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C. Soldatini [a]; Y. V. Albores-Barajas [b]; D. Mainardi [a]; P. Monaghan [b]
[a] Department of Environmental Sciences, University of Venice, Italy
[b] Institute of Biomedical and Life Sciences, Division of Environmental & Evolutionary Biology, University of Glasgow, UK

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C. SOLDATINI[1]*, Y. V. ALBORES-BARAJAS[2], D. MAINARDI[1] & P. MONAGHAN[2]

[1]*Department of Environmental Sciences, University of Venice, Italy*, and [2]*Institute of Biomedical and Life Sciences, Division of Environmental & Evolutionary Biology, University of Glasgow, UK*

Abstract

Since the early 1970s in Italy, the yellow-legged gull *Larus michahellis* has been colonizing new kinds of nesting areas, in particular moorland and the rooftops of inhabited buildings. The incidence of rooftop colonies is now such that the yellow-legged gull has come in many urban areas to be regarded as a pest. Yet its colony structure and breeding biology in the urban situation in Italy have remained largely undocumented. This paper reports observations of yellow-legged gulls breeding in the town of Venice and in the surrounding lagoon during the 2003–2005 breeding seasons. The aim of this study was to examine the performance of birds breeding in natural and urban areas and to investigate the links between the natural and the newly established urban colony. For this, we analysed and compared factors indicative of breeder quality. Breeding performance was not substantially different in the two colonies. This suggests that gulls are successfully exploiting a new habitat, adapting to new resources, as other opportunistic species do.

Keywords: *Breeding success, gull, roof nesting, sex-ratio, urban habitat*

Introduction

Roof nesting by gulls has been documented for about 100 years (Goethe 1960). The widespread use of roofs and other urban areas has expanded recently in many European countries (Cramp & Simmons 1983; Vincent 1987; Dalton 1991; Raven & Coulson 1997) and now includes Italian coastal cities. It is believed that roof-top nesting by large gulls first occurred in Bulgaria between 1890 and 1893 (Nankinov 1992). While there were small numbers of gulls nesting on buildings in a number of European countries in the early part of the twentieth century, for example Norway and Britain, major expansion of urban colonies in France and Britain did not start until the 1960s and 1970s, and, throughout much of continental Europe, roof-nesting was recorded for the first time during the 1980s; however, in Belgium, urban breeding was not recorded until 1998 (Rock 2005). Roof-top nesting now extends over a wide area of Europe, from northern Norway south to Portugal, and eastwards to Italy, Croatia (W. Klinger, personal communication) and Bulgaria. Gulls nesting on buildings are a common sight in coastal and, more recently, inland areas of Europe (Vincent 1987) and North America (Vermeer et al. 1988).

Some gulls started settling in towns much earlier than others (Goethe 1960). In Europe, the herring gull, *Larus argentatus* Pontoppidan 1763, was the first gull recorded to nest on buildings (Monaghan & Coulson 1977; Monaghan 1979). Since the first reports from southwest England early this century, the habit has spread dramatically. More recently, other species of gulls have undergone a similar increase in number of roof nesters such as lesser black-backed gull, *Larus fuscus* Linnaeus 1758, great black-backed gull, *Larus marinus* Linnaeus 1758, and common gull, *Larus canus* Linnaeus 1758. In addition to *Larus* gulls, the black-legged Kittiwake, *Rissa tridactyla* (Linnaeus 1758), is also found nesting on buildings in Britain and Ireland (Coulson 1963; Cramp & Simmons 1983; Gibbons et al. 1993). Usually nesting gulls cause disturbance to the inhabitants of a building due to noise, fouling and the aggression of adult gulls in defence of their young, and can also damage the facade of the building, therefore the spread of gulls into urban areas is a matter of growing concern.

