ESTIMATING THE ABUNDANCE OF SHEARWATERS AND GULLS IN THE NORTH AEGEAN SEA

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SUMMARY

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We estimate the population size of the three most abundant seabird species in the north Aegean Sea (*Calonectris diomedea*, *Larus michahellis* and *Puffinus yelkouan*), along with their distribution patterns. Sampling was carried out from May to September 2009 in line transects 300 m or 600 m wide and with a total length of 3 007 km. The sampling was opportunistic, using a variety of ships. After the data were corrected for movement bias, populations were estimated by using two types of stratification method: a novel fractal–based method as well as generalized additive models, which yielded the most conservative estimate of the population, although all estimates were quite similar. Overall, taking the mean estimate of the three most credible methods, we estimate the density of birds for the area to be 0.46 birds/km^2 for the three species together (*C. diomedea* 0.10 birds/km^2 , *L. michahellis* 0.11 birds/km^2 and *P. yelkouan* 0.26 birds/km^2). These densities of seabirds in the north Aegean are smaller than observed in studies in other parts of the world, but not surprisingly so, given the low productivity of the north Aegean. In view of the widespread and growing threats to seabird populations, the results of this study provide a useful basis for further scientific studies and for applied research including the designation of marine Important Bird Areas for the region.

INTRODUCTION

Seabird populations are subject to numerous, increasing pressures both on land and at sea, including disruption of breeding areas by introduced species, such as rats or cats (Martin *et al.* 2000, Tranchant *et al*. 2003, Bonnaud *et al.* 2007, Bourgeois & Vidal 2008), massive tourism development (James 1984, Gallo-Orsi 2003, Bourgeois & Vidal 2008), fisheries bycatch (Cooper *et al*. 2003 and Arcos *et al.* 2008) and disturbance of food sources through overfishing (Furness 2003, Karpouzi 2005). While traditional problems such as harvest of eggs or individuals (Krpan 1970, Vigne *et al.* 1991) have decreased, others, such as oil spills, have increased (Bourgeois & Vidal 2008). The latest to be added to the list of threats is global warming, as seabirds' prey distribution is changing through various complex interactions (Wolf *et al.* 2010). According to the IUCN Red List Index, since 1994 seabirds are doing worse than other bird categories (Butchart *et al.* 2004).

To preserve seabird populations, an accurate knowledge of their current abundance and distribution is necessary. Surveys of seabirds at sea are useful in complementing breeding bird estimates or providing an overview of the patterns occurring away from the breeding grounds. Efforts to estimate the numbers of seabirds at sea started about a century ago (Jespersen 1924), and much of the sampling methodology has been standardized (Tasker *et al*. 1984). Regarding at-sea surveys, very little has been published about seabird populations for the Mediterranean Sea, although there has been substantial work on seabird populations' assessment in the area, primarily based on coastal surveys (e.g., Abello *et al*. 2003, Cama *et al*. 2011). Various LIFE projects (http://ec.europa.eu/environment/life/index.htm) begun in 1996 supported systematic research on seabirds in the Mediterranean area but were limited to studies of colonies and coastal counts. Studies farther from the coast did not begin until 2004. The fact that most of the global population of Cory's Shearwater *Calonectris diomedea* breeds in the Mediterranean and that Yelkouan Shearwater *Puffinus yelkouan* is endemic to the area (Birdlife International 2010) indicates the importance of the area for seabirds.

The eastern Mediterranean Sea is known to be one of the most oligotrophic seas globally, due to being an enclosed basin with low rates of water replacement as well as having a dry climate (Tsikliras *et al.* 2001). In the Aegean Sea there are no strong currents to agitate the water and help nutrients detach from the sediment. Nutrient availability is based on inputs from the Black Sea, the rest of the Mediterranean and rivers (Tsikliras *et al.* 2001, Azov 1991). Despite considerable influxes of nutrients into the north Aegean from large river estuaries and from the Black Sea, we still observe low productivity and depressed biodiversity (Tsikliras *et al.* 2001).

STUDY AREA AND METHODS

The study area comprised the north Aegean Sea (Fig. 1). The southwestern limit for sampling was at the Sporades islands and the southeastern limit was at Samos Island. We considered the area of the Aegean sea with latitude north of 37.6° (in WGS84 projection). The surface of the defined study area is 86 100 km^2. We surveyed the area for 29 days in total: eight days in spring, 14 in summer and 7 in autumn 2009. Total transect length was 3 007 km (740 km in spring, 1 376 km in summer and 881 km in autumn).

Survey methods

Seabirds were recorded at sea according to the "ESAS" (European Seabirds At Sea) methodology (Camphuysen & Garthe 2004), using 5 min intervals for recording the birds sitting on the water, at a distance up to 300 m from the vessel, as well as a "snapshot" count every minute for the flying birds. For our survey we used the datasheets that were designed by the Royal Netherlands Institute for Sea Research (NIOZ) for the Hellenic Ornithological Society (HOS) seabirds project. Our survey was conducted with two different types of vessel: either passenger ferry boats with standard routes or small private vessels running dedicated missions. We used line transect surveys, continuously recording while the vessel was underway during daylight (Fig. 1). Observations were made in the bow of the vessel either on one or both sides, depending on the vessel type and the number of observers. As a result, the transect width was either 300 m or 600 m. Surveys covered 1 337 km^2, 1.55% of the total study area. We also recorded the sea state, visibility and presence of other floating objects that might affect behavior, including other vessels.

