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Distribution and population trends of the 'black shaheen' Peregrine Falcon *Falco peregrinus peregrinator* and the eastern Peregrine Falcon *F. p. calidus* in Sri Lanka

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A total of 232 historical sight records from 1876 onwards, including records from field surveys from 1995 to 2000, of two Peregrine Falcon *Falco peregrinus* subspecies in Sri Lanka were used to assess their geographical distribution, seasonal occurrence and population trends. Eastern Peregrine Falcon *F. p. calidus* and 'black shaheen' Peregrine Falcon *F. p. peregrinator* showed significantly different distributions. *F. p. calidus* is a winter visitor inhabiting mainly coastal areas from October to March, whereas the resident *F. p. peregrinator* is largely confined to the central part of the island. Sightings from 1944 onwards for the two subspecies show similar population trends to peregrine populations elsewhere, with declines presumably driven by the use organochloride and organophosphate pesticides. *F. p. peregrinator* populations declined until the mid-1970s when DDT was banned, correlating positively with the incidence of malaria infections, and appear to have now recovered to pre-DDT levels. *F. p. calidus* populations declined less steeply until the early 1980s, and have increased gradually since then, but apparently not yet to pre-DDT levels.

INTRODUCTION

Although few specific data are available the 'black shaheen' Peregrine Falcon *Falco peregrinus peregrinator* is an apparently rare, breeding resident in Sri Lanka, preferring rocky outcrops over forest areas (Wait 1931, Henry 1971, Cade 1982, Brown and Amadon 1989, Weick 1989, Lamsfuss 1998, Döttlinger 2002). The national red data list classified the subspecies as 'vulnerable' (Hoffmann 1998). This status is concordant with a population estimated to number 63–82 breeding pairs (Döttlinger and Hoffmann 1999, Döttlinger 2002). It is assumed that the population has always been numerically small. Tropical raptors tend to have smaller populations than temperate species (Newton 1979, Deshmukh 1986).

In Sri Lanka, sight records of *F. p. peregrinator* may be confused with eastern Peregrine Falcon *F. p. calidus*, so estimates of the status of *F. p. peregrinator* have been unclear. *F. p. calidus* is apparently a winter visitor to Sri Lanka in small numbers from October to March (Henry 1971, Phillips 1975, Lamsfuss 1998). Both subspecies prey upon birds (Cade 1982, Cade *et al.* 1988, Brown and Amadon 1989). The competitive exclusion principle (Hardin 1960) would predict that wintering *calidus* peregrines might be expected to avoid food competition with *F. p. peregrinator* by, for example, habitat segregation (Deshmukh 1986).

The Ceylon Bird Club Notes (CBCN) are a useful source of information on the status and distribution of birds in Sri Lanka. These notes have been published monthly since 1944 and are mainly based on sight records by amateur birdwatchers (Lamsfuss 1998). Although amateurs' records are unsystematic and non-random, they have nonetheless proved invaluable in detecting long-term trends in North American raptor populations (Bildstein 1998). This paper therefore aims to evaluate the information published in CBCN and other sources in order to determine the distribution and trends of *F. p. peregrinator* and *F. p. calidus*.

METHODS

A total of 232 records of both subspecies during 1876–1999 was collected, comprising 68 records of *F. p. calidus* from CBCN and 164 records of *F. p. peregrinator* (119 from CBCN, ten from other literature sources, four from museum specimens and 31 from field surveys during 1995–1999: Döttlinger *et al.* 1999, Döttlinger 2002). Field surveys were carried out annually from 1995 to 1999. Peregrine Falcons were searched for in all habitats outside protected areas from the roadside along 1,000–2,000 km of roads each year. From 17 March to 4 April 1995, road transects were driven from Colombo via Sigiriya towards Polonnaruwa district, covering the east cost from Eastern province to Uva province, returning to Colombo through Central province. During 7 April–7 May 1996, 12 May–15 June 1997, 6 March–11 April 1998, 6 March–11 April 1999 and 28 February–13 March 2000, surveys were made in Western province, Southern province and northern Central province (Eastern province was not accessible owing to the security situation). Multiple records in the vicinity of a nest site were treated as a single location in the analysis of distribution.