Initial dispersal of gulls to roofs for nesting may occur during periods of rapid growth of colonies on natural sites in surrounding areas, and may be related to overwintering dispersal, since it is known that some young pairs will recruit or form breeding colonies in wintering areas (Monaghan & Coulson 1977; Belant 1997). Several authors (e.g. Dolbeer et al. 1990) suggested that buildings represent suboptimal nesting habitats, a consequence of dispersal in populations experiencing rapid growth and lacking more suitable nest sites. Other studies, in contrast, suggest that urban sites are a suitable habitat for breeding gulls that has only recently been exploited; the success of such colonies is in part attributed to the local availability of food from anthropogenic sources (Monaghan 1979; Belant 1993).

The Mediterranean yellow-legged gull, *Larus michahellis michahellis* Naumann 1840, is one of the species involved in urban nesting. It is a large gull widely distributed and increasing in the whole Mediterranean basin. It is common all year on Italian coasts and on North Adriatic coasts where it regularly breeds. The species was considered common in Venetian lagoon already in the 19th Century (Contarini 1847; Arrigoni Degli Oddi 1929); since 1970 it is documented as regularly breeding and sparsely distributed in the lagoon of Venice (Fasola 1986). On Italian coasts, as in the whole Mediterranean basin, the yellow-legged gull population has undergone a remarkable increase. During IWC surveys (mid-winter International Waterfowl Census), a doubling in numbers has been recorded in less than 10 years (maximum recorded in 1991–1995: 45,965, while in 1996–2000, 99,098 wintering gulls were recorded) with an annual rate of increase of 11.5% (Baccetti et al. 2002). The overall Italian breeding population has been estimated as 45,000–60,000 (Brichetti & Fracasso 2006), but a more up-to-date estimate is needed.

Whereas overall numbers of urban breeding gulls in Italy are small and only the yellow-legged gull is involved, numbers are increasing rapidly. The first colony in an urban habitat in Italy was recorded in 1971 in Rome (Cignini & Zapparoli 1996). This colony is still increasing and is spreading to the northern quarters of the city (Fraticelli, personal communication). In 1984, the first breeding pair was recorded in Livorno (Dinetti 1994). In Genova, the first rooftop nest was recorded in 1986, and one year later roof-top breeding was reported in Trieste (Benussi & Bembich 1998). The population expansion in Trieste has since been well documented. Breeding numbers increased at a rate of 46.6% per annum from 1988 to 1992, and 31.3% from 1992 to

1997. Such high rates of increase clearly involve immigration from elsewhere, the most likely source being nearby natural colonies. In 1990, the first pair was recorded in Naples (Milone 1996).

We focused on the urban colony of yellow-legged gulls in Venice. The city of Venice is in the middle of a lagoon where yellow-legged gulls habitually breed on natural islands. The natural population has been estimated at 3096 breeding pairs in 2003 (Soldatini et al. submitted). The aim of this study was to examine the performance of birds breeding in natural and urban areas and to investigate the links between the natural and the newly established urban colony. For this, we analysed and compared factors indicative of breeder quality. Since this may differ between urban and natural colonies, in addition to examining the timing and breeding success of the birds, we also examined the sex ratio of chicks produced (although our sample size from the urban colony was very small for logistic reasons). Maternal condition seems to be particularly important in gulls (Nager et al. 1999), and a number of studies on birds, including large gulls, have demonstrated that offspring sex ratios can differ from equality, and that such adjustments are linked to environmental circumstances that influence female condition. Females in poor condition tend to produce more of the smaller sex, usually daughters (e.g. Burley 1981; Clutton-Brock et al. 1985; Weatherhead & Teather 1991; Ellegren et al. 1996; Nager et al. 1999; Alonso-Alvarez & Velando 2003). As in the closely related lesser black-backed gull *Larus fuscus*, and herring gulls *Larus argentatus*, male yellow-legged gulls are larger than females and as chicks likely to be more vulnerable to food shortages (Griffiths 1992). Therefore, we also examined the survival of male and female chicks to fledging.