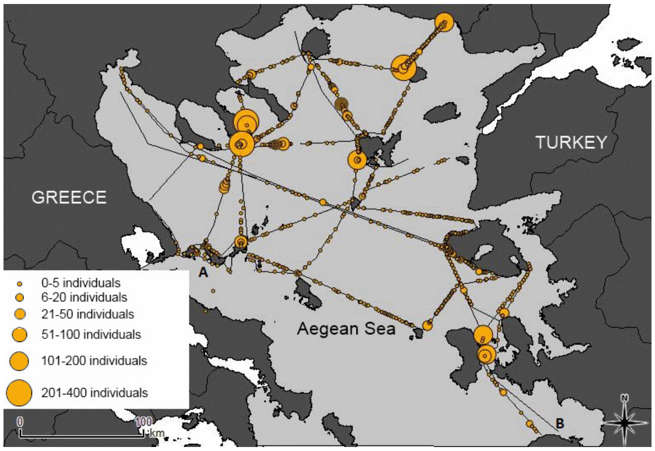

Fig. 1. The study area showing the line transects covered during the survey. The southwestern limit for sampling was at the Sporades islands (A) and the southeastern limit was at Samos Island (B). The study area is shown in light grey. Circles represent the number of birds observed per 5′ segments throughout the study area.

We recorded the direction of flight for flying birds as well as any ship-following behavior in order to adjust the counts we made for the effect of bird movement relative to that of the ship for flying birds, using a correction factor derived by Spear *et al.* (1992). We then considered two methods that are based on the upscaling of density in order to estimate the abundance on seabirds in the north Aegean Sea.

Estimating densities and population sizes

We estimated densities only for the three most abundant species. As our dataset is rather unusual, being opportunistic rather than design-based and dealing with species not investigated by other at-sea surveys, we wanted also to have a more immediately intuitive picture of the data. Thus we implemented four different methods for the analysis: simple upscaling of distance classes, post-stratification, fractal dimension and generalized additive models (GAMs). The latter are currently widely used in this kind of analysis and make use of other parameters as well, leading to more sophisticated predictions, while the first three approaches also have an intuitive connection to the biology of the species, enabling an ease of interpretation.

