Biodiversity and Conservation **11**: 357–377, 2002.

Changes in the Alyki Kitrous wetland in northern Greece: 1990–1999, and future prospects

A. HAILEY[1,*] and V. GOUTNER
Department of Zoology, Aristotelian University of Thessaloniki, GR-540 06 Thessaloniki, Greece;
*[1] Present address: 52 Mascotts Close, Cricklewood, London NW2 6NS, UK; *Author for correspondence (e-mail: ah2@ahailey.force9.co.uk)*

Received 18 August 2000; accepted in revised form 2 April 2001

Abstract. The Alyki wetland in northern Greece is a site of notable herpetological and ornithological importance. A large population of the tortoise *Testudo hermanni* began to recover slowly ($r = 0.016$) between 1990 and 1999, following catastrophic habitat destruction in 1980 and slow decline from 1980–1990. Heathland vegetation showed signs of desiccation, probably due to increased drainage by the salt works, including deterioration of *Crataegus*, *Ruscus* and *Asphodelus*, and loss of formerly important food plants of tortoises. Activity and body mass condition of tortoises were reduced in summer in grassy heath habitats. Predation of artificial (chicken egg) tortoise nests increased, and the relative frequency of juveniles (about 1% of samples) was lower than after severe habitat destruction or pesticide damage. These changes were attributed to an increasing population of badgers, *Meles meles*. Population levels of waders were lower in 1998/1999 than in 1988/1989, especially avocets (*Recurvirostra avosetta*) for which the site was internationally important. Breeding populations of most waders and larids also declined. Mediterranean gulls, for which Alyki was formerly the most important breeding area outside Russia, did not nest from 1990 to 1998, and nests were unsuccessful in 1999. Changes in breeding populations were due to falling lagoon levels, exposure to predators and vegetation encroachment on islet breeding sites. Midwinter waterfowl populations remained high or increased, however, as alternative feeding areas were available in the lagoon. Preservation of the habitats against development of the salt works and increasing desiccation are necessary to maintain the long-term conservation value of the Alyki site.

Key words: avocet, desiccation, Greece, habitat condition, Mediterranean gull, *Testudo hermanni*, tortoise, waterbird, wetland

Introduction

Greece is one of the key parts of the Mediterranean basin for biodiversity (Myers 1990; Troumbis and Dimitrakopoulos 1998), with 22–45% of the total area being potentially valuable for nature protection (Hadjibiros 1991; Bischoff and Jongman 1993). The Gulf of Thermaikos in Macedonia, northern Greece has been identified as a threatspot (an area with high diversity of rare and threatened species) for birds within Greece (Troumbis and Dimitrakopoulos 1998). This area of wetlands is also important for other taxa, although only the herpetofauna have been studied in detail. The Alyki Kitrous (literally the ‘Kitros salt works’) wetland in particular has been recognised as being of international importance for reptiles and waterbirds

(Gooders 1974; Honegger 1981; Corbett 1989; Zalidis and Mantzavelas 1994; Dafis et al. 1996). This paper describes changes at Alyki during the 1990s.

The coastal heathland surrounding the lagoon at Alyki supported a diverse herpetofauna (Willemsen and Hailey 1989) including a large population of Hermann's tortoise, *Testudo hermanni*. However, the population of about 5000 tortoises on the main heath was reduced by 64% by an intense summer fire and subsequent mechanical habitat destruction in 1980, with further damage in winter 1989/1990 leading to an additional 14% reduction (Stubbs et al. 1985; Hailey and Goutner 1991; Hailey 2000a). The recovery of the population from these disturbances is of particular interest for the conservation biology of chelonians, which are characterised by late maturity and long generation times (Gibbons 1987; Condgon et al. 1993). The 1980 catastrophe affected juveniles most severely, reducing their frequency in samples from about 15% down to 3% (Hailey 2000a). Recovery between 1980 and 1990 restored the original population structure, with juveniles increasing to 15% of sightings, but the number of larger tortoises continued to decline slowly due to a lack of recruitment (Hailey 2000a). The major question concerning the tortoise population during the 1990s was whether the restored population structure and juvenile recruitment were sufficient to allow the number of larger tortoises to increase.

The threats to small wetlands in Greece and their importance to waterbirds have been discussed by Joensen and Jerrentrup (1988) and Goutner and Handrinos (1990). Alyki was an internationally significant breeding, passage or wintering site for several waterbird species up to 1990, including great white egret (*Egretta alba*), spoonbill (*Platalea leucorodia*), shelduck (*Tadorna tadorna*), Eurasian wigeon (*Anas penelope*), avocet (*Recurvirostra avosetta*), collared pratincole (*Glareola pratincola*) and gull-billed tern (*Gelochelidon nilotica*). It was also the most important breeding area outside Russia for the Mediterranean gull (*Larus melanocephalus*) (Goutner and Papakostas 1992). The salt works developed substantially during the 1980s and 1990s, with increasing extraction of groundwater from drainage channels by pumping stations, designed to prevent dilution of the sea water and increase salt production. Such hydrological changes may affect both the use of the lagoon by feeding waterbirds, and the availability of islet breeding areas by allowing vegetation encroachment and access by terrestrial predators.

There are currently proposals for further development of the salt works, including a new drainage dyke bisecting the lagoon and expansion of the area used for salt extraction. Studies at other Mediterranean salinas indicate that such development is likely to have major impacts on the ecology of the area. The diversity of invertebrate faunas are inversely related to water salinity, resulting in changes in waterbird populations as a lagoon is developed into salinas (Britton and Johnson 1987). The aims of the present paper are to describe changes in the habitat and the status of tortoises and waterbirds at Alyki between 1990 and 1999, and to discuss the impact of possible further development on biodiversity at this important Mediterranean site. The paper focuses on tortoises and waterbirds because of their significance for conservation and the availability of long-term data for comparison.

Study area

Lake Alyki lies at the southwestern corner of the Gulf of Thermaikos in northern Greece (40°22′ N, 22°38′ E). The total study area was 1185 ha, made up of the following regions (numbered as in Figure 1).

Lagoon (1)

The lagoon of Lake Alyki (area 352 ha) is connected to the sea by a narrow (4 m) opening controlled by sluices and is used by the salt works for the storage of sea