In seven CBCN records where the observers reported merely 'peregrine', this was assumed to refer to *F. p. calidus*, as according to T. W. Hoffmann (*in litt.* 2004), 'peregrine' is used exclusively for this subspecies and 'shaheen' is used for *F. p. peregrinator*. Some difficulty was encountered in determining the locations of older records. For these, clarification was sought through the 'Oriental birding' and 'Indian Natural History' discussion groups. In addition, we used the GEOnet Names Server, which provides access to the National Imagery and Mapping Agency database of foreign geographic feature names (http://164.214.2.59/gns/html/index.html). Coordinates were determined for all except two locations (Kumbaqumia hill and Mahalla). A metric

grid frame was used to cover Sri Lanka, setting zero on the x and y axes to 06°N 79°E. For fix-plotting, the converted values were entered in RANGES V Analysis Software (Kenward 1987, Kenward and Walls 1994, Walls and Kenward 1994). Where there were multiple records at the same location, these were grouped on a monthly basis, providing one record per month per location, both for the mapping and subsequent analysis. Three records could not be assigned to a month and were discared from the seasonal analysis.

Distribution

To investigate the distribution of the two subspecies, Sri Lanka was subdivided into three zones (Fig. 1): (a) The coastal zone (20,000 km²), extending from the coast to 50 m elevation, and consisting of marshes, sand bars, peninsulas, dunes, mangroves and lagoons. In the south-west, the coastal zone is sufficiently narrow that it can effectively be considered part of the central zone; (b) The central zone (44,900 km²), lying at 50–500 m, including a south-western region well-watered by summer and winter monsoons, an eastern and south-eastern region of plains, dotted with isolated hills, and a northern lowland plain at 50–100 m, all of which were heavily forested until recently; and (c) The mountain zone/central highlands (667 km²), lying above 500 m, bounded in the south by the southern mountain wall and in the north by the transverse valley of the Mahaweli river. There are two ranges detached from the central massif: the Knuckles range in the north and the Rakwana massif in the south-west.

Analysis

Analysis of occurrence and assignment of occupied area was performed with RANGES V software (Kenward 1987). The significance of distributional differences between the two subspecies in the different zones was tested using a χ^2 test (Lamprecht 1992). Sight records are non-random, unsystematically collected data, and so moving average models were used in order to reduce the error variance of sightings for examining long-term trends (Precht and Kraft 1992). In these models, single exponential smoothing gives predicted values by computing exponentially weighted averages. The single dynamic component in a moving average model is the exponentially weighted average of all data up to time *t*. Measures of accuracy of the fitted model are indicated by minimal values for Mean Absolute Percentage Error (MAPE). The number of sight records was numerically low and most likely related to the number of active birdwatchers. Therefore, a relative measure of abundance was derived using the ratio of predicted records (derived from the model above) to the number of active birdwatchers for a given time period, as estimated by T. W. Hoffmann (*in litt.* 2004). Similar types of ratios have proved to be useful tools for relative population comparisons (Peterson 1995, Bildstein 1998). To determine population trends, this ratio was regressed against date.

RESULTS

Distribution and seasonal occurrence

Of 232 sight records from 1876–2000, 29% were of *F. p. calidus* and 71% were of *F. p. peregrinator*. Records came from 100 different locations (Fig. 1, Table 2). The overall distribution of records of the two subspecies was significantly different (χ^2=36.06, DF=2, P<0.001). Most locations of records of *F. p. peregrinator* (59%) fell within the central zone, with 12% in the coastal zone and 29% in the mountain zone. In contrast, most locations of records of *F. p. calidus* (71%) fell in the coastal zone, with 11% in the mountain zone and 17% in the central zone. Range analysis showed that 95% of *F. p. calidus* records fell in an area of 14,830 km², predominantly in the coastal area (Fig. 1a), and 95% of *F. p. peregrinator* records fell in an area of 39,400 km² of the central zone (Fig.1b). The majority of *F. p. calidus* records were from southern coastal areas (e.g. Bundala, Yala and Uda Walawe National Parks, and Kalametiya and Kumana Bird Sanctuaries), which are popular with birdwatchers during migration periods. *F. p. calidus* records were mainly from October–March, whereas *F. p. peregrinator* records were from throughout the year (Fig. 2).