Material and methods

The yellow-legged gull is a sexually dimorphic species with adult males about 15% heavier and skeletally larger than females (Coulson et al. 1983). Their clutch size typically comprises three eggs, laid over a 3–6-day period (Cramp & Simmons 1983). We examined all the accessible nests of the urban colony (Venice city) and a sample of nests in a 'natural' colony in a relatively old and stable colony on an artificial island, Cassa di Colmata B, in the Lagoon of Venice (45°22′ N, 12°28′ E). Data were collected during breeding periods (April–June) in 2003, 2004 and 2005. During field surveys, we recorded laying date, clutch sizes and egg measurements, hatching and fledging dates and breeding

success from both colonies (Table I). Egg measurements in the urban colony were taken only from the five reachable nests, thus the same breeding pairs are probably involved, since gulls have high survival and show strong nest site fidelity. In 2004 we also collected blood samples from chicks at a total of 50 nests, 13 from the urban colony and 37 from the natural colony.

Laying date and egg volume as an indicator of breeder condition

Nests in the natural and the urban colony were marked with small coded flags. Before hatching, most of the eggs were measured with callipers to the nearest 0.05 mm (maximum length and width) and marked with small pieces of paper tape A, B or C with waterproof ink, indicating laying order.

We calculated egg volume (in ml) as $V = 0.000485 \times \text{egg length} \times (\text{egg width})^2$ following Oro et al. (1996). Data obtained from the natural colony were analysed by computing Generalized Linear Mixed Models using only three-egg clutches. The following fixed factors were included in the model to examine factors influencing egg volume: egg order, year and laying date. We included nest as random factor. Further analysis of relative egg volumes within clutches were carried out by expressing the volume of the C egg as a percentage of A egg, in the same clutch C%A.

Breeding performance

Surveys in urban and natural areas were conducted in three reproductive periods (2003–2004–2005) with standardized methodology. Starting in the last week of March and ending when all chicks fledged (usually second half of June), weekly surveys were conducted of the same study plot in the natural colony and of all visible nests from the three observation points in the city and of the rooftop nests at the cemetery. We recorded nest building material, number of eggs, hatching success and

fledging success. This allowed us to compare breeding performance and, mainly in the urban area, to investigate variation in laying date, hatching success, fledging success, nest and partner fidelity.

These last two points have been investigated only in the urban colony, and required bird marking and ringing activities. Initially, breeders were marked using nest sponges soaked with Picric Acid (Cavanagh et al. 1992); during this phase eggs were replaced with dummies in order to avoid any egg contamination (Belant & Seamans 1993). We then used a walk-in trap using the nest as bait. Once caught, birds were measured and ringed with metal ring and red PVC ring with a white alpha-numeric code. This allowed us to recognize breeders in successive years. In order to compare success in fledging chicks, the performance of pairs laying three egg clutches (the majority in both colonies) was compared.

As there was a considerable variation in nesting density, we considered it in relation to clutch size and survival until fledging. Density was plotted as the number of neighbouring nests within a 5 m radius of individual nests (Parsons 1971a).

Sex ratio

In 2004 we recorded hatching order of 87 (out of 132) chicks. Chicks were marked and a small blood sample (80 μl) was taken from the vena ulnaris. No side effects of taking a blood sample from chicks were observed, the broods being monitored until fledging. We collected the blood in capillary tubes containing heparin. Samples were transported to the lab in a cool box, mixed with 300 μl of absolute ethyl alcohol and stored at $-20°C$ until DNA extraction 19 weeks later.

Sex was determined through the PCR amplification of the CHD gene fragments with primers 2550F and 2718R (Fridolfsson & Ellegren 1999). Following the protocol of Griffiths et al. (1998), fragments of CHD1 genes located on Z and W chromosomes were both amplified and subsequently

Table I. Clutch size and egg volume in natural and urban colonies in 2003, 2004 and 2005.

	n	Modal clutch size	A egg vol. (mean)	B egg vol. (mean)	C egg vol. (mean)
Venice					
2003	5	2	79.10	74.90	68.26
2004	5	3	80.20	76.95	73.27
2005	5	3	81.43	78.59	69.57
Lagoon of Venice					
2003	65	3	87.05	82.73	71.31
2004	83	3	79.07	75.42	74.81
2005	58	3	85.01	80.53	75.87

distinguished by a difference in their intron size using electrophoresis.