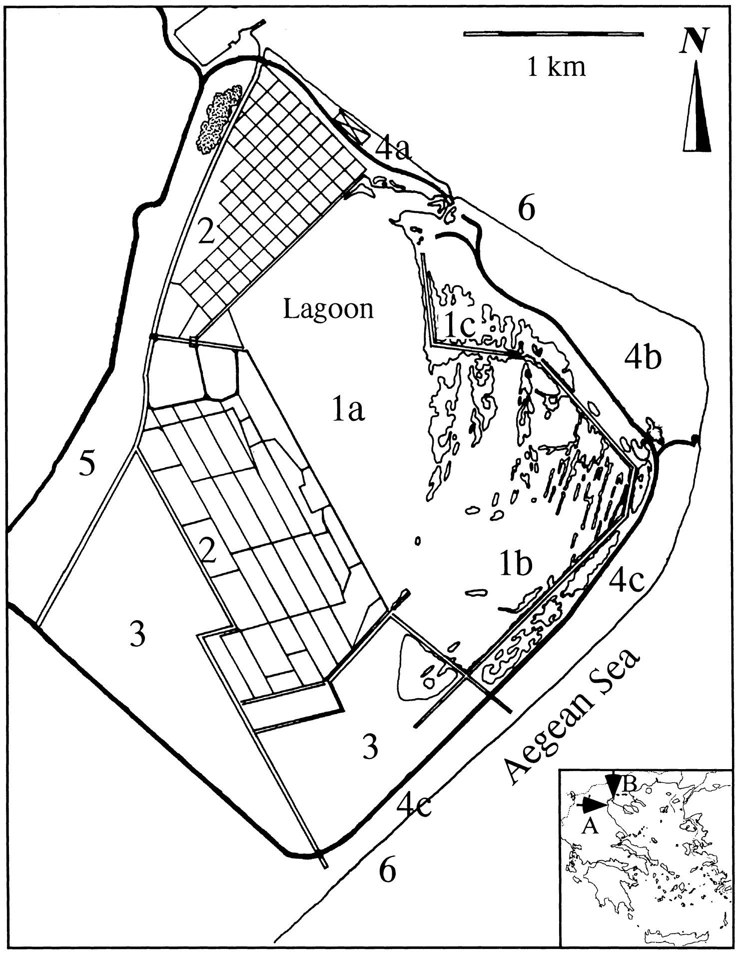

Figure 1. Map of the study site indicating the areas described in the text: (1a) lagoon, open water area, (1b) lagoon, shallow area with islets, (1c) lagoon, temporary pools, (2) salines, (3) saltmarshes, (4a) salt works heath, (4b) main heath, (4c) southern heath, (5) west terrestrial zone, (6) coastal region. Arrow A in the inset location map indicates the Alyki site, and arrow B shows the position of the Mikra meteorological station.

water. Three different habitats can be distinguished: (1a) an open water area of 159 ha in the western side of the lagoon, with water up to 50-cm deep, and islets less than 1 ha in extent in the north; (1b) a shallow (maximum 25-cm deep) area of 193 ha at the eastern side, of which 33 ha are islets with halophytic vegetation; (1c) a 44-ha area of unvegetated pans which are periodically covered by water but separated from the lagoon by a drainage dyke, with some islets with halophytic vegetation. Changes in water level greatly affect the area covered by water in the lagoon; these changes are principally tidal, but the water level is also affected by pumping, rainfall and evaporation.

Salines (2)

The aquatic part of the salt works occupies 254 ha, of which 171 ha in the southern part are pans used for gradual concentration of the salty water. There are small islets within some of the pans in this area. The remaining 83 ha in the northern part are used for salt crystallisation. The saline pans are separated by dykes which are covered by vegetation to various degrees. There are pumping stations (old and new) between the two areas, which pump water from the drainage dykes into the main drainage channel, which opens into the sea to the north.

Saltmarshes (3)

An area of 170 ha south and south west of the lagoon, covered by halophytic vegetation dominated by *Arthrocnemum fructicosum*, *A. glaucum*, *Halocnemum strobilaceum*, *Salicornia europaea*, *Halimione portulacoides* and *Limonium* spp.

Coastal heathland (4)

An area of low ground with sandy substrate, characterised as heathland due to its physiography rather than taxonomic composition (Stubbs et al. 1981, 1985). The area was 165 ha in total, comprising: (4a) the salt works heath; (4b) the main heath; (4c) the southern heath.

The salt works heath was a small disturbed area (15 ha) occupied by the salt works buildings and salt storage areas. This was divided into southern (1) and northern (21) sectors for recording tortoise captures. The main heath (88 ha) was the location of the principal study population of *T. hermanni*. This was divided into 12 sectors mostly in relation to the three major vegetation types (Figure 2): Dry heath – sparse cover of low herbs and grass on firm sandy soil, with scattered *Crataegus* bushes and low-growing clumps of *Ruscus aculeatus*, *Artemisia* and *Rubus*. Coastal heath – very sparse cover of herbs and grass on loose sand, with clumps of *Ammophilla arenaria* on dunes near the beach. Grassy heath – dense cover of 0.5–1 m tall grasses on damper compact sandy soil, with many *Asphodelus microcarpus* but no scrub. The general distribution

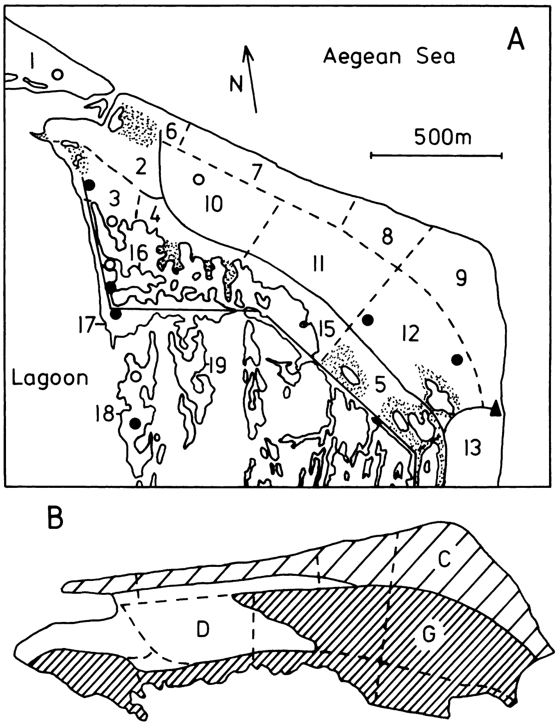

Figure 2. (A) Map of the main tortoise study area, showing sampling sectors. The main heath comprises all numbered areas except the salt works heath (1), the southern heath (13) and the inner (16) and outer (17–19) islets. (○) Artificial nests; (●) badger sett; (▲) lighthouse; major areas of saltmarsh on the main heath are shown by stippling. (B) The distribution of the major vegetation types on the main heath, with sector boundaries shown: habitats are coastal heath (C), dry heath (D) and grassy heath (G).

of the three major vegetation types is shown in Figure 2b; a detailed vegetation map is given by Stubbs et al. (1985). The southern heath (62 ha) was an area of similar habitats to the main heath but with taller dunes along the coast, especially to the south. This was divided into northern (13) and southern (20) sectors.

West terrestrial zone (5)

The west boundary of the site, an area of 90 ha, including cultivations, grazing fields, reedbeds and groups of trees.

Coastal region (6)

An area of 154 ha of sea surrounding the coastal heathland up to a distance of 200 m from the coastline. Within this area water depth is no more than 6 m and, according to the Ramsar Convention definition, is considered as a wetland.

Methods

Tortoises were found by walking throughout the site, systematically searching all sectors and habitat types of the main heath and the salt works heath. The southern heath was also sampled in 1999, but not in 1998 due to lack of time. Tortoises were handled in the field as described by Stubbs et al. (1984), and released immediately afterwards at the point of capture. The straight carapace length (SCL) was measured to the nearest 1 mm, and mass was measured with a 100 g, 1 or 2.5 kg Pesola spring balance. The sex of tortoises <10 cm SCL could not be distinguished, and these are termed juveniles. The sex of tortoises ≥ 10 cm was distinguished by external characteristics (tail length and plastral shape); these animals are termed 10-cm tortoises rather than adults, because sexual maturity occurs at a larger size (Hailey 1990; Hailey and Loumbourdis 1990). Each individual was marked with a unique number by notching the marginal scutes with a hacksaw blade. The coding scheme of Stubbs et al. (1984) gives numbers from 1 to 1499; this was extended by using the left and right sides of the supracaudal scute for 1500 and 3000, respectively. These notches are permanent and can be identified even in dead animals. The chance of misidentification of individuals with scute irregularities or due to notches being obscured with mud was greatly reduced by checking animals in the field against a book containing details of first captures.