Long-term trends

Fig. 3 shows the pattern of records over time for both subspecies during 1944–1998. The smoothed trend for *F. p. peregrinator* shows an increase from 1975 onwards, whereas the trend for *F. p. calidus* is level. However, the accuracy of the moving average plots is low for both *F. p. peregrinator* (Fig. 3a; MAPE=47.4%) and *F. p. calidus* (Fig. 3b; MAPE=44.5%) and so must be interpreted with caution. Furthermore, there was an increase in the number of active observers through the period, from six in 1944 to 25 in1997 (T. W. Hoffmann *in litt.* 2004). The number of records showed a significant positive correlation with the number of observers (Pearson correlation: r = 0.408, P = 0.002), so the ratio of the predicted number of sightings to number of observers was calculated for each year to produce a measure of relative abundance. Regression of relative abundance against year for *F. p. peregrinator* showed that it declined from 1944 until the 1970s and then increased (Fig. 4a). The pattern for *F. p. calidus* was similar, falling until the 1980s with very gradual increase into the 1990s (Fig. 4b).

DISCUSSION

The CBCN records are a valuable and unique source of data on birds in Sri Lanka, but a number of limitations and biases must be acknowledged: (1) the majority of records are from areas and locations favoured by birdwatchers (e.g. Sigiriya); (2) from 1983 onwards, visits to the north and the east of Sri Lanka became difficult or impossible owing to armed conflict (Domrös 1993, Lamsfuss 1998), leading to under-representation of data for these areas during this period; (3) seasonal variation in the conspicuousness of *F. p. peregrinator* probably influences the number of observations: there were many records in February–March during the early courtship and pre-

laying period, fewer during the incubation period in March–April, more during April–May when pre- and post-fledged young are dependent, and fewer after May when young gain independence.