To test for differences between and within colonies, we analysed the survival of male and female offspring. To avoid pseudoreplication errors, we used generalized linear mixed models and generalized linear models. Sex ratio and survival data were analysed using GLIMMIXmacro (SAS Institute 2001) and univariate analysis of variance GLM; we used generalized linear mixed model for the sex ratio at hatching and at fledging (binomial distribution) and generalized linear models to test laying order and colony effect on sex ratio within clutches and for processing survival data (Poisson distribution). The generalized linear mixed model takes into consideration the nested relationship of chicks in the same nest in order to prevent pseudo replication and controls for multiple (independent) variables. Significance was then tested using the covariance estimation method and post-hoc tests carried out. To compare laying sex ratios, we considered only three egg clutches that had been completely sexed since we could then be sure that no eggs were missed.

The following independent variables were included in the model examining variation in sex ratio within clutches: nest (as random factor), egg order (categorical variable), clutch size, colony (independent variable) and all the possible interactions; sex of the chicks was the dependent variable. This first model focused on the within-nest variance in order to test for any evidence of difference in sex ratio within the urban and natural colonies.

Thus categorized nest values of the previously tested variables were included in a second model obtaining separated estimations for the between-nest effects. The following independent variables were included in the second model: nest, sex composition of the brood (number of males within the brood) clutch size (in this phase we considered two and three egg clutches), number of chicks hatched, number of chicks fledged, sex of the third egg offspring; and chicks' survival until fledging (number of chick fledged vs. hatched) as dependent variable. The second model analysed the differences in survival in broods differently composed, testing which composition of sexes, and which sex of offspring of third egg laid, is more likely to survive.

Although we are quite sure of the fledging success of the urban colony, for the natural colony we considered as fledged chicks aged more than 20 days no longer found in the colony area. This could lead to an over-estimation of the breeding success for the natural colony.

Results

Laying date and egg volume as an indicator of breeder condition

The modal clutch size encountered in all the three years for both colonies was three, the only exception was in 2003 where the modal clutch size recorded in the urban colony was 2 (Table I). As expected, laying order had a significant effect on egg volume ($F_2=16.936$, $P<0.01$) (being A egg larger than B egg, and this larger than C egg, Table I); year ($F_2=6.471$, $P<0.01$) and laying date ($F_{17}=2.292$, $P<0.01$) were also significant. Effect of year on egg size may be a consequence of differences in breeders' quality in the three years, while laying date effect may be due to high quality breeders, producing larger eggs, laying earlier. Interestingly, the interaction between laying order and year was also significant (laying order*year: $F_4=3.463$, $P<0.05$) showing that the effect of laying order on egg volume was not the same in all three years, as for example in 2003 the modal clutch size of the urban colony was 2, meaning the absence of a C egg in many cases, and more in general ratio between egg sizes where different in the three years (Figure 1 and 2).

Separately analysing the colonies, in the individuals breeding naturally in 2003, C eggs were
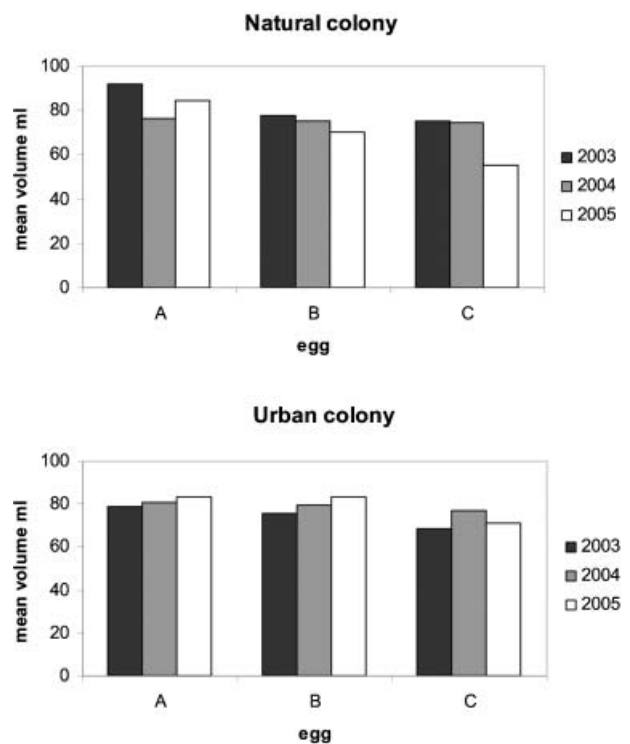