Each individual was assigned to its most frequented sector for mark-recapture analysis. This was the sector where an individual was most often found, or in the event of ties the sector where it was found in most different years, or where it was found in 1989 or closest to 1989. This procedure removes migration to and from and within the main heath from the mark-recapture analysis, since each animal is included in the results for only one sector, even if it is occasionally captured elsewhere, and all areas around the main heath occupied by tortoises were also sampled. The tortoise population was analysed in groups of sectors (Figure 2), pooled on the basis of similar habitats to obtain larger samples (Hailey 2000a). These were: $2+10$, dry heath; $3+4$, grassy heath and some dry heath; 5,11,12 and 15 (termed 5–15), grassy heath; $6+7$, coastal heath and some dry heath; $8+9$, coastal heath.

Tortoises had been marked on the main heath in all years from 1980 to 1990 except 1981 and 1987 (Hailey 2000a). The main heath population was also sampled in July and August 1998 and in April and May 1999. There was low activity of tortoises in some sectors in summer 1998 and the whole main heath population could not be estimated for that year. The large 1999 sample was therefore divided into April (1999a) and May (1999b) to estimate population size (N) for the whole main heath. The full unconstrained Jolly–Seber model of the program JOLLY (Pollock et al. 1990) allowed estimates of N for different years, and of survival between samples (including the period 1990–1999) expressed as annual rates (S). The instantaneous rate of population growth (r) was calculated as the difference between two values of $\ln N$ divided by elapsed time in years, where ln is the natural logarithm.

Annual survival rates were converted to instantaneous death rates as $d = -\ln S$ (Charnov 1993), and recruitment rates were calculated as $b = r + d$ (Caughley 1977).

Body mass in relation to length was used as a measure of the condition of 10-cm tortoises. A seasonally adjusted condition index (CI_s) was calculated as log M/M', where M is observed mass and M' is mass estimated from the regression of log mass on log length; separate regressions were used for females and males in each month (Hailey 2000b). Rainfall data were from the Mikra meteorological station on the opposite shore of the Gulf of Thermaikos (40°31′ N, 22°58′ E, altitude 5 m). The rainfall year appropriate for tortoise ecology was calculated from October of the previous year up to September (Willemsen and Hailey 1999).

An experiment on disturbance of simulated tortoise nests (Swingland and Stubbs 1985) in 1986 (Hailey and Loumbourdis 1990) was repeated in 1990 to show any change in predation levels. Twenty chicken eggs were buried in each of five locations, in dry heath and grassy heath habitats of the main heath, salt works heath and islets in the lagoon (Figure 2a). Eggs were buried separately about 5 m apart, and were covered by 3–5 cm of soil and disguised with fragments of vegetation. The location of each simulated nest was marked with a stone 50 cm away, to prevent a predator finding the egg *via* the marker (Hailey and Loumbourdis 1990). Eggs were buried on 29 and 30 May and retrieved on 27 and 28 June 1990.

A survey of *Crataegus* bushes was made in the original dry heath (that undamaged by the fires and mechanical destruction of 1980) of sectors 2 and 7 in 1989 and again in 1998. On each occasion the height and width of the shrubs were estimated, together with the approximate percentage of the shrub volume that was dead.

The area was surveyed completely for waterbirds once every month from June 1998 to May 1999, although results from June 1998 and March 1999 were excluded due to disturbance in the area during fieldwork. This disturbance (from activity of salt works personnel in the southern lagoon) was exceptional, and waterbird flocks were observed moving north out of the area towards the Aliakmon delta. Data from 1998 and 1999 were compared with previous results from November 1988 to October 1989 (Goutner and Papakostas 1992). These periods are henceforward termed 1999 and 1989 for brevity. Only midwinter counts were available for intervening years. More than one survey was made in each month in 1989, so dates most similar to the 1999 visits were used for comparison. We compared the data of four waterbird groups: herons (ciconiiforms and flamingos), waterfowl, waders, and larids (related species were pooled for each group; see Goutner and Papakostas 1992). Specific analyses were made for avocet, due to the past importance of the site for this species, and for flamingo, due to their rapidly increasing numbers. Finally, we compared the number of breeding pairs between the 1989 and 1999 breeding seasons.

We also compared the available midwinter counts for waterfowl, flamingos, and avocets between 1973–1989 and 1990–1999. Mann–Whitney *U*-tests were used to assess differences between median population number in the 1990s compared to earlier observations. This analysis was not specifically related to the habitat disturbance of 1989/1990, which affected the heath but not the birds in the lagoon, but was rather designed to show long-term changes subsequent to the analysis of Goutner and Papakostas (1992) which included data up to October 1989. The analysis included anatids because of their general availability during midwinter counts, and flamingos because of the importance of this species for conservation and the need to monitor apparent changes of numbers in Greece. Waders apart from avocets (which were of importance for conservation) were excluded because of difficulties of identification by some observers. Other waterbirds were excluded from this analysis because their numbers were too low to be reliable indicators of change.

Results

Changes in habitats and predators

There were no signs of further habitat destruction by fire or building on the main heath or southern heath between 1990 (when the area was extensively damaged; Hailey 2000a) and 1999. Wooden fence posts were left in place when building terminated in 1990; these were not burnt, showing that there had been no further fires in the area. The new track along the main heath and the track perpendicular to this (constructed in 1989/1990) were still functional, but the other new parallel tracks had been abandoned. A spring on the main heath had ceased to flow in 1998 and 1999, though water was visible 5 cm below the lip of the pipe. This spring previously flowed slowly but continuously, sufficient to create a small pool and damp area, and originally to fill a drinking trough for livestock (constructed in 1974). Flow in 1979 was sufficient to create a small stream (Figure 1 of Stubbs et al. 1979).

Vegetational changes indicated desiccation of the heathland from 1989/1990 to 1998/1999. Hawthorn bushes *Crataegus* spp. (Rosaceae) were in poor condition on the main heath in 1998, with some completely dead bushes and most showing some dead branches, compared to the situation in 1989 (Figure 3). Mean morbidity (the % of the bush which was dead) was 31.0% ($n = 122$, excluding completely dead bushes) or 39.9% ($n = 140$, including all bushes) in 1998 compared to 6.7% in 1989 ($n = 30$) (Mann–Whitney tests, both $P < 0.001$). These results were from an area of dry heath undamaged in 1980 (or subsequently), but increasing morbidity and mortality was not due to an ageing population as bushes of all sizes were equally affected; there was no correlation between height and morbidity (Spearman rank correlation $r_s = -0.049$, $n = 140$, $P = 0.561$).