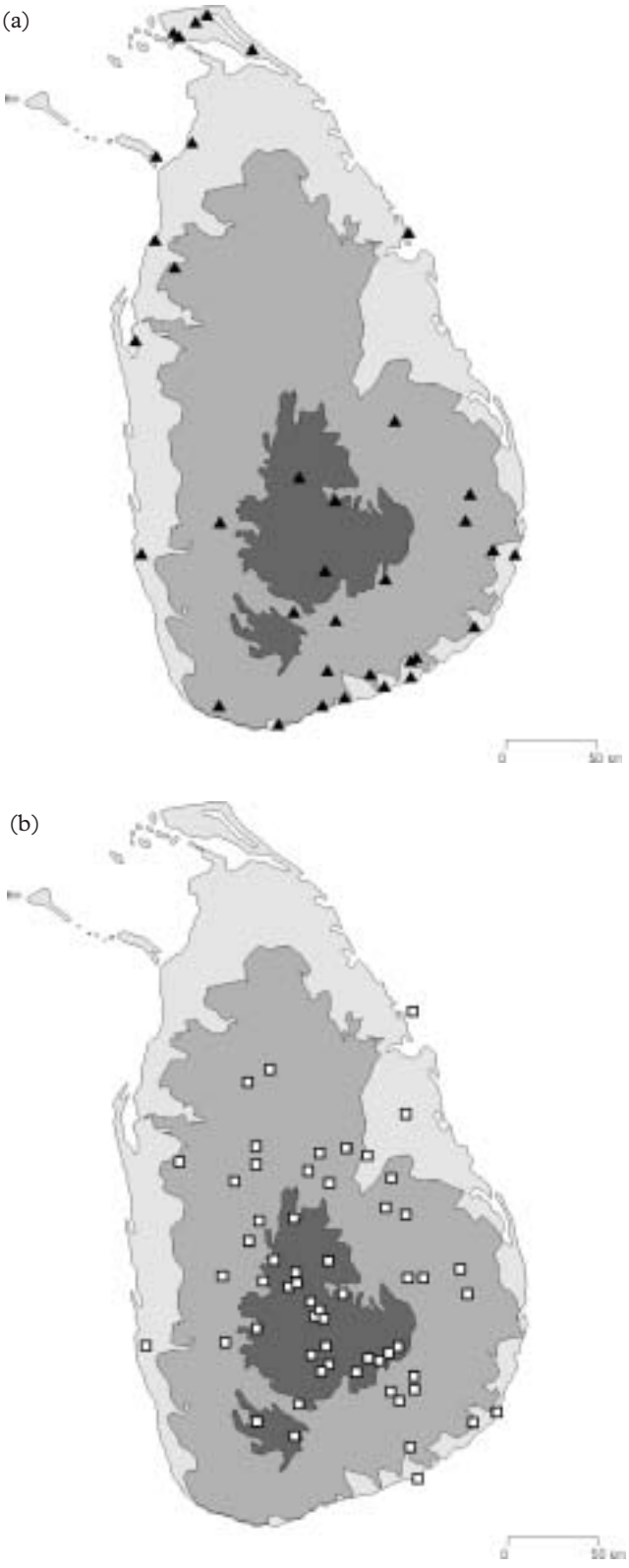

Figure 1 (a) The locations (n=35) of 68 records of *F. p. calidus*; and (b) the locations (n=65) of 164 records of *F. p. peregrinator*. Pale, moderate and dark shading indicate the coastal, central and mountain zones respectively.

The data corroborate previous authors (Wait 1931, Henry 1971, Weick 1980, Cade 1982, Brown and Amadon 1989, Lamsfuss 1995, 1998) that *F. p. peregrinator* is resident in Sri Lanka and occurs inland in forested areas rather than coastal territories. By contrast, *F. p. calidus* is a winter visitor from October to March being observed mainly at coastal sites. This

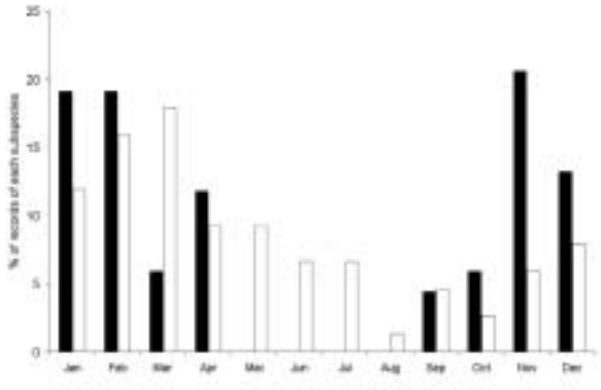

Figure 2. The pattern of seasonal occurrence of records of *F. p. calidus* (N=62 records; solid bars) and *F. p. peregrinator* (N= 119 records; open bars).

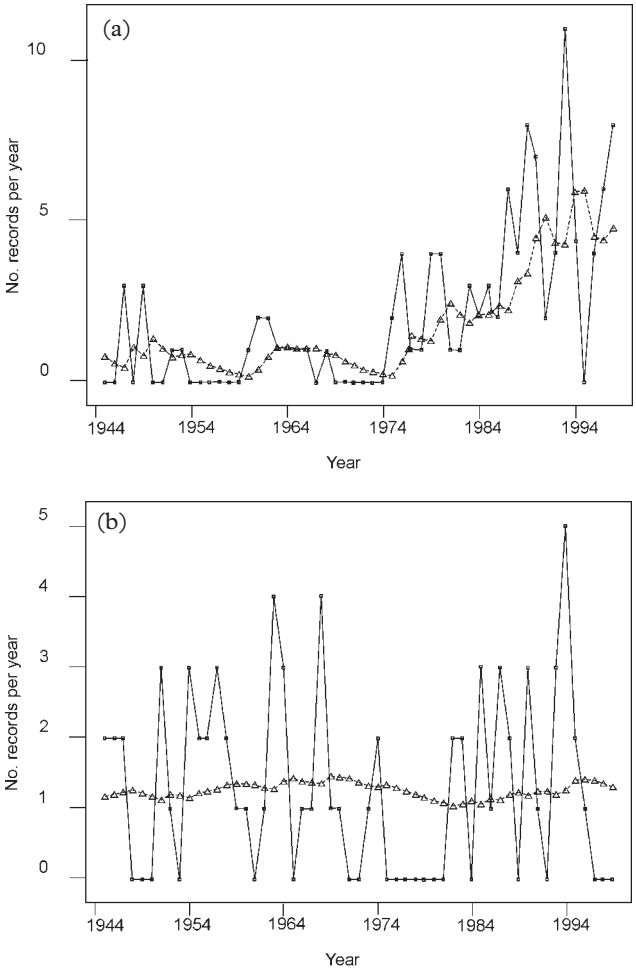

Figure 3. Actual records (squares, solid line) and predicted values (triangles, dashed line) for (a) *F. p. peregrinator* and (b) *F. p. calidus* from 1944 to 1998; predicted values are generated by a moving average function with single exponential smoothing.

