science 225: 713-716.
- Seber, G. A. F. 1965. A note on multiple-recapture census. Biometrika 52: 249-259.
- Seber, G. A. F. 1982. Estimation of animal abundance. C. Griffin, London.
- Spendelov, J. A. and J. D. Nichols. 1989. Annual survival rates of breeding adult Roseate Terns. Auk 106: 367-374.
- Telleira J. L., 1980. Autumn migration of Cory's Shearwater through the Strait of Gibraltar. Bird Study 27: 21-26.
- Teixeira, A. M. 1987. The wreck of Leach' Storm Petrels on the Portuguese Coast in the autumn of 1983. Ringing and Migration 8: 27-28.
- Thibault, J. C. 1995. Effect of predation by black rat *Rattus rattus*, on the breeding success of Cory's Shearwater *Calonectris diomedea* in Corsica. Marine Ornithology 23: 1-10.
- Thibault, J.-C., 1997. *Calonectris diomedea* Cory's Shearwater. Pages 75-98 in Birds of Western Palearctic. Update, Vol. 1 (D. W. Snow and C. Perrins, Eds.). Oxford University Press, Oxford.
- Trenberth, K. E. 1997. The definition of El Niño. Bulletin of American Meteorological Society 78: 2771-2777.
- Trenberth, K. E., G. W. Branstator, D. Karoly, A. Kumar, N.-C. Lau and C. Ropelewski 1998. Progress during TOGA in understanding and modeling global teleconnections associated with tropical sea surface temperatures. Journal of Geophysical Research. 103: 14291-1434.
- Underwood, L. A. and T. J. Stowe. 1984. Massive wreck of seabirds in eastern Britain, 1983. Bird Study 31: 79-88.
- Weimerskirch, H., J. Clobert and P. Jouventin. 1987. Survival in five southern albatrosses and its relationship with their life history. Journal of Animal Ecology 56: 1043-1055.