Figure 1. Mean egg volumes of ABC eggs in the three years, in the two colonies.
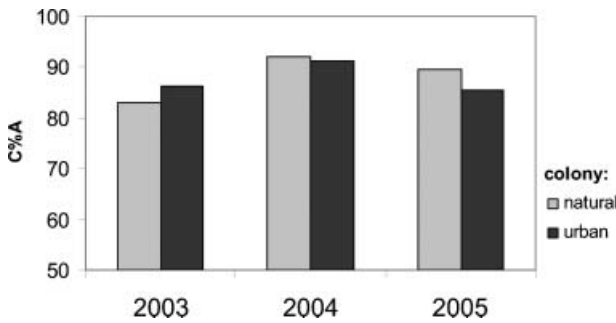
Figure 2. Comparison between colonies and years of the volume of the C egg expressed as a percentage of A egg, C%A.

proportionally smaller than those laid in subsequent years ($F_2=4.960$, $P<0.01$, Tukey $P<0.05$; Figure 1). On the contrary differences of C as percentage of A (C%A) in the three years in urban colony are not significant ($F_2=2.189$, $P>0.05$; Figure 2). This could involve improving the breeding capability of parents. Samples sizes from the urban colony are, however, very small. In the natural colony in 2003 C%A resulted borderline significantly smaller than in 2004 and 2005 ($\chi^2_2=5.812$, $P=0.05$) while no difference is detected in the urban colony ($\chi^2_2= 2.900$, $P>0.05$).

We observed no significant difference comparing C%A values of the two colonies each year ($P>0.05$ in all cases). In fact the proportion of egg volumes within the clutches, C%A, did not differ between the colonies in any year (colony $F_2=1.125$, $P>0.05$; year $F_1=0.595$, $P>0.05$; colony*year $F_2=1.167$, $P>0.05$).

We registered no significant difference in laying date in the three years in the urban colony ($H_2=0.441$, $P=0.80$; Figure 3). Incidentally, comparing laying date trends in the three years, we can
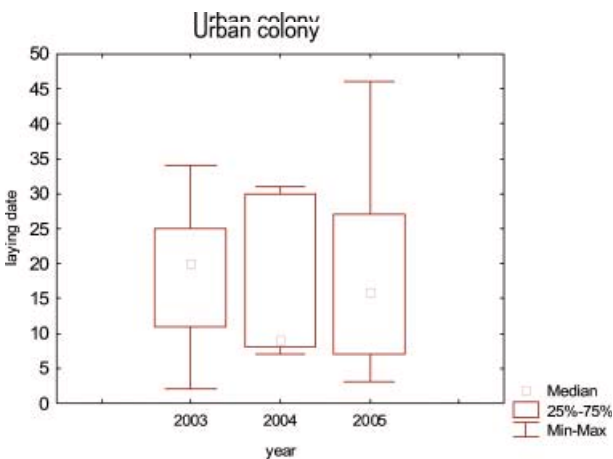
observe that in 2004 most "A" eggs were laid earlier than in the other years (Figure 4).

Breeding performance

We found no differences in breeding success in the urban colony comparing the three breeding seasons ($\chi^2_6=4.937$, $P>0.05$), in fact the incidence of failed and successful nests (1, 2 or 3 chicks fledged) did not vary significantly between years ($\chi^2_2=1.734$, $P>0.05$; Figure 5). In contrast, in the natural colony comparing 2004 and 2005, the proportion of failed

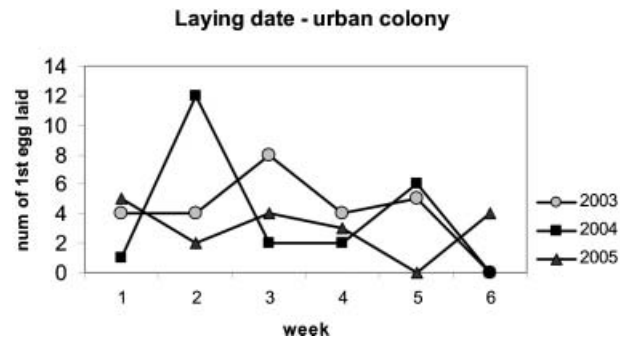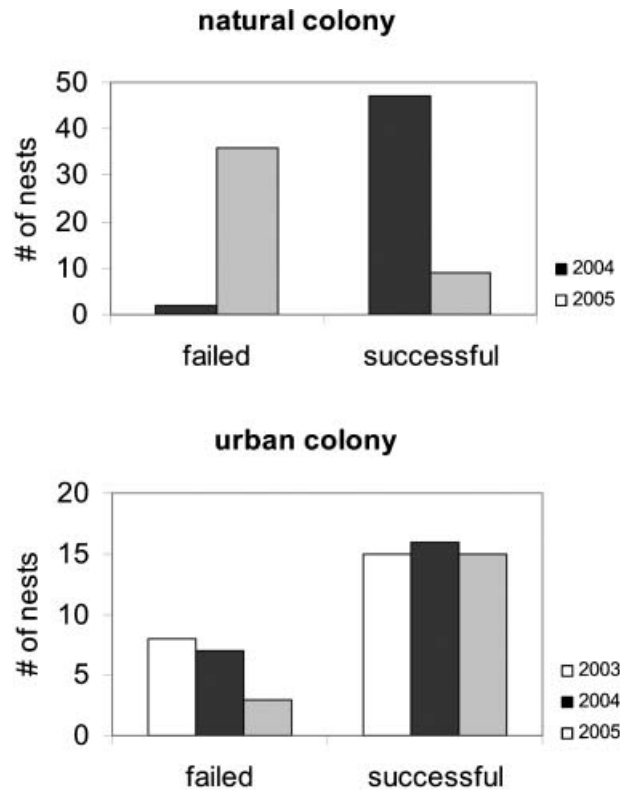Figure 4. First egg laying date in the urban colony.

Figure 5. Comparison of the breeding success of the two colonies in the three breeding seasons (only two for the natural colony). Successful is comprehensive of pairs that fledged 1, 2 or 3 fledglings.

Figure 3. Laying dates in the urban colony (*y*-axis: number of days from the starting of the breeding season, 1 April as conventional date).

nests is significantly different ($\chi^2_1=56.138$, $P<0.01$; Figure 5). Indeed, comparing breeding success in the two colonies in 2004 and 2005, we observed a higher proportion of failed nests in the natural colony (2004: $\chi^2_1=9.938$, $P<0.01$; 2005: $\chi^2_1=21.868$, $P<0.01$) while the proportion of successful nests was similar ($P>0.05$ in both cases), resulting in a higher breeding success in the urban colony. Indeed mean breeding success recorded in the natural colony was lower than that recorded in the urban colony (0.35 vs. 0.41).

Most of the birds of the urban colony bred in the same place as in previous years (19 cases); marked birds confirmed this site fidelity (75%) and showed some partner fidelity (50%).

Predation risk was higher in natural colonies with low nest densities ($r=-0.300$, $P=0.020$) in fact nests in very low density areas are the least successful (Figure 6), this is not the case of urban colonies where usually nest are sparsely distributed.
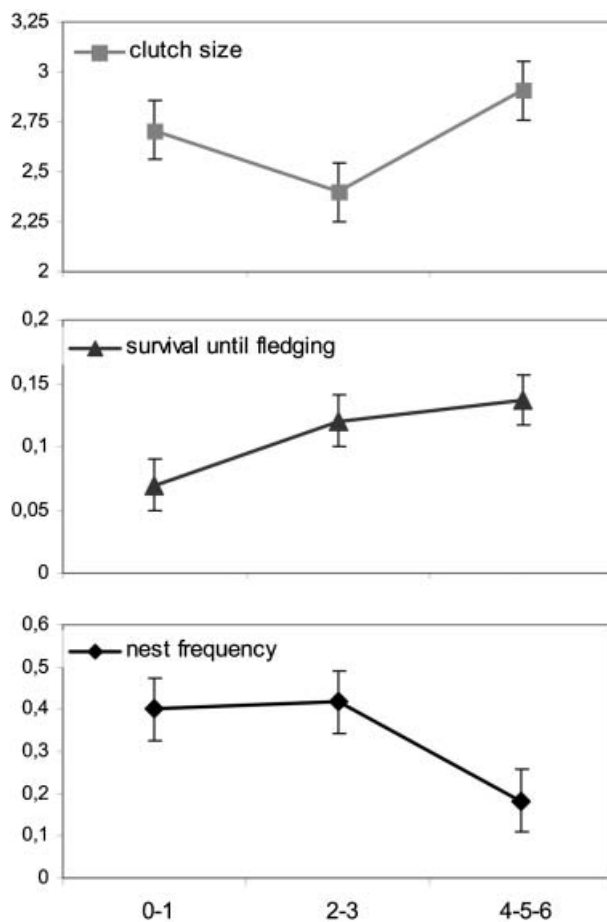

Figure 6. The relationship between nesting success and nesting density. (a) Variation in clutch size; (b) survival until fledging; and (c) nest frequency for variation in nesting density. Density plotted as the number of neighbouring nests within a 5 m radius of individual nests.

Sex ratio

In 2004, 86 chicks from 50 nests were successfully sexed (we sexed both 2- and 3-egg clutches; unhatched and missing chicks were not sexed because they were lost, probably predated) and 96% of the chicks that hatched, most of which survived until fledging.

The overall sex ratio in our sample of 86 sexed chicks was not different from equality and the proportion of males was 0.454. Considering only three egg clutches, there was no significant difference in overall sex ratio in the two colonies ($t=0.699$; $P=0.492$): natural colony (0.481), urban colony (0.333). There is no significant difference ($t=-0.045$; $P=0.953$) between overall sex ratios at hatching (0.465) and at fledging (0.455).

However, brood composition had an effect on chick survival probability ($F_{4,45}=2.59$, $P=0.04$; Table II); in both colonies nests where chicks were all female or where there were only two chicks, obviously, were more likely to have a high survival rate ($H_4=9.36$ $P=0.05$), analysed separately in post-hoc tests. Indeed, considering only three-egg clutches we computed GLM where last egg survival was the dependent variable and the number of males in the brood and colony were fixed factors. These analysis results confirmed that the number of males within a brood influences survival probability of the last laid egg ($F_3=3.284$, $P=0.03$). In parallel, the sex of the last egg influences its survival probability ($F_{1,29}=3.98$ $P=0.05$); in this, case males in the last laid position were more likely to survive than females (Figure 7).

Discussion

This study enabled a description of the main features describing gull colonies on the basis of three-years of monitoring. We found a modal clutch size of three eggs in the natural colony in all three years and in the last two of the urban one, while the first year survey a modal clutch size of two was recorded in the urban colony. This could indicate a lower breeder quality in the urban colony in 2003 (Kilpi 1990); however, this was not confirmed by further breeding success analysis. In all cases, the "C" egg is smaller than

Table II. Results of brood composition effects on survival probability between nests.

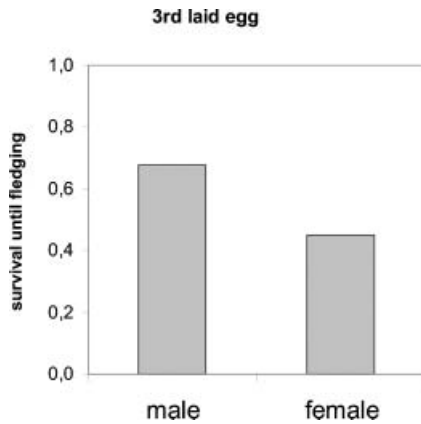|	df	Den df	F	P
Brood composition	4	45	2.59	0.049
Colony	1	45	0.05	0.821
Sex last egg	1	29	3.98	0.055

3rd laid egg

Figure 7. Probability of survival of male and female yellow-legged gull chicks hatching from third laid eggs in the two colonies combined.

"A" and "B" eggs, confirming what has been found in other studies on this species and closely related ones (Pons 1993; Kilpi et al. 1996; Bosch et al. 2000). Analysing the relative egg volumes within clutches, we observed that in 2003 in the natural colony "C" eggs where smaller relative to A eggs. This may result in a lower success of the third laid egg as suggested by Kilpi et al. (1996). In early laid clutches of both colonies "C" egg was bigger than in later ones.

In both colonies we found smaller mean egg volumes than those measured in 1996 by Bosh et al. (2000) in an unculled natural colony; as has been suggested for body size (Pons et al. 2004), the difference could be due to geographical variation. Fledging success and breeding success of the two colonies we considered are within the mean values registered in Medes Islands, Spain, from 1993 to 1996 (Bosch et al. 2000). There is no evidence of a difference in breeding success between natural and urban colonies. Indeed, overall, it is clear that the strong negative influence of environmental factors, such as floods and predators that affect the natural colony are absent in the urban one.

Mainly in the natural colony, predation and cannibalism are important causes of chick and egg loss (Parsons 1971b; Kilpi 1989). Density of the colony may be an important factor, even if is not the main one, influencing survival rates (Parsons 1976; Marin et al. 1995). Nests in the natural colony are distributed in small patches of vegetation; when these patches are very small they host just a few nests. The latter can be disadvantaged, being less protected than others and more vulnerable to predators (Parsons 1971a).

Comparing Venice's urban colony to Trieste's (Benussi & Bembich 1998), we found a slightly

higher breeding success in the latter, probably due to the longer history of the colony (established in 1987) and likely older age of the birds, with more experienced breeders.

The urban and natural colonies we considered are very close and there is visible frequent translocation between them and the close by feeding sites, where breeding and young gulls from both colonies feed (personal resighting data). Both colonies are thought to be increasing (Baccetti et al. 2002; Associazione Faunisti Veneti 2004). We can assess that the status indicators, such as egg volume and sex ratio, describe the populations in good health (Alonso-Alvarez & Velando 2003) and they are likely to expand in future if food resources continue to be available in large quantities.

This study outlined a prevalent success of male offspring from the third laid egg, according to recent studies (Muller et al. 2005) the adaptative significance of the male bias in the last-laid egg may relate to the interference competition and the dominance of the larger sex (Bortolotti 1986; Anderson et al. 1993; Velando et al. 2002). Our results underline the lack of any evidence that the urban sites are doing better than natural ones due to better access to food. Their only advantage seems to be the protection from predators influencing natural colonies.

We also did not find any real difference in breeding performance, in contrast to what has been found for example in herring gull (Monaghan 1979). Our study has been conducted at the beginning of the urban population growth, and may involve relatively young breeders. While breeding performance of yellow-legged gulls in the urban habitat does not seem to be substantially different from those nesting in the natural colony, this may change. Gulls are effectively exploiting a new habitat, adapting to new resources, as other opportunistic species do, and the colonies are evolving as they would in a natural environment with a surplus of food resources. Populations experiencing high growth rates observed in many Italian and European coastal cities are probably influenced by immigration movements from crowded natural colonies.

Acknowledgements

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