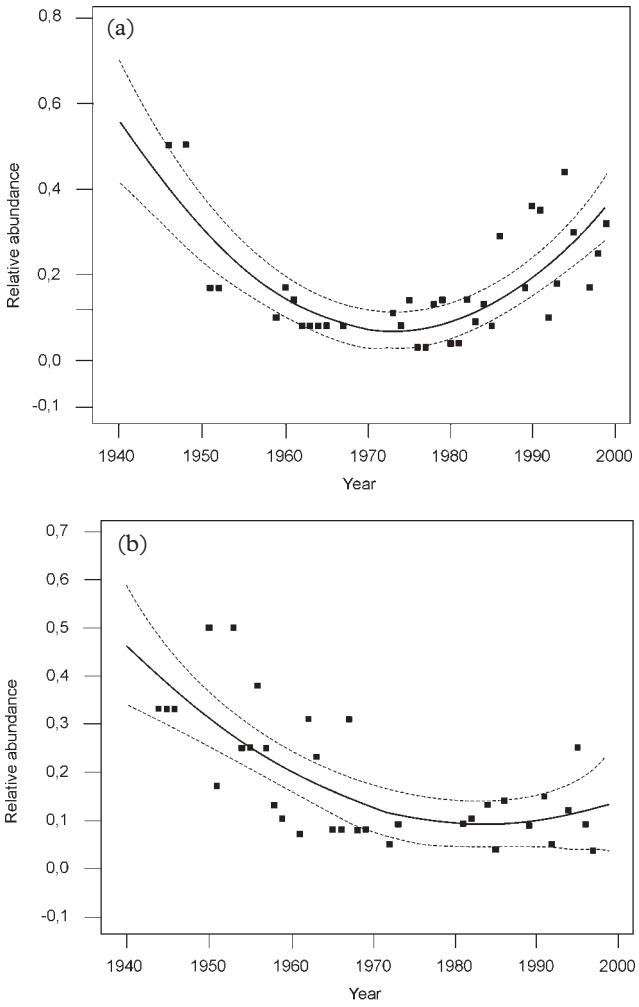

Figure 4. Regression of the ratio of predicted number of records to active birdwatchers against year, for (a) *F. p. peregrinator* and (b) *F. p. calidus* from 1944 to 1998. Dotted lines show the 95% confidence limits.

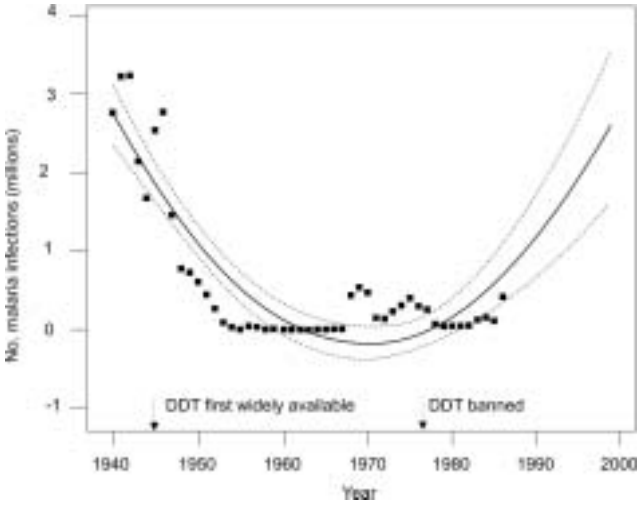

Figure 5. Number of malaria infections in Sri Lanka between 1940 and 1986 (data from Sponsler 2000). Dotted lines show the 95% confidence limits.

apparent segregation may be a way in which the two subspecies avoid competition for food (Deshmukh 1986). Studies of other peregrine populations have generally found that migratory northern hemisphere races winter in coastal regions and avoid intrusion into the territories of resident populations (Hunt and Ward 1988, Dobler and Spencer 1989, Thiollay 1989, White *et al.* 1989).