The low bush *R. aculeatus* (Liliaceae) also showed poor condition in 1998 and 1999 with dead sections and yellowing leaves. The heathland (particularly the interface between dry and coastal heath) was being invaded by the turpentine tree *Pistacia terebinthus* (Anacardiaceae), a characteristic scrub plant of dry open woods (Polunin 1980). Two plants commonly used as food by tortoises in the 1980s had al-

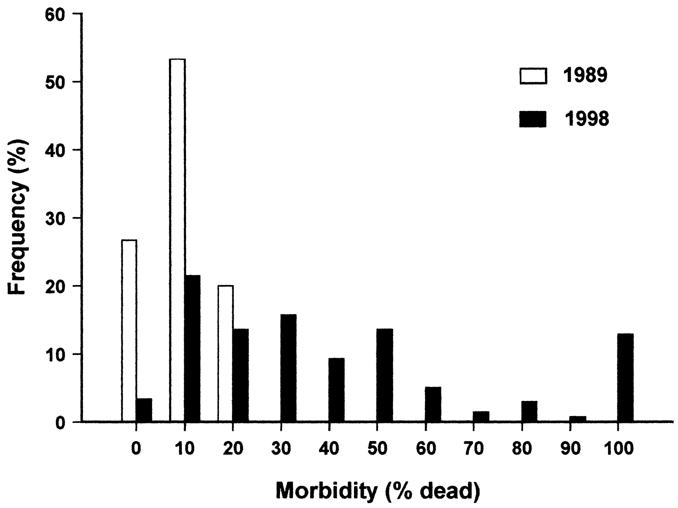

Figure 3. Frequency histogram (% of shrubs in each morbidity class) of morbidity (% of the shrub volume which was dead) of hawthorn bushes (*Crataegus* spp.) in the original dry heath of sectors 2 and 7 in 1989 and 1998.

most disappeared from the heathland: the buck's-horn plantain (*Plantago coronopus*, Plantaginaceae) and *Chondrilla juncea* (Compositae). Both species were formerly widespread in grassy heath and transitional areas with coastal heath and dry heath, but were restricted to very small areas in 1998 and 1999. In contrast, the joint pine (*Ephedra fragilis*, Ephedraceae), the fruits of which are eaten by tortoises in summer, increased greatly in distribution, extending from the dunes near the lighthouse where it was found in the 1980s to many areas of coastal and dry heath. This plant had also colonised the heaps of sand remaining from the 1980 bulldozing. The asphodel *As. microcarpus* (Liliaceae) was widely distributed in grassy heath as before, but was in poor condition in spring 1999 with yellowing and dying leaves (condition in 1998 was unknown because foliage is normally dead in summer), possibly as a result of increasing ground salinity (D. Babalonas pers. comm.).

Vegetation of *A. fructicosum*, *H. portulacoides* and *Halo. strobilaceum* had grown considerably on the lagoon islands in the 1990s, covering almost all the space that could be used by nesting birds. The dykes were also covered by vegetation in 1999, in contrast to 1989, reducing the space available for breeding.

Large mammal burrows were first observed in the new dyke (which was constructed in 1980; Stubbs et al. 1981) in sector 17 from 1984 to 1986. A second burrow system was seen further along the dyke on the main heath in sector 3 in 1988 (Hailey and Loumbourdis 1990). These later proved to be setts; badgers (*Meles meles*, Carnivora) were observed there in the long evenings of June 1990. No other badgers were observed directly as they are nocturnal and their activity periods do not overlap with those of tortoises. There were several additional setts in 1998/1999, on the outer islet (sector 18), on the dyke bank facing the inner islet (sector 16) and on the main heath (sector 12) (Figure 2a). There were additional signs of badger utilisation over the whole main heath including droppings (especially in 1998 when they were feeding on *Ephedra* fruits), tracks and pathways, diggings, and two skulls. Indirect evidence therefore showed that the number of badgers on the coastal heathland had increased substantially, from being absent from the area in 1980.

Tortoises

Activity in the dry/grassy heath and grassy heath sectors 3 + 4 and 5–15 was very low in July and August 1998. The size of the whole main heath population was therefore estimated only for 1999, using separate 1999a and 1999b samples (Table 1), divided into the areas used previously (Hailey 2000a). The total main heath population in 1999 was estimated as 46% of the original (1980 pre-fire) size. The estimate for 1990, based on the pooled 1990 sample and recaptures in 1998 and 1999, is slightly above that estimated previously from captures in 1990 (Hailey 2000a); the revised estimate is used here, because this corresponds to the survival rates for 1990–1999. The 1990 population of 1209 was thus 40% of the original size of 3055. Population growth was highest in sectors 2 + 10 and 5–15, which were the areas where population size was most reduced in 1980. Indeed, the population in sectors 3 + 4, 6 + 7 and 8 + 9 showed small declines from 1990 to 1999 (Table 1). Annual survival rates for the period 1990–1999 were above 0.9 in all areas, and were on average slightly higher than those for 1982–1989 (when the main heath was also undisturbed). The average survival rate of 0.933 corresponds to an instantaneous death rate of $d = 0.069$. Population growth of 1209 to 1399 in 9 years corresponds to an instantaneous rate of increase of $r = 0.016$ and an annual recruitment rate of $b = 0.085$ over this period.

The abundance of juveniles on the main heath declined dramatically between 1990 and 1998 (Figure 4). Juveniles made up 14.7% of the original (pre-fire) sample in 1980, decreased to 3.1% after the catastrophe, then slowly increased to about the

Table 1. Population analysis of 10-cm *T. hermanni* on the main heath. Values shown ± 1 SE.

			Survival rate S		Population size N			
Sector	Habitat	I[a]	1982–1989[b]	1990–1999	1980[b]	1990[b]	1990	1999
2 + 10	Dry heath	993	0.880	0.970 ± 0.017	890	250	271 ± 18	427 ± 73
3 + 4	Dry/grassy heath	614	0.893	0.926 ± 0.013	549	280	278 ± 17	247 ± 30
5–15	Grassy heath	704	0.930	0.921 ± 0.019	1136	282	312 ± 30	411 ± 77
6 + 7	Dry/coastal heath	452	0.928	0.933 ± 0.015	288	190	204 ± 16	196 ± 30
8 + 9	Coastal heath	309	0.948	0.914 ± 0.021	192	130	144 ± 15	118 ± 22
Total			0.916	0.933	3055	1132	1209	1399

[a] I is the total number of individuals involved in the analysis of each group of sectors from 1980 to 1999.
[b] From Hailey (2000a).

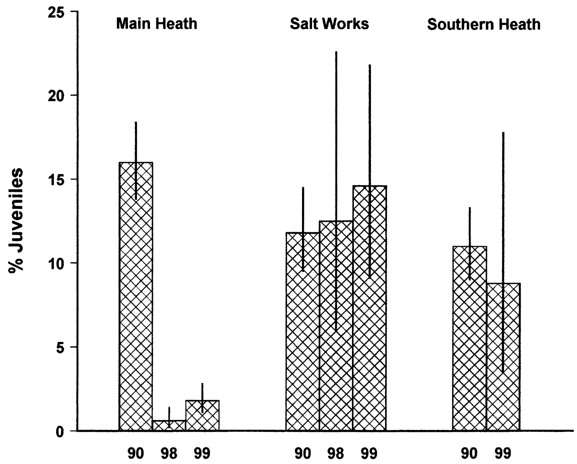

Figure 4. Changes in the population structure (% juveniles) of tortoises between 1990 and 1998/1999. Bars show 95% confidence intervals from the binomial distribution (Sokal and Rohlf 1981).

original level, reaching 16.0% (n = 1793 observations) in 1990 (Hailey 2000a). Juveniles were rarely seen in 1998 (0.6%, n = 684) and 1999 (1.8%, n = 1280). The proportion of juveniles in 1998/1999 is significantly different from that in 1990 ($\chi^2 = 262$, 1 df, $P < 0.001$). Two other areas, selected on the basis of minimal disturbance and exposure to predators, are examined as controls against reduced juvenile activity during 1998/1999 (Figure 4). First, the northern salt works heath (sector 21); juveniles made up 11.8% of observations (total n = 642) up to 1990, 12.5% (n = 72) in 1998, and 14.6% (n = 130) in 1999. The proportion of juveniles is not significantly different up to and after 1990 ($\chi^2 = 0.58$, $P > 0.05$). Second, the southern heath (sectors 13 + 20); juveniles made up 11.0% of observations (n = 829) up to 1990, and 8.8% (n = 80) in 1999 (this area was not sampled in 1998). The proportion of juveniles is again not significantly different up to and after 1990 ($\chi^2 = 0.38$, $P > 0.05$). The low frequency of juveniles on the main heath in 1998 and 1999 is thus not due to their low activity at that time.

