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Supplementary material

Cyprus wheatears *Oenanthe cypriaca* likely reach sub-Saharan African wintering grounds in a single migratory flight

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Supplementary material Appendix 1

Tag effects
Figures A1a-f
Figures A2a-f

Tag Effects:

Tag effects were assessed to determine if returning birds were a representative sample. We compared the ratios of returning and non-returning birds for both tagged and colour-ringed only birds using a chi-square test. The binomial probability of return of a tagged bird (a proxy for survival because birds return to the same breeding grounds – see Xenophontos & Cresswell 2015b) was also modelled as a binomial variable with predictors, presence/absence of a tag, age (1st year and 2nd year or older), sex, mass at capture and wing length. The effect of the use of two different light stalk lengths and other potential confounding tagging variables was assessed by including light stalk length (5 mm or 10 mm, because longer light stalks may increase drag), order of fitting, and proportion added mass of the tag (mass of the tag/mass of the bird at capture because tags on lighter birds would represent a heavier relative load) (see Blackburn et al. 2015).

Overall tag presence or design did not affect Cyprus Wheatear return rates. The return rate of tagged birds (58.3%) was very similar to that of colour-ringed only birds (55.6%): $\chi^2_1 = 0.001$, P = 0.99. Seven out 12 males and seven out of 12 females returned to the tagging site. The probability of return of a Cyprus Wheatear did not depend on tag presence (0.34, 0.51 SE, z = 0.7, P = 0.51), age (0.55, 0.43 SE, z = 1.3, P = 0.21), sex (0.33, 0.52 SE, z = 0.6, P = 0.54) or wing length (0.13, 0.14 SE, z = 1.0, P = 0.33) but the probability of return was significantly greater for birds of lower mass when captured (-0.35, 0.16 SE, z = -2.2, P = 0.026). Any effects of mass on survival were independent of sex (sex*mass interaction, 0.50, 0.39 SE, z = 1.2, P = 0.21) and tag presence (mass*tag presence interaction, 0.16, 0.31 SE, z = 0.5, P = 0.61). Considering only tagged birds, there were no significant effects of probability of return of a tagged Cyprus Wheatear dependent on length of light stalk (-0.31, 0.97 SE, z = -0.3, P = 0.75), order of fitting (0.08, 0.07 SE, z = 1.1, P = 0.26) or proportion added mass by the tag (2.8, 1.6 SE, z = 1.7, P = 0.09), controlling for age, sex and wing length (all also non-significant).

Figure A1a: Variation in latitude and longitude derived from geolocator sunrise and sunset times for Bird 57. Top left panel shows 7-day moving average values (green for longitude, red for latitude using the summer sun elevation angle and blue for latitude using the winter sun elevation angle; the shaded bar indicates when all data were broadly unreliable because of the equinox). Bottom left panel maps mean (+/- 2 SE) monthly averaged locations (Nov black, Dec dark grey, Jan light grey, Feb white). The two right hand panels show monthly variation in the raw data with fitted lines (+/- 2 -SE) for the interaction term of Julian date * month to illustrate systematic deviations with time that are likely to represent errors due to environmental variation rather than actual shifts in position. Post-hoc Tukey tests showed all winter months significantly different from June, and during the winter there was no significant variation by latitude, but all winter months differed significantly from Feb in longitude, suggesting a late-winter movement in February.