Accounting for observer effort, the data suggest that the *F. p. peregrinator* population declined from 1944 until the mid-1970s and then increased until 1998 at least. By comparison, the population of *F. p. calidus* seems to have declined slowly until the early 1980s and then gradually recovered subsequently. The minimum population for *F. p. calidus* was reached about ten years after that of *F. p. peregrinator*. The population of *F. p. peregrinator* appears to have reached 1950s levels again, but the population of *F. p. calidus* seems to still be lower.

It is widely accepted that worldwide declines of Peregrine Falcon populations in recent decades were caused by the use of organochloride and organophosphate pesticides (Hickey and Anderson 1968, Bitman *et al.* 1969, Hickey and Anderson 1969, White and Cade 1977, Ratcliffe 1980, Cade *et al.* 1988, Peakall and Kiff 1988, Mellanby 1992). The intake of these pesticides occurs via contaminated prey items, often accumulated in the food chain (Fyfe *et al.* 1988, Nisbet 1988). From 1946, the organochloride insecticide DDT became available in Sri Lanka when the governmental anti-malaria campaign developed an eradication programme of the insect vectors using DDT. During the 1950s and 1960s, DDT and BHC (another organochloride) were also widely used in the cultivation of rice and vegetables (Gerberg and Wilcox III 1977). In 1977, DDT spraying for malaria control was banned in Sri Lanka, (Department of Census and Statistics 1977, Kondrashin and Rashid 1987) and the importation and use of DDT and similar persistent insecticides was prohibited. The recovery of *F. p. peregrinator* populations coincided with this ban. A similar phenomenom was found with *F. p. peregrinus* in Britain, where the population recovered from a low point in the 1970s following step-by-step restrictions imposed on organochlorinated insecticides (Ratcliffe 1980). Further evidence of a link between population trends and the use of organochlorine pesticides for malaria control is provided by the significant positive correlation between the relative abundance of *F. p. peregrinator* and the number of reported cases of malaria in Sri Lanka during 1942–1988 (Fig. 5; r=0.765, P<0.005). There was no such significant correlation for *F. p. calidus* (r=0.341, P=0.081). This subspecies may have been less exposed to pesticides on its breeding grounds in Siberia than *F. p. peregrinator* is in Sri Lanka. Data on the effects of pesticides on migrant Peregrine Falcon populations are extremely rare (Ratcliffe 1980, Cade *et al.* 1988). However, birds from Alaska which winter in Central and South America also showed delayed effects of DDT (White and Cade 1977). Similarly, data from Finland show that pesticide-induced declines varied with geography. Peregrine Falcons in the south of Finland nearly disappeared by the early 1970s, while populations in the north of Finland declined by only 50% (Lindberg *et al.* 1988, Peakall and Kiff 1988). Falcons may still be

exposed to DDT in Sri Lanka: between April 1998 and January 1999, India exported 186,000 kg of DDT and 213,000 kg of aldrin to various countries including Sri Lanka (Toxic Link 1999), but the quantities to each country cannot be determined.

Recent habitat changes in Sri Lanka may have also influenced Peregrine Falcon populations. From the late 1970s, the major Mahaweli Development Project was implemented, resulting in the clear-felling of over 4,000 km^2 of forest for rice and sugar-cane cultivation (OED Precis 1995, Lamsfuss 1996a,b). Forest cover in Sri Lanka has subsequently declined to <20% of the area. Habitat loss may have limited the recovery of *F. p. peregrinator* populations. Alternatively it is conceivable that fragmentation may have had a positive effect by increasing prey availability and accessibility. This has apparently been the case in the Stellenbosch area of South Africa where populations of *F. p. minor* appear to have benefited from the establishment of small homestead agriculture in an otherwise semi-arid habitat, with associated increases in dove populations (Peplar *et al.* 1991, Peplar and Martin 1994). Further research on hunting habitat selection in *F. p. peregrinator* is needed to test these possibilities.

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