Simulated tortoise nests were left in place for 1 month in 1990, and significantly more were destroyed than in 1986 (Table 2) although eggs were left for 3 months that year (Hailey and Loumbourdis 1990). Overall, the level of egg destruction was about twice as high in 1990 as in 1986. The level of egg destruction was similar on the main heath and the southern end of the salt works heath, and increased about threefold from 1986 to 1990, a difference which was significant in both areas (Table 2). The level of nest destruction was significantly lower on the islets (comparison of the three areas in 1990; $\chi^2 = 14.87$, 2 df, $P < 0.001$), which were not investigated in 1986 because few female tortoises occur there (Hailey and Willemsen 2000).

Activity in the grassy heath sectors 3 + 4 and 5–15 was very low in summer 1998. These areas accounted for only 0.4% of the main heath sample in 1998 (n = 684) compared to 38.1% in other years (n = 11484; $\chi^2 = 326$, 1 df, $P < 0.001$). Some

Table 2. Predation on chicken eggs buried at Alyki in 1986 and 1990.

	1986	1990	χ^2	P
Main heath	17 (40)	47 (40)	8.20	<0.01
Salt works heath	17 (60)	45 (20)	6.65	<0.01
Islets	–	10 (40)	–	
Total	17 (100)	32 (100)	6.08	<0.05

Values are the percentage of eggs in each area which were damaged or removed from the nest, with sample sizes in parentheses, and χ^2 tests comparing 1986 and 1990.

Table 3. Variation of condition of 10-cm *T. hermanni* with vegetation and year.

	1998		1999	
Vegetation	CI_S	*n*	CI_S	*n*
Grassy heath	-0.0082 ± 0.0359	51	0.0160 ± 0.0264	421
Other	0.0022 ± 0.0305	443	0.0146 ± 0.0265	537
Total	0.0011 ± 0.0312	494	0.0152 ± 0.0265	958

CI_S = seasonally adjusted condition, *n* = sample size, ± shows 1 SD.

individual tortoises were known to have moved into adjacent habitats. Seasonally adjusted condition was significantly lower in grassy heath than other vegetation types in summer 1998 (Table 3, one-way ANOVA, $P = 0.024$), but not in spring 1999 ($P = 0.417$). A two-way ANOVA showed a significant effect of year ($P < 0.001$) and interaction between vegetation type (grassland/others) and year ($P < 0.001$). Overall, condition was higher in 1999 than in 1998. The former was a year of near-average rainfall (354 mm for the period October–May, compared with a mean of 350 mm for these months for 1960–1998), while annual rainfall was only 360 mm in 1998 (compared to a mean of 451 mm for the whole year for 1960–1998).

Waterbirds

Numbers of ciconiiforms and flamingos were higher during 1999 than 1989, except for July and August (Figure 5a). The increase was due to flamingos, which constituted the bulk of the grouped heron population in 1999 (Figure 6a). Flamingos were practically absent from Alyki in the 1980s; the long-term increase is shown by the midwinter numbers during the 1990s (Appendix). Most flamingos were adults or subadults, and many exhibited breeding behaviour (both courtship rituals and copulations). Waterfowl numbers were higher in 1999 than in 1989, especially during December (Figure 5b). Nevertheless, the median numbers of midwinter total Anatidae did not differ significantly before and after 1990 (Appendix). Of the waterfowl species counted, the shelduck (*Ta. tadorna*) and mallard (*An. platyrhynchos*) num-

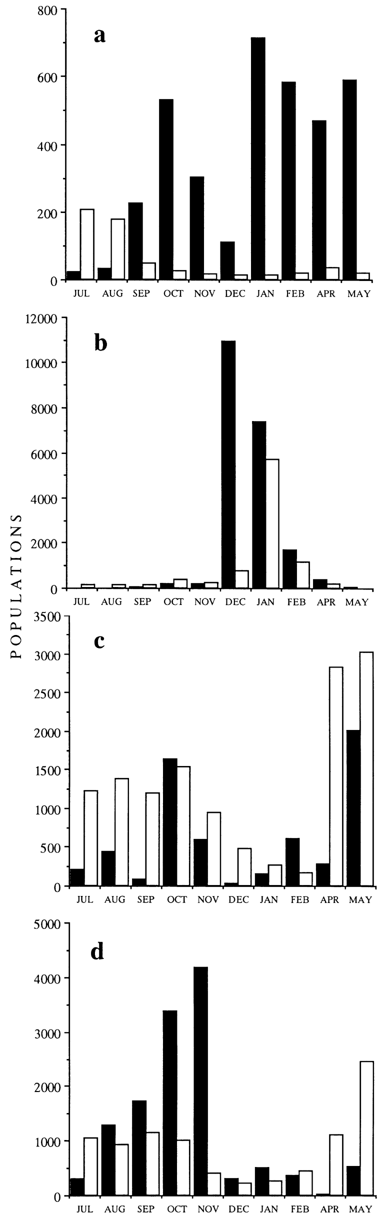

Figure 5. Comparison of population levels of waterbird groups at Alyki between 1989 (open columns) and 1999 (closed columns); (a) herons; (b) waterfowl; (c) waders; (d) larids.

bers increased significantly in the 1990s, while other species showed no significant changes (Appendix).

Numbers of waders were lower in 1999 than in 1989 in most months (Figure 5c). Avocets constituted an important proportion of the total wader population in both

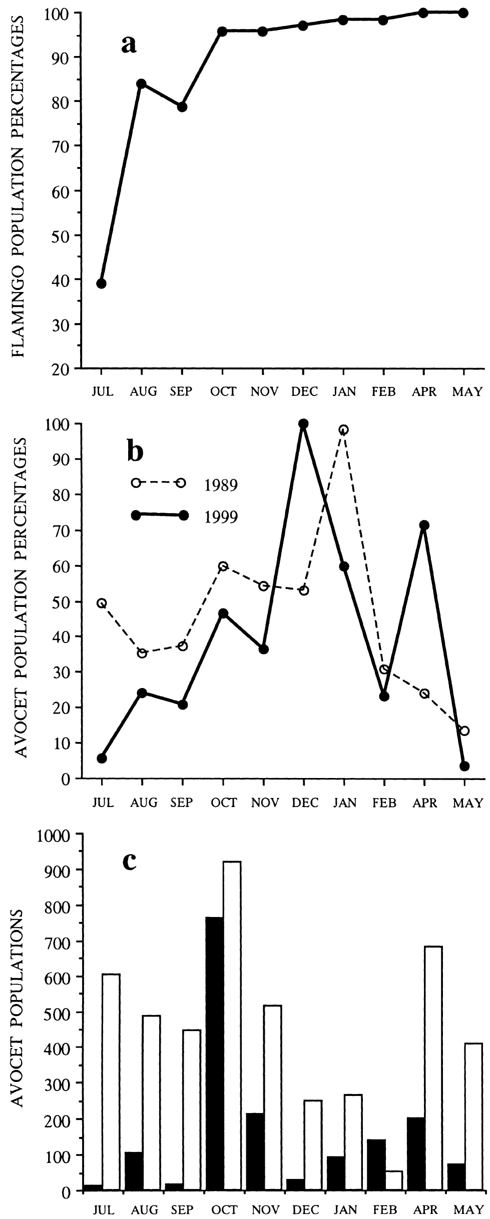

Figure 6. Waterbird group composition: (a) flamingos as a proportion of the total heron population in 1999, (b) avocets as a proportion of the total wader population in 1989 and 1999, (c) population levels of avocets in 1989 (open columns) and 1999 (closed columns).