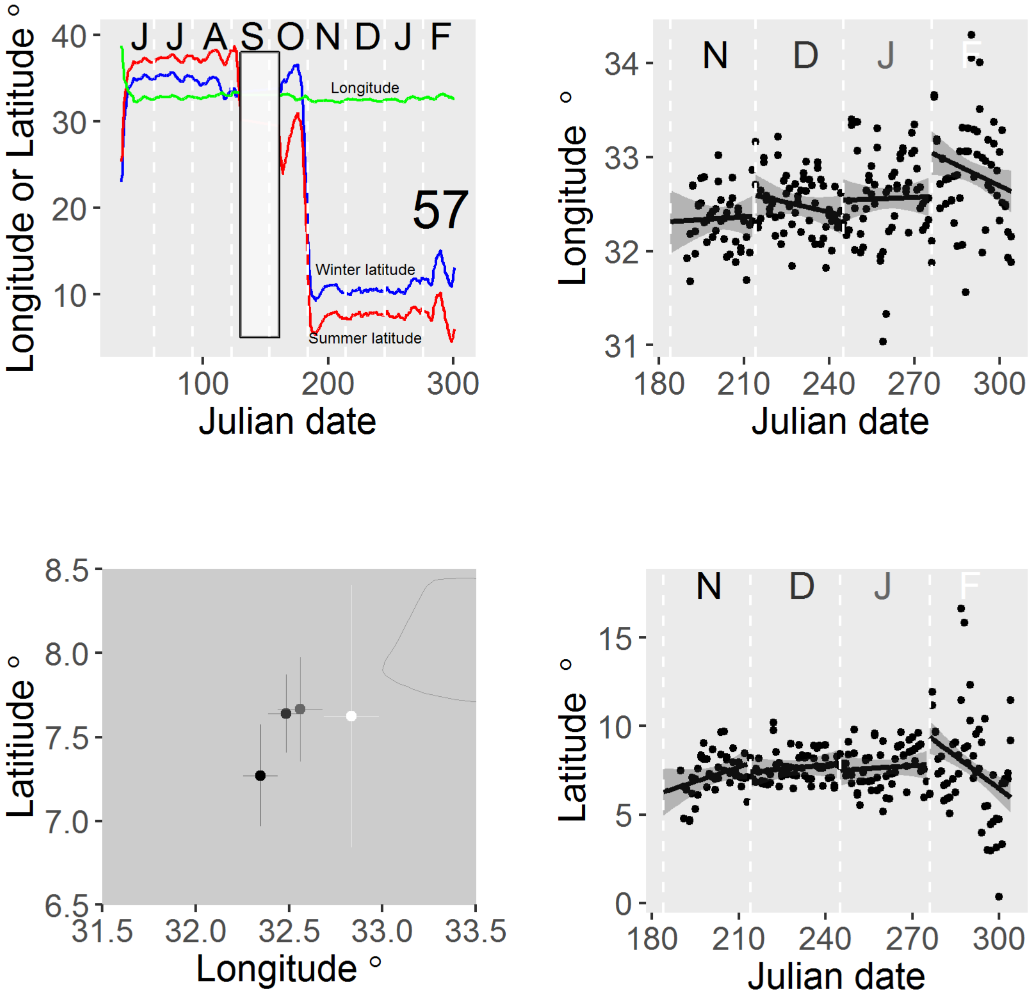

Figure A1b: Variation in latitude and longitude derived from geolocator sunrise and sunset times for Bird 89. Top left panel shows 7-day moving average values (green for longitude, red for latitude using the summer sun elevation angle and blue for latitude using the winter sun elevation angle; the shaded bar indicates when all data were broadly unreliable because of the equinox). Bottom left panel maps mean (+/- 2 SE) monthly averaged locations (Oct purple, Nov black, Dec dark grey, Jan light grey, Feb white). The two right hand panels show monthly variation in the raw data with fitted lines (+/- 2 SE) for the interaction term of Julian date * month to illustrate systematic deviations with time that are likely to represent errors due to environmental variation rather than actual shifts in position. Post-hoc Tukey tests showed all winter months significantly different from June, and during the winter Nov & Dec but not Jan, differed from Feb in latitude, and Jan differed significantly from Feb in longitude, suggesting a late-winter movement in February.

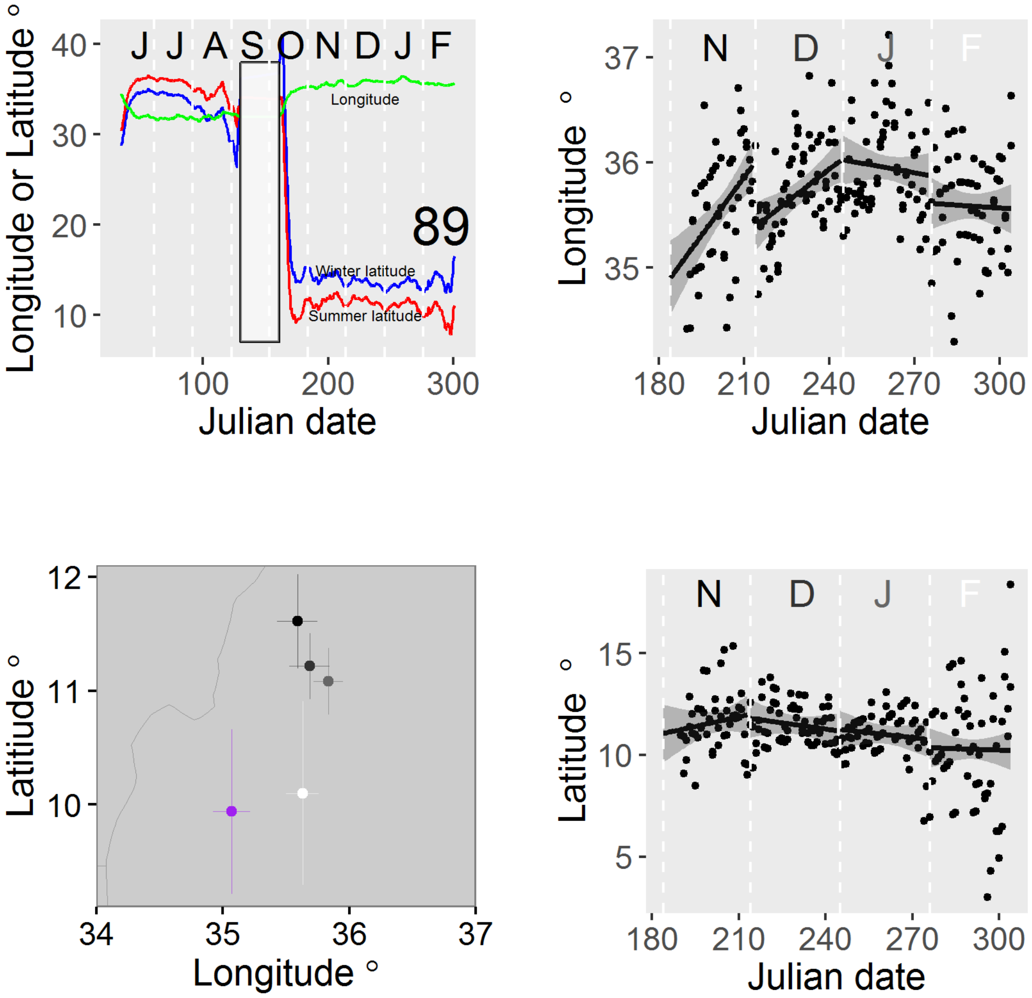

Figure A1c: Variation in latitude and longitude derived from geolocator sunrise and sunset times for Bird 100. Top left panel shows 7-day moving average values (green for longitude, red for latitude using the summer sun elevation angle and blue for latitude using the winter sun elevation angle; the shaded bar indicates when all data were broadly unreliable because of the equinox). Bottom left panel maps mean (+/- 2 SE) monthly averaged locations (Oct purple, Nov black, Dec dark grey, Jan light grey, Feb white). The two right hand panels show monthly variation in the raw data with fitted lines (+/- 2 SE) for the interaction term of Julian date * month to illustrate systematic deviations with time that are likely to represent errors due to environmental variation rather than actual shifts in position. Post-hoc Tukey tests showed all winter months significantly different from June, and during the winter Dec & Jan but not Nov differed from Feb in latitude, but there was no significant within-winter variation in longitude, suggesting that there was only weak evidence for any within-winter movement.