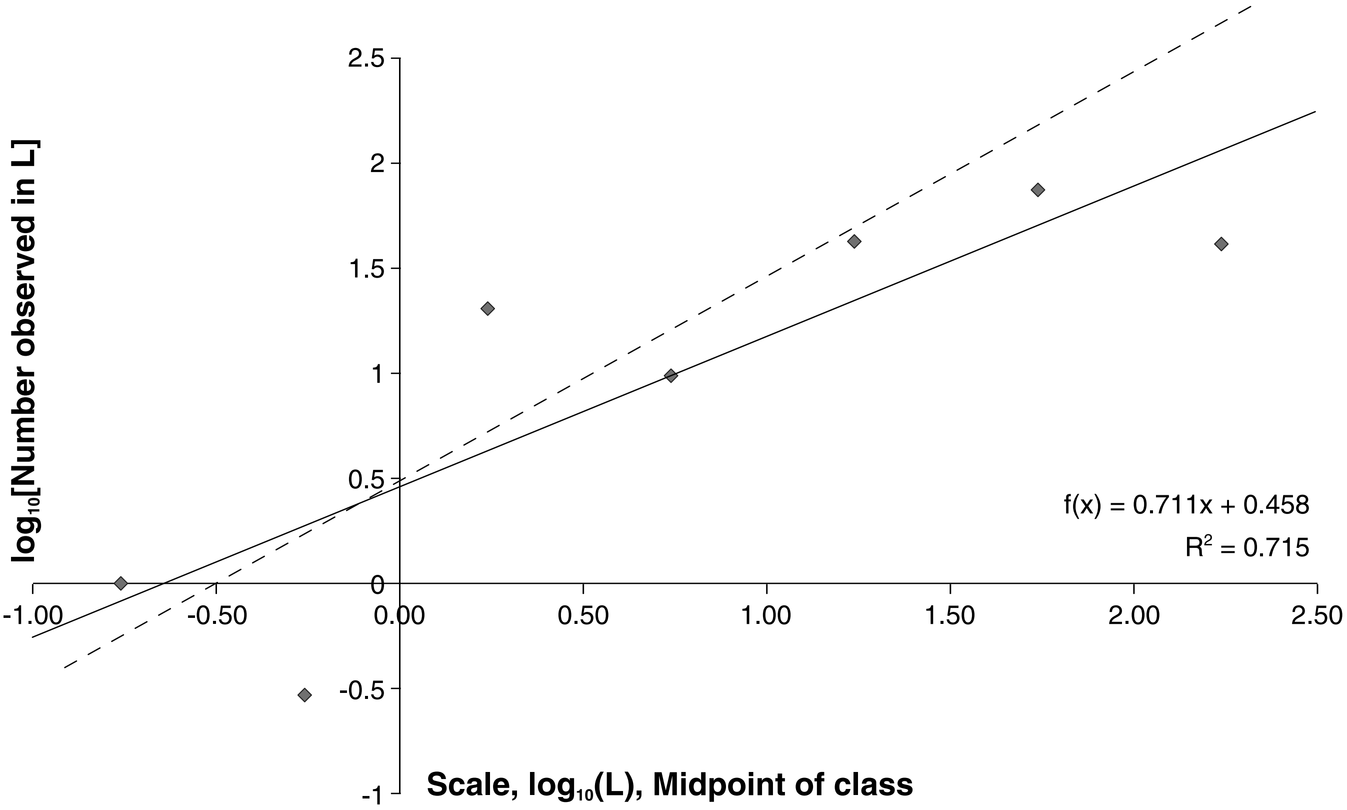

Fig. 2. Total number of birds observed as a function of scale (km) of transect (solid line). The log10 of the number of observed birds is shown on the vertical axis, and the horizontal axis indicates the log10 of the midpoint of the length class of the transect within which the observations were made. The dashed line has a slope of 1 and is shown for comparison. The slopes of the individual-species power lines were -0.092, 0.404 and 0.749 for *C. diomedea*, *L. michahelli* and *P. yelkouan,* respectively.

Method 1: Simple upscaling of distance classes

The most basic estimate is found by a simple direct upscaling of density, where the total population size is estimated to be:

$$N = \frac{n}{a} A \tag{1}$$

where A is the total area of interest, n the number of individuals observed during survey and a the sampling area.

In order to work properly, the above estimate depends on a uniformly random placement of transects within the area A. Without random placement, such design-based estimators that assume even coverage probability of the region are not appropriate, because estimates of population may be seriously biased (de Gruijter *et al*. 2006). However, most transects begin and end on coasts and the population likewise, as is evident from Fig. 1, is strongly clustered, particularly around coastal areas. As a result, these two sources of clustering are correlated, leading to biases (in this case, overestimations) that involve upscaling to a wider region. In order to compensate for this bias, we calculated separately the populations inshore (within 10 km from the coast) and offshore (beyond 10 km from the coast), as we observed that the bird density beyond 10 km from the coast was reduced by more than 70%, while 80% of the birds were recorded within that distance. Such a pattern is expected, as the nearshore environment is very different from regions farther offshore, both in ecology (shallow water, wave action, rocks, etc.) and in its accessibility to shore-based species such as gulls and cormorants.

Method 2: Post-stratification

This method was introduced by Anganuzzi & Buckland (1993) as a model-based method to reduce the bias associated with opportunistic non-random surveys. In this method, the data from the study area are divided into strata, according to the observed density of the species of interest. Before stratification, the data are smoothed in order to reduce spatial strata fragmentation due to sampling variation. After defining the strata, the population size is estimated for each stratum using the previous upscaling method, and finally the results for each stratum are added to make an estimate for the whole study area.

Cory's Shearwater *Calonectris diomedea*, photo courtesy of Aris Christidis

We overlaid a regular rectangular grid of 120 × 84 cells with basic cell size of approximately 4 × 4 km in order to facilitate both smoothing and stratification. We used this resolution, as it is similar to the resolution produced after converting the raster satellite images of MODIS Aqua (http://seadas.gsfc.nasa.gov), which we used for the GAMs in method 4, into vector format with GIS.

On this grid, we applied smoothing in the following way. For each occupied cell, the population was redistributed over a disc of a specified radius. This disk was composed of all cells whose center lay within a distance r from the occupied cell. Two levels of smoothing were applied: $r = 1$ (occupied cell plus four closest cells) and $r = 2$ (occupied cell plus 12 closest cells), and the average values were used for the analysis. Land areas, for which the density is assumed to be zero, are not included in the analysis.

As the actual width of the line transects was far less than 4 km, observed areas cover only a small percentage of any cell—at most 20%. Because of this, the grid area was far larger than the actual sampling area. Thus, using this grid would have caused an underestimate of the population, as the method uses the simple upscaling method described by Equation 1. For this reason, we divided these cells into a finer grid. To do this, we calculated the total area of all cells intersected by the transects and divided it by the actual sampling area; we called this ratio R. We assumed that the new cell size is equal to $1/R$ times the original cell size. The new finer grid consisted of 384 × 269 cells of approximately 1.26 × 1.26 km. Of the total of 53 840 cells in coarse grid that composed the whole study area, the sampled area consisted of 835 large cells, while after making the grid finer, we assumed that, for each cell with observation, only one sub-cell was sampled, in order to be consistent with the true sampling area.

After the above corrections, the number of strata (m) was defined so that n observations were divided nearly equally between strata, with approximately n/m equal numbers of observations per stratum. We set the number of strata to 5 in order to have an adequate gradient of densities and, at the same time, avoid having too few data in a stratum with low effort to allow reliable estimation and avoid generating too many fragmented strata (Anganuzzi & Buckland 1993).

Method 3: Fractal dimension

It has previously been noted that in many such cases the clustering of populations can best be understood in terms of fractal geometry (Kunin 1998, Kunin *et al*. 2000, Kallimanis *et al*. 2002, Halley *et al*. 2004). Thus, while in equation (1) population scales as a function of $A \propto L^2$ (where L is the diameter of the area), if population has a fractal-type distribution we expect it to rise more slowly with some lower power of L where this power is typically >1 and <2. In principle, we can estimate the population by upscaling in this fashion if we can estimate the exponent. If two objects of dimensions $F1$ and $F2$ intersect in the plane, the resulting intersection has, in general, a fractal dimension (Halley *et al.* 2004):

$$\gamma = F_1 + F_2 - 2 \tag{2}$$

Thus, if we measure the dimension of the intersection, we can infer the fractal dimension of the population distribution through this intersection formula. Our transect data are the result of the intersection of a one-dimensional object (the transect line, $F1=1$) with a fractal population (Halley *et al.* 2004) of dimension $F2$.

We estimated the fractal dimension *g* of the distribution along the transect by fitting a power law for the number of individuals recorded per transect as a function of length.

$$N = kL^{\gamma} \quad (3)$$

When fitting this equation we found that the basic set of transects had a limited length range. However, in some cases the angles between successive transects were small, and we could merge the two transects into one longer transect, which gave us a wider set of length scales.

We then used the intersection formula (2) to find the distribution of the population in the whole study area, knowing *g* and knowing that the dimension of the transect itself is $F1=1$, thus

$$F_2 = \gamma + 1 \quad (4)$$

Fractal dimension was not applied at the level of groups of transects as proposed by Halley *et al.* (2004), but only at the individual transect level. This was in order to avoid intersections and other complications arising from the complex path. The transects were classified into seven classes according to their length: 0.1–0.3 km, 0.3–1 km, 1–3 km, 3–10 km, 10–30 km, 30–100 km and 100–300 km.

For the fractal-dimension approach, the fitted equation for all species was

$$N = 2.87 \times L^{0.7114} \quad (5)$$

This power line was fitted in the log-log domain where the R^2 for the fit was 0.715. Thus, a fractal dimension of 1.711 is estimated for the overall distribution of seabirds.

Method 4: Generalized Additive Models

In order to account for habitat variation, we also implemented GAMs using R-package ‘mgcv’ (Hastie & Tibshirani 1986, Ihaka & Gentleman 1996; Wood 2006, Wood 2011, R Development Core Team 2008). We used the 5′ interval observations of each species within each grid cell, defined above in Method 2, as the response variable. The data were log-transformed prior to the analysis in order to obtain normality. The parameters we used for each model included longitude, latitude, chlorophyll concentration, bathymetry, distance from coast and distance from the nearest colony of the species (Clarke *et al.* 2003, Louzao *et al*. 2009). Bathymetry data were obtained from the Hellenic Center for Marine Research (http://arch.her.hcmr.gr), while the distance from the coastline and the colonies was calculated for each grid cell using GIS. We derived the monthly chlorophyll concentration values from MODIS/Aqua (available at http://seadas.gsfc.nasa.gov) for each of our sampling months. For dynamic variables such as chlorophyll, it is unlikely that marine top predator distribution responds instantaneously to changes in oceanographic variables (Redfern *et al*. 2006). Thus, we used the integrated value of those variables for the period from May to September.

Each species’ data were analyzed separately. The covariates for each model were selected with forward stepwise selection on the basis of Akaike’s Information Criterion (Akaike 1973). Population

TABLE 1

Distribution by species of the 6652 birds recorded

Species	Number of birds observed
P. yelkouan	3516
L. michahellis	1726
C. diomedea	893
P. aristotelis	273
Larus ridinundus	51
Larus minutus	42
Larus melanocephalus	24
Phalacrocorax carbo	4
Calidris alpina	3
Larus genei	3
Sterna hirundo	3
Sterna paradisaea	2
Sterna sandvicensis	2
Hydrobates pelagicus	1
Larus auduiini	1
Sterna caspia	1
Non-seabird species	107

TABLE 2

Number of birds observed and effect of Spear’s correction

Species	n counted	n after Spear’s correction	% reduction
C. diomedea	893	886	1
L. michahellis	1726	1330	23
P. yelkouan	3516	1896	46

Yelkouan Shearwater *Puffinus yelkouan*, photo courtesy of Aris Christidis size was estimated as the sum of the predicted number for each grid cell of the study area.

Bootstrap estimates of confidence intervals

For the estimates derived from Method 1, Method 3 and Method 4, we applied bootstrap resampling. As a sampling unit, we used the number of individuals recorded per day for all days of sampling, and we generated 200 bootstrap resamples for each data set we examined.