periods, especially between October and January, when they made up more than 45% of the wintering populations (Figure 6b). In other months, the avocets were outnumbered by other migrating waders, primarily calidrids (Papakostas and Goutner, unpub-

Table 4. Wader and larid populations breeding at Alyki in 1989 and 1999.

	Number of pairs					
	Lagoon islets		Saline dykes		Totals	
Species	1989	1999	1989	1999	1989	1999
Hi. himantopus	0	0	11	30	11	30
Re. avosetta	5	3	123	35	128	38
L. genei	36	0	0	[a]	36	[a]
L. melanocephalus	0	100	654	30	654	130
S. hirundo	43	0	112	15	155	15
S. albifrons	20	3	58	3	78	6

[a] Evidence of breeding from destroyed eggs; number of pairs unknown.

lished data). Avocet numbers were lower in 1999 than in 1989 in all months except February (Figure 6c). Median numbers of wintering avocets were similar between 1973–1989 and 1990–1999 (Appendix). Larid populations were higher in 1999 than in 1989 from August to November (Figure 5d), mainly due to migrating black-headed gulls (*L. ridibundus*). Populations were similar in 1989 and 1999 from December to February. Populations were lower in 1999 than in 1989 in April and May due to lower breeding populations, especially of Mediterranean gulls (*L. melanocephalus*).

All breeding populations were considerably lower in 1999 than in 1989, except for the black-winged stilt (*Himantopus himantopus*), whose numbers were higher. The saline dykes and small islets in evaporation pans attracted most breeding pairs, except for Mediterranean gulls in 1999 which used mostly lagoon islets (Table 4). After 1989, the Mediterranean gulls did not attempt to breed at Alyki until 1999, when they were again unsuccessful because of colony desertion at the start of breeding. Some species which bred at Alyki in 1989 were not found breeding in 1999, such as the collared pratincole (*G. pratincola*) and gull-billed tern (*Sterna nilotica*). Slender-billed gulls (*L. genei*) breeding in 1999 were only observed as eggs destroyed by predators on saline dykes. These nests were probably lost early in the season, and the exact number of pairs attempting to breed in 1999 is not known.

Discussion

Changes 1990–1999

The major changes in the terrestrial ecology of Alyki were probably due to increased desiccation (and possibly salinity) and increased presence of predators. The main effect in the dry heath habitat was damage to *Crataegus* and *Ruscus*, and replacement by *Pistacia* scrub, while in the wetter grassland areas there was loss of some important tortoise-food species and damage to *Asphodelus*. These changes affected the condition and activity of tortoises in summer (1998) in grassy heath, but not in other habitats or in spring (1999). They appear to have had little direct effect on the population so far, since the main grassy heath area of sectors 5–15 showed strong population growth (Table 1).

The population size of 10-cm tortoises increased at the rate of $r = 0.016$, or about 1.6% year^{-1}, reversing the declining trend of the 1980s. This rate of increase was well below the intrinsic rate which is about 15% year^{-1} in Mediterranean tortoises, a value recorded in a small exponentially increasing population of *T. graeca* at Alyki (Hailey 2000c). Such a rate of increase is only likely to be achieved in conditions of very low adult mortality. A better comparison is of the recruitment rate $b = 0.085$, which was about half that found in the *T. graeca* population ($b = 0.15$). Recruitment was thus fairly high, particularly in view of the 3:1 sex ratio of adult males to adult females of *T. hermanni* on the main heath (Hailey 1990) compared to the even sex ratio of the *T. graeca* population (Hailey 1988). The recruitment rate per adult female was thus comparable to that in *T. graeca*.

The increase in mammalian predators appears to have had a more immediate impact on the tortoises than has desiccation, with numbers of juveniles being substantially reduced on the main heath compared to earlier years and to other areas. Badgers were absent in 1980 but colonised the dyke separating the lagoon from the heath within a few years of its construction (which was in progress in 1980). The subsequent spread of setts follows the typical pattern for an increasing badger population (Neal 1976). The effect of badgers on mortality of nests of *T. hermanni* in France has been described by Stubbs and Swingland (1985), and such predation is likely to have caused the increased destruction of artificial nests between 1986 and 1990. Juveniles on the main heath were more reduced in numbers in 1998 and 1999 than they were by fire and severe habitat destruction (Hailey 2000a) or spraying with pesticides (Willemsen and Hailey 2001). Badgers are widespread in Greece (De Beaufort 1991). This species is typically a forest dweller, and populations in open Mediterranean ecosystems are apparently under threat (Revilla et al. 2000). Measures to control or reduce the badgers at Alyki would therefore be controversial. We recommend further monitoring of the populations of tortoises and badgers, and the effects of predation on nesting waterbirds at their increasingly exposed breeding sites.

The waterbird populations of Alyki remained high after 1990 compared to earlier years. Flamingos and some wintering waterfowl populations increased during the 1990s, and larids were also higher in most months in 1999 than in 1989, apart from in the breeding season. The increase in numbers of flamingos at Alyki parallels that at other Greek wetland sites, which began in the mid 1980s, probably due to the dispersal of the western Mediterranean population (Handrinos and Akriotis 1997). The birds made a number of low nest cones at the end of May and beginning of June 1999, after a drop in water level in a winter reservoir (used to retain high salinity water from last year's salt production). No breeding occurred, but Alyki seems to be a suitable environment for flamingos, which breed in such saline areas in southern France and Spain (Rendon and Johnson 1997).

Wader populations, including avocets, that used the site declined between 1989 and 1999. Manipulation of water level and salinity has been found to be a suitable tool to increase avocet and other wader populations in Havergate Island and other RSPB reserves (Hill et al. 1989; Burgess and Hirrons 1990). Long-term changes in the hydrological regime at Alyki due to the salt works and consequent change in prey dynamics could therefore affect wader populations. The situation warrants further investigation because Alyki held an internationally important avocet population during most months (Goutner and Papakostas 1992).

The differences in breeding populations between 1989 and 1999 are also important. The water level in the lagoon appears to be an important factor regulating the presence of breeding Mediterranean gulls in the area. The occurrence of suitable undisturbed islets is of prime importance for breeding larids and waders in Mediterranean wetlands (Fasola and Canova 1997; Goutner 1997; Sadoul et al. 1998). Increased salt production and activity of the salt works probably resulted in a drop in the water level in the southern part of the lagoon, and thus to desertion of the Mediterranean gull colony. In addition, vegetation had grown considerably on the lagoon islets and dykes in the 1990s, covering almost all the available space. Vegetation growth discourages ground-nesting birds from using a site (Blokpoel et al. 1978; Burger and Lesser 1978; Goutner 1986). The reduction of breeding populations is thus a combination of direct human influence (increased salt production and drop in water levels) and natural processes (increased vegetation cover).

Since there are no regular counts available of breeding populations between 1989 and 1999, it cannot be determined whether the difference in the breeding populations is due to large interannual variations, or marks a true decline. Alyki is a part of the extensive wetland complex of the Thermaikos Gulf. No conclusions can be drawn about overall breeding bird populations in the area, apart from the Mediterranean gull which has been monitored there over the long term. Between 1990 and 1997 Mediterranean gulls bred on coastal islets in the Axios delta, situated 20 km north of Alyki. Their breeding populations varied from 150 pairs in 1990 to 1200 pairs in 1997 (overall mean for 1990–1997: 930 pairs) while none bred in 1998 (Goutner et al. 1999) and only a few pairs bred in 1999 (J. Tsougrakis pers. comm.). Breeding levels in the Axios delta therefore never approached those at Alyki in the 1980s (Goutner and Isenmann 1993), showing an overall decline of this species in the area.

Prospects and recommendations

Alyki evidently remains a herpetologically and ornithologically important site, and its long-term conservation should be promoted and safeguarded. Desiccation of terrestrial habitats had little effect on tortoises up to 1999, and increasing numbers of predators appear to be a greater immediate threat to population recovery. Waterbirds were most affected by disturbance of breeding areas rather than feeding sites, and midwinter waterfowl numbers remained high or increased. No fires or building efforts took place by the local people after 1990 due to strict discouragement by the Ministry of Environment, Housing, and Public Works. A Ministerial Decree (No. 14874/3291 of 6 July 1998) included Alyki in the protected wetland complex of the Thermaikos Gulf, fitted boundaries around the area important for conservation, and made building and other disturbance illegal. An upcoming Presidential Decree (which will replace the Ministerial Decree) plans to allow building further to the south west of area 3 to cope with pressure from local people.

In 1998, the Hellenic Saltworks Company proposed to expand the area of the salt works in area 3 and further to the south west, and also to construct a dyke separating areas 1a and 1b of the lagoon (Figure 1). The open water area 1a would then provide sea water to the salt works, while flow to area 1b would be by pumping. The Hellenic Saltworks Company requested an environmental impact assessment of these proposals by the University of Thessaloniki, the detailed results of which will be published locally. The general conclusion was to reject the construction of the dyke in the lagoon, as this would interfere with the hydrodynamics of the area. In particular, flow to the feeding and nesting areas of area 1b would become artificial, and further drainage would increase exposure of the islets and lower the water table of the surrounding heath. The assessment also recommended that only a part of area 3 (principally that between areas 2 and 4c) should be allowed for expansion of the salt works. A more substantial expansion would cause further degradation of vegetation and disturbance to wildlife, which is already concentrated in a very limited area at Alyki.

Acknowledgements

We are grateful to G. Papakostas, G. Handrinos and the Hellenic Ornithological Society (especially D. Bousbouras and S. Kazantzidis) for providing information or data, particularly midwinter bird counts, and B. Grammatikopoulos, N. Loumbourdis, G. Theophilidis, and M. Lazaridou-Dimitriadou for help in Thessaloniki and Alyki. P. Menounos and K. Poirazidis aided the 1998–1999 bird surveys, D. Babalonas discussed the condition of *Asphodelus* at Alyki, the Greek Meteorological Service provided rainfall data, James Hines provided the program JOLLY, and Roger Avery and two reviewers gave valuable comments. V. Goutner was supported by a project of the Hellenic Saltworks A. E. (1998–1999).

Appendix

Available midwinter counts of waterfowl, flamingos and avocets at Alyki from 1973 to 1999.

	1973	1983	1984	1985	1986	1987	1989	1990	1992	1993	1994	1995	1996	1997	1998	1999	*U*	*P*
A. anser	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	27	0.257
A. albifrons	0	0	0	0	0	0	1	0	0	0	0	7	0	0	0	0	31	0.927
C. olor	0	0	0	0	0	0	0	0	0	0	0	10	60	22	0	0	21	0.103
T. tadorna	0	1	17	6	26	0	1142	849	28	672	356	265	557	423	167	777	9	0.017
A. penelope	7000	310	1010	40	220	0	2500	960	96	25	460	230	585	10	310	749	26.5	0.596
A. crecca	0	510	0	0	0	0	700	438	0	0	65	10	0	2200	225	845	21.5	0.258
A. platyrhynchos	40	200	10	10	12	0	62	24	10	210	235	72	248	629	180	426	10	0.022
A. acuta	50	110	78	0	18	0	1156	560	13	21	125	50	28	200	6	79	26.5	0.596
A. clypeata	0	40	60	60	37	0	6	13	16	0	0	24	20	310	2	17	26	0.557
A. strepera	0	0	0	0	0	0	5	0	0	0	0	0	17	10	0	0	28	0.587
A. ferina	0	0	60	3	210	0	616	100	0	0	45	0	390	0	0	1840	29.5	0.821
F. atra	0	3400	3500	45	240	0	206	0	0	0	60	0	471	50	85	2626	23	0.356
Total Anatidae[a]	7090	1171	1238	188	532	0	6201	3836	163	928	1286	668	1905	3804	890	4733	28	0.711
Flamingos	0	1	0	0	0	0	0	0	0	118	520	699	602	866	1623	701	8	0.012
Avocets	0	0	0	0	7	170	272	165	0	0	118	11	1	161	26	94	22	0.473

[a] Including *Aythya* sp., *Bucephala* sp., *Mergus* sp., *Oxyura leucocephala* and unidentified. Results of a Mann–Whitney *U*-test comparing median population numbers up to 1989 and from 1990 are also shown.

References

Bischoff NT and Jongman RHG (1993) Development of Rural Areas in Europe: The Claim for Nature. Netherlands Scientific Council for Government Policy, The Hague

Blokpoel H, Catling PM and Haymes GT (1978) Relationship between nest sites of common terns and vegetation on the Eastern Headland, Toronto Outer Harbor. Canadian Journal of Zoology 56: 2057–2061

Britton RH and Johnson AR (1987) An ecological account of a Mediterranean salina: the Salin de Giraud, Camargue (S. France). Biological Conservation 42: 185–230

Burger J and Lesser F (1978) Selection of colony sites and nest sites by common terns *Sterna hirundo* in Ocean County, New Jersey. Ibis 120: 433–449

Burgess ND and Hirons GJM (1990) Management Case Study: Techniques of Hydrological Management at Coastal Lagoons and Lowland Wet Grasslands on RSPB Reserves. RSPB, Tring

Caughley G (1977) Analysis of Vertebrate Populations. John Wiley, Chichester, UK

Charnov EL (1993) Life History Invariants: Some Explorations of Symmetry in Evolutionary Ecology. Oxford University Press, Oxford

Congdon JD, Dunham AE and van Loben Sels RC (1993) Delayed sexual maturity and demographics of Blanding's turtles (*Emydoidea blandingii*): implications for conservation and management of long-lived organisms. Conservation Biology 7: 826–833