RESULTS

In total we observed 31 bird species, of which 16 species were either seabirds or species related to the sea (such as the estuarine species *Calidris alpina*) (Table 1). Of these 16 bird species, five breed on islets in the open sea in Greece: *Calonectris diomedea, Larus michahellis, Puffinus yelkouan*, *Phalacrocorax aristotelis* and *Hydrobates pelagicus*. Three species accounted for more than 93% of all observed seabirds (*C. diomedea, L. michahellis* and *P. yelkouan*) and were sufficiently common to warrant population estimates (Table 2). Other observations either involved non-seabird species or species with insufficient records.

After applying Spear's correction, the observed counts were reduced by 0.76%, 22.96% and 46.07% for *C. diomedea, L. michahellis* and *P. yelkouan,* respectively. According to Spear *et al*. (1992), the degree of reduction depends mainly on the angle between bird and ship directions of the majority of birds. For birds flying perpendicular to the direction of the ship's movement, the correction is zero, while for those flying along with or against the ship, the correction is substantial. If birds are flying against the direction of the ship, this has a negative value, implying that the uncorrected formula overestimates the population density, whereas it is positive if birds are flying in the same direction as the ship. In the special case where birds are flying alongside the ship, the correction formula diverges and no estimation is possible. For *P. yelkouan,* 66.1% of birds were flying in the opposite direction of the ship, while only 31.8% were flying along with it. For *C. diomedea*, nearly as many birds were flying in the same direction as the ship so on average there was virtually no net correction.

Some species were highly clustered, with several big flocks being observed during one day (Fig. 1). Specifically, for *L. michahellis,* a large flock of 300 individuals plus a few others with 20–60 individuals were observed on 27 May. These recordings amount to a large proportion (41.7% of the total) of all individuals observed. Likewise, on 15 July, 29% of all *C. diomedea* were seen in a single group of 180 individuals. On the other hand, *P. yelkouan* was more evenly distributed.

Estimated population sizes

The simple upscaling of transect densities yielded a total population estimate of 344 800 birds (75 200 *C. diomedea*, 108 000 *L. michahellis* and 161 600 *P. yelkouan*), but this is certainly an overestimate, as the non-random placement of transects does not permit such an approach. As indicated by Anganuzzi & Buckland (1993), bias in estimating population size is much more likely when using unstratified data.

Other estimates of the seabird population in the north Aegean are presented in Table 3.

When applying the GAMs for *C. diomedea,* the selected model included "latitude," "longitude" and "distance from colony" as covariates (AIC = 279.23), while the full model's AIC for this species was equal to 281.19. For *L. michahellis,* the selected model included "chlorophyll concentration," "bathymetry," "distance from shore" and "distance from colony" (AIC = 652.69, full model AIC = 654.07). For *P. yelkouan,* the selected model included "latitude", "longitude", "chlorophyll concentration" and "distance from shore" (AIC = 675.05, full model AIC = 676.47).

When applying the "simple upscaling by distance strata" method the overall density of seabirds was estimated to be 1.53/km^2, while

TABLE 3
Estimated seabird population in the north Aegean Sea for the three species of interest

Method of estimation	Confidence interval	Estimated population (thousands)			
		C. diomedea	*L. michahellis*	*P. yelkouan*	Total
Simple upscaling of distance classes	Min *N*	7.9	27.4	28.3	63.6
	Max *N*	52.8	89.7	117.1	159.6
	Mean *N*	19.6	52.3	59.5	131.4
Post-stratification	Min *N*	–	–	–	–
	Max *N*	–	–	–	–
	Mean *N*	13.0	15.8	16.9	45.7
Fractal dimension	Min *N*	1.3	2.4	9.3	12.8
	Max *N*	75.9	14.9	96.0	92.0
	Mean *N*	9.2	5.7	27.3	47.9
Generalized additive model	Min *N*	3.7	6.1	19.6	29.3
	Max *N*	3.8	6.5	26.2	36.5
	Mean *N*	3.7	6.3	22.1	32.0

with the "post stratification," the "fractal dimension" and the GAM methods, the estimated densities were 0.53/km^2, 0.49/km^2 and 0.37/km^2, respectively. The corresponding estimates for the fractal dimensions of the populations were 0.988, 1.404 and 1.749 for *C. diomedea*, *L. michahellis* and *P. yelkouan,* respectively. This is consistent with all populations being clustered over a range of scales (Kunin 1998, Halley *et al*. 2004).

DISCUSSION

There have been few studies in the Mediterranean Sea on seabird abundance and distribution (Louzao *et al*. 2006, Louzao *et al*. 2009), with most existing surveys being conducted along coastlines (Oro 1995). In the northwest Mediterranean Sea, Abello & Oro (1998) recorded 11 species, with the most abundant being *C. diomedea*, *L. audouinii* and *P. yelkouan*, and with *L. michahellis* being abundant near the coast. In the Alboran Sea, the most abundant species observed were *C. diomedea*, *L. michahellis* and *L. fuscus* (Paracuellos & Jerez 2003).

The stratified upscaling method suggested populations of 19 600 *C. diomedea,* 52 300 *L. michahellis* and 59 500 *P. yelkouan*, yielding a total of 131 400 birds. However, these estimates are much larger than for the other three methods, for all species. Since distance from the coast is not the only factor leading to aggregation of populations, this was expected. For this reason, these estimates were not included in the final estimates of the mean population size in the area.

There is a natural aggregation of populations over all scales of observation (Kunin 1998, Halley *et al.* 2004), which is why a fractal-based method population estimation is feasible. Our analysis is one of the first attempts to use this fact. The fractal-based method relies on the observation that the number of birds observed in a transect does not on average increase linearly with transect length, but is proportional to a power of length somewhat less than one, which can be used to modify the upscaling procedure. Estimates by this method usually require large amounts of data in order to work well (Kallimanis *et al* 2002). The post-stratification method of Anganuzzi & Buckland (1993) also uses the aggregation property. Both of these methods lead to estimations in the order of 44 000 for the total population in the Aegean for the three species considered (11 100 for *C. diomedea*, 10 750 for *L. michahellis* and 22 100 for *P. yelkouan*). On the other hand, estimates with GAMs have been proven to be more precise than stratified sampling in fish and fish-egg abundance surveys (Borchers *et al*. 1997; Augustin *et al*.1998), as they capture non-linear trends in density with the use of few parameters (Clarke *et al*. 2003).

Adult breeding plumage Yellow-legged Gulls *Larus michahellis*, photo courtesy of Aris Christidis

GAMs constitute the most widely used method today, and in our case they also give the most conservative estimate of the population. The lower estimates of the GAMs, compared with the other methods, are due to the larger number of cells deemed unsuitable for environmental reasons due to the extra parameters in the model. However, the difference from the other two methods is small enough that the error bars overlap.

Our overall results, taking the mean estimate of the three methods (post-stratification, fractal dimension and GAM), suggest that the north Aegean Sea is an important area for the seabirds of the Mediterranean, as it holds more than 32% of *P. yelkouan* total population as estimated by Birdlife International (2012). For *C. diomedea,* our estimate represents almost 4% of the European breeding population. Information on *L. michahellis* population size is not available due to recent taxonomic splits.

When we compare the density of seabirds at sea with other areas where there have been similar studies, we notice that the density in the north Aegean Sea, at 0.46 birds/km^2, is relatively poor. For example, around Fallaron Islands, in the California Current upwelling zone, the density is about 9.27 birds/km^2, consisting of three species, over an area of 14 000 km^2 within a distance of 75–80 km from the colony (Clarke *et al.* 2003). In Europe, the most studied area is the North Sea, where both seabird density and species richness are high. Besides, two of the most important seabird areas worldwide are in the European region. These are the British Isles and the Barents Sea (Cheung *et al.* 2005). Vanermen & Stienen, in 2009, made an estimate of the density of seabirds in the Belgian part of the North Sea. The estimate varied from 4 birds/km^2 in summer to 11.5 birds/km^2 in winter within an area of 3 600 km^2 along a coastline of about 67 km.

Laurs *et al.* (1977) and Schneider (1993) have observed the strong relationship between seabird population sizes and ocean primary productivity. The low population densities in the north Aegean Sea, relative to that of other areas, are thus understandable in the light of the sea's low primary productivity (Blondel *et al*, 2010).

Our study, the first study of this kind in the north Aegean, is an important step, providing initial estimates of population and biodiversity. It also provides a basis for further studies, both pure and applied, including the designation of marine Important Bird Areas for the region.

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REFERENCES

ABELLO, P. & ORO, D. 1998. Offshore distribution of seabirds in the northwestern Mediterranean in June 1995. *Colonial Waterbirds* 21: 422–426.

ABELLO, P., ARCOS, J.M. & DE SOLA, L.J. 2003. Geographical patterns of seabird attendance to a research trawler along the Iberian Mediterranean coast. *Scientia Marina* 67: 69–75.

AKAIKE, H. 1973. Information theory as an extension of the maximum likelihood principle. In: Petrov, B.N. & Csaki, F. (Eds.). *Second international symposium on information theory.* Budapest, Hungary: Akademiai Kiado. pp. 267–281.

ANGANUZZI, A.A. & BUCKLAND, S.T. 1993. Post-stratification as a bias-reduction technique. *Journal of Wildlife Management* 57: 827–834.

ARCOS, J.M., LOUZAO, M. & ORO, D. 2008. Fishery ecosystem impacts and management in the Mediterranean: seabirds point of view. In: Nielsen, J., Dodson, J., Friedl, K., Hamon, T., Hughes, N., Musick, J., Verspoor, E. (Eds.). Proceedings of the Fourth World Fisheries Congress: Reconciling Fisheries with Conservation. Bethesda, MD, USA: American Fisheries Society, Symposium 49. pp. 587–596.

AUGUSTIN, N.H., BORCHERS, D.L., CLARKE, E.D. & BUCKLAND, S.T. 1998. Spatio-temporal modelling for the annual egg production method of stock assessment using generalized additive models. *Canadian Journal of Fisheries and Aquatic Sciences* 55: 2608–2621.

AZOV, Y. 1991. Eastern Mediterranean – a marine desert? *Marine Pollution Bulletin* 23: 225–232.

BIRDLIFE INTERNATIONAL. 2010. Species factsheet: *Calonectris diomedea/Larus michahellis/Puffinus yelkouan* [Available online: http://www.birdlife.org; accessed on 20 July 2012]

BONNAUD, E., BOURGEOIS, K., VIDAL, E., KAYSER, Y., TRANCHANT, Y. & LEGRAND J. 2007. Feeding ecology of a feral cat population on a small Mediterranean island. *Journal of Mammalogy* 88: 1074–1081.

BORCHERS, D.L., BUCKLAND, S.T., PRIEDE, I.G. & AHMADI, S. 1997. Improving the precision of the daily egg production method using generalized additive models. *Canadian Journal of Fisheries and Aquatic Sciences* 54: 2727–2742.

BOURGEOIS, K. & VIDAL, E. 2008. The endemic Mediterranean yelkouan shearwater *Puffinus yelkouan*: distribution, threats and a plea for more data. Fauna and Flora International. *Oryx* 42: 187–194.

BURGER, E., HITCHCOCK, C.L. & DAVOREN, G.K. 2004. Spatial aggregations of seabirds and their prey on the continental shelf off SW Vancouver Island. *Marine Ecology Progress Series* 283: 279–292.

BUTCHART, S.H.M., STATTERSFIELD, A.J., BENNUN, L.A., SHUTES, S.M., AKCAKAYA, H.R., BAILLIE, J.E.M., STUART, S.N., HILTON-TAYLOR, C. & MACE, G.M. 2004. Measuring global trends in the status of biodiversity: Red List Indices for birds. *PLoS Biology* 2: 2294–2304.

CAMA, A., JOSA, P., FERRER-OBIOL, J. & ARCOS, J.M. 2011. Mediterranean Gulls *Larus melanocephalus* winteringalong the Mediterranean Iberian coast: numbers and activity rhythms in the species' main winter quarters. *Journal of Ornithology* 152: 897–907.

CAMPHUYSEN, C.J. & GARTHE, S. 2004. Recording foraging seabirds at sea: Standardized recording and coding of foraging behavior and multi-species foraging associations. *Atlantic Seabirds* 6: 1–32.

CHEUNG, W., ALDER, J., KARPOUZI, V., WATSON, R., LAM, V., DAY, C., KASCHNER, K. & PAULY, D. 2005. Patterns of species richness in the high seas. Montreal: Secretariat of the Convention on Biological Diversity, Technical Series no. 20. pp. 31.

CLARKE, E.D., SPEAR, L.B., McCRACKEN, M.L., MARQUES, F.F.C., BORCHERS, D.L., BUCKLAND, S.T. & AINLEY, D.G. 2003. Validating the use of generalized additive models and at-sea surveys to estimate size and temporal trends of seabird populations. *Journal of Applied Ecology* 40: 278–292.

COOPER, J., BACCETTI, N., BELDA, E.J., BORG, J.J., ORO, D., PAPACONSTANTINOU C. & SANCHEZ, A. 2003. Seabird mortality from longline fishing in the Mediterranean Sea and Macaronesian waters: a review and a way forward. *Scientia Marina* 67: 57–64.

DAVOREN, G.K., MONTEVECCHI, W.A. & ANDERSON, J.T. 2002. Scale dependent associations of predators and prey: constraints imposed by flightlessness of common murres. *Marine Ecology Progress Series* 245: 259–272.

DE GRUIJTER, J.J., BRUS, D., BIERKENS, M. & KNOTTERS, M. 2006. Sampling for Natural Resource Monitoring. New York: Springer. pp. 341.

FURNESS, R.W. 2003. Impacts of fisheries on seabird communities. *Scientia Marina* 67: 33–45.

GALLO-ORSI, U. 2003. Species action plans for the conservation of seabirds in the Mediterranean Sea: Audouin's gull, Balearic shearwater and Mediterranean shag. *Scientia Marina* 67: 47–55.

HALLEY, J.M., HARTLEY, S., KALLIMANIS, A.S., KUNIN, W.E., LENNON, J.J. & SGARDELIS, S.P. 2004. Uses and abuses of fractal methodology in ecology. *Ecology Letters* 7: 254–271.

HASTIE, T. & TIBSHIRANI, R. 1986. Generalized Additive Models. *Statistical Science* 1: 297–318.

IHAKA, R. & GENTLEMAN, R. 1996. R: A language for data analysis and graphics. *Journal of Computational and Graphical Statistics* 5: 299–314.

JAMES, P.C. 1984. The status and conservation of seabirds in the Mediterranean Sea. *International Council for the Preservation of Birds Technical Publication* 2: 371–375.

JESPERSEN, P. 1924. The frequency of birds over the high Atlantic Ocean. *Nature* 114: 281–283.

KALLIMANIS, A.S., SGARDELIS, S.P. & HALLEY, J.M. 2002. Accuracy of fractal dimension estimates for small samples of ecological distributions. *Landscape Ecology* 17: 281–297.

KARPOUZI, V.S. 2005. Modeling and mapping trophic overlap between fisheries and the world's seabirds [MSc thesis]. Vancouver, BC, Canada: University of British Columbia. pp. 141.

KRPAN, M. 1970. Prilog poznavanjuornitofaune otoka Lastova. *Larus* 21–22: 65–83.

KUNIN, W.E. 1998. Extrapolating species abundance across spatial scales. *Science* 281: 1513–1515.

KUNIN, W.E., HARTLEY, S. & LENNON, J.J. 2000. Scaling down: on the challenge of estimating abundance from occurrence patterns. *American Naturalist* 156: 560–566.

LAURS, R.M., YUEN, H.S.H. & JOHNSON, J.H. 1977. Small-scale movements of albacore, *Thunnus alalunga*, in relation to ocean features as indicated by ultrasonic tracking and oceanographic sampling. *Fisheries Bulletin* 75: 347–355.

LOUZAO, M., HYRENBACH, K.D., ARCOS, J.M., ABELLO, P., DE SOLA, L.G. & ORO, D. 2006. Oceanographic Habitat of an Endangered Mediterranean Procellariiform: Implications for Marine Protected Areas. *Ecological Applications* 16: 1683–1695.

LOUZAO, M., BECARES, J., RODRIGUEZ, B., HYRENBACH, K.D., RUIZ, A. & ARCOS J.M. 2009. Combining vessel-based surveys and tracking data to identify key marine areas for seabirds. *Marine Ecology Progress Series* 391: 183–197.

MARTIN, J.L., THIBAULT, J.C. & BRETAGNOLLE, V. 2000. Black rats, island characteristics, and colonial nesting birds in the Mediterranean: consequences of an ancient introduction. *Conservation Biology* 14: 1452–1466.

ORO, D. 1995. The influence of commercial fisheries in daily activity of Audouin's Gull *Larus audouinii* in the Ebro Delta, NE Spain. *Ornis Fennica* 72: 154–158.

PARACUELLOS, M. & JEREZ, D. 2003. A Comparison of two Seabird Communities on Opposite Coasts of the Alboran Sea (western Mediterranean). *Scientia Marina* 67: 117–123.

R Development Core Team (2008). R: A language and environment for statistical computing. R Foundation for Statistical Computing. Vienna, Austria. Available from: http://www.R-project.org.

REDFERN, J.V., FERGUSON, M.C., BECKER, E.A., HYRENBACH, K.D., GOOD, C., BARLOW, J., KASCHNER, K., BAUMGARTNER, M.F., FORNEY, K.A., BALLANCE, L.T., FAUCHALD, P., HALPIN, P., HAMAZAKI, T., PERSHING, A.J., QIAN, S.S., READ, A., REILLY, S.B., TORRES, L. & WELMER, F. 2006. Techniques for cetacean–habitat modelling. *Marine Ecology Progress Series* 310: 271–295.

SCHNEIDER, D.C. 1993. The role of fluid dynamics in the ecology of marine birds. *Oceanography and Marine Biology: An Annual Review* 29: 487–521.

SPEAR, L.B., NUR, N. & AINLEY, D.G. 1992. Estimating absolute densities of flying seabirds using analyses of relative movement. *Auk* 109: 385–389.

TASKER, M.L., JONES, P.H., DIXON, T. & BLAKE, B.F. 1984. Counting seabirds at sea from ships: A review of methods employed and a suggestion for a standardized approach. *Auk*. 101: 567–577.

TRANCHANT, Y., VIDAL, E. & KAYSER, Y. 2003. Premières données sur le régime alimentaire du chat haret *Felis catus* en situation micro-insulaire Méditerranéenne. *Revue d'Ecologie (Terre and Vie)* 58: 411–418.

TSIKLIRAS, A., SYLAIOS, G., STAMATIS, N. & KALLANIOTIS, A. 2001. Distribution of nutrients and chlorophyll in various water masses in the Northern Aegean Sea, Greece. Proceedings of an International Conference: Ecological Protection of the Planet Earth, Xanthi, Greece 5–8 June 2001. Vol. I: 297–303.

VIGNE, J.D., LEFEVRE, C., THISBAULT, J.C. & GUYOT, I. 1991. Contribution archéozoologique à l'histoire récente des oiseaux marins de l'île Lavezzi (Corse XIV–XVème siècles). *Alauda* 59: 11–21.

WOLF, H.G., SNYDER, M.A., SYDEMAN, W.J., DOAK, D.F. & CROLL, D.A. 2010. Predicting population consequences of ocean climate change for an ecosystem sentinel, the seabird Cassin's auklet. *Global Change Biology* 16: 1923–1935.

WOOD, S.N. 2006. Generalized Additive Models: An introduction with R. Boca Raton, Florida: Chapman & Hall/CRC.

WOOD, S.N. 2011. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *Journal of the Royal Statistical Society (B)* 73:3–36.