Corbett K (1989) Conservation of European Reptiles and Amphibians. Helm, London

Dafis S, Papastergiadou E, Georghiou K, Babalonas D Georgiadis T, Papageorgiou M, Lazaridou T and Tsiaoussi V (1996) Directive 92/43/EEC The Greek 'Habitat' Project Natura 2000: an Overview. Commission of the European Community DGXI/Goulandris Natural History Museum/Greek Biotope/Wetland Centre, Athens

De Beaufort F (1991) La faune des mammifères de Grèce: caractéristiques, endemisme, particularisme. Biologia Gallo-Hellenica 18: 99–106

Fasola M and Canova L (1997) Conservation of gull and tern colony sites in northeastern Italy, an internationally important bird area. Colonial Waterbirds (Special Publication 1) 19: 59–67

Gibbons JW (1987) Why do turtles live so long? Bioscience 37: 262–269

Gooders J (1974) Where to Watch Birds in Europe. Andre Deutsch, London

Goutner V (1986) The ecology of the first breeding of the Mediterranean gull (*Larus melanocephalus* Temminck 1820) in the Evros Delta (Greece). Ökologie der Vögel 8: 189–197

Goutner V (1997) Use of the Drana Lagoon (Evros Delta, Greece) by threatened colonially nesting waterbirds and its possible restoration. Biological Conservation 81: 113–120

Goutner V and Handrinos G (1990) The occurrence of slender-billed curlews *Numenius tenuirostris* in Greece. Biological Conservation 53: 47–60

Goutner V and Isenmann P (1993) Breeding status of the Mediterranean gull (*Larus melanocephalus*) in the Mediterranean Basin. In: Aguilar JS, Monbailliu X and Paterson A (eds) Status and Conservation of Seabirds – Ecogeography and Mediterranean Action Plan, pp 59–63. MEDMARAVIS, SEO, Madrid

Goutner V and Papakostas G (1992) Evaluation of the ornithological importance of the Alyki Kitrous wetland, Macedonia, Greece: a priority for conservation. Biological Conservation 62: 131–138

Goutner V, Jerrentrup H, Kazantzidis S and Poirazidis K (1999) Population trends, distribution, ring recoveries and conservation of Mediterranean gull *Larus melanocephalus* in Greece. In: Meininger PL, Hoogendoorn W, Flamant R and Raeval P (eds) Proceedings of the First International Mediterranean Gull Meeting, pp 31–37. Econum, Bailleul, France

Hadjibiros K (1991) Création d'une banque de données pour l'environnement naturel de Grèce. Rapport intermediaire. Université Nationale Technique/Commission des Communautés Européennes DGXI, Athens

Hailey A (1988) Population ecology and conservation of tortoises: the estimation of density, and dynamics of a small population. Herpetological Journal 1: 263–271

Hailey A (1990) Adult survival and recruitment and the explanation of an uneven sex ratio in a tortoise population. Canadian Journal of Zoology 68: 547–555

Hailey A (2000a) The effects of fire and mechanical habitat destruction on survival of the tortoise *Testudo hermanni* in northern Greece. Biological Conservation 92: 321–333

Hailey A (2000b) Assessing body mass condition in the tortoise *Testudo hermanni*. Herpetological Journal 10: 57–61

Hailey A (2000c) Implications of high intrinsic growth rate of a tortoise population for conservation. Animal Conservation 3: 185–189

Hailey A and Goutner V (1991) Villas, villagers and tortoises in Greece – a sequel. Oryx 25: 169-171

Hailey A and Loumbourdis NS (1990) Population ecology and conservation of tortoises: demographic aspects of reproduction in *Testudo hermanni*. Herpetological Journal 1: 425–434

Hailey A and Willemsen RE (2000) Population density and adult sex ratio of the tortoise *Testudo hermanni* in Greece: evidence for intrinsic population regulation. Journal of Zoology, London 251: 325–338

Handrinos G and Akriotis T (1997) The Birds of Greece. A & C Black, London

Hill D, De Jong S, Cadbury J and Partridge J (1989) Management Case Study: Hydrological Management and Lagoon Creation for Avocet in Havergate. RSPB, Tring

Honegger RE (1981) Threatened Amphibians and Reptiles in Europe. Akademische Verlagsgesellschaft, Wiesbaden

Joensen AH and Jerrentrup H (1988) The Agios Mamas Lagoon, Halkidiki, Greece, an area of international importance for breeding waders. Natura Jutlandica 22: 185–188

Myers N (1990) The biodiversity challenge: expanded hotspot analysis. The Environmentalist 10: 243–256

Neal E (1976) The Badger, 5th edition. Collins, London

Pollock KH, Nichols JD, Browne C and Hines JE (1990) Statistical inference for capture–recapture experiments. Wildlife Monographs 107: 1–97

Polunin O (1980) Flowers of Greece and the Balkans. Oxford University Press, Oxford

Rendon M and Johnson AR (1997) Management of nesting sites for greater flamingos. Colonial Waterbirds (Special Publication 1) 19: 167–183

Revilla E, Palomares M and Delibes M (2000) Defining key habitats for low density populations of Eurasian badgers in Mediterranean environments. Biological Conservation 95: 269–277

Sadoul N, Walmsley J and Charpentier B (1998) Salinas and nature conservation. Conservation of Mediterranean wetlands, Medwet Publication no. 9. Tour du Valat, France

Sokal RR and Rohlf FJ (1981) Biometry, 2nd Edition. W.H. Freeman & Co., San Francisco

Stubbs D, Espin P and Mather R (1979) Report on expedition to Greece 1979. University of London Natural History Society, London

Stubbs D, Hailey A, Pulford E and Tyler W (1984) Population ecology of European tortoises: review of field techniques. Amphibia-Reptilia 5: 57–68

Stubbs D, Hailey A, Tyler W and Pulford E (1981) Expedition to Greece 1980. University of London Natural History Society, London

Stubbs D and Swingland IR (1985) The ecology of a Mediterranean tortoise (*Testudo hermanni*): a declining population. Canadian Journal of Zoology 63: 169–180

Stubbs D, Swingland IR, Hailey A and Pulford E (1985) The ecology of the Mediterranean tortoise *Testudo hermanni* in northern Greece (The effects of a catastrophe on population structure and density). Biological Conservation 31: 125–152

Swingland IR and Stubbs D (1985) The ecology of a Mediterranean tortoise (*Testudo hermanni*): reproduction. Journal of Zoology, London 205: 595–610

Troumbis AY and Dimitrakopoulos PG (1998) Geographic coincidence of diversity threatspots for three taxa and conservation planning in Greece. Biological Conservation 84: 1–6

Willemsen RE and Hailey A (1989) Status and conservation of tortoises in Greece. Herpetological Journal 1: 315–330

Willemsen RE and Hailey A (1999) Variation of adult body size of the tortoise *Testudo hermanni* in Greece: proximate and ultimate causes. Journal of Zoology (London) 248: 379–396

Willemsen RE and Hailey A (2001) Effects of spraying the herbicides 2,4-D and 2,4,5-T on a population of the tortoise *Testudo hermanni* in southern Greece. Environmental Pollution 113: 71–78

Zalidis CG and Mantzavelas AL (1994) Inventory of Greek Wetlands as Natural Resources. First Approximation. Greek Biotope/Wetland Centre (EKBY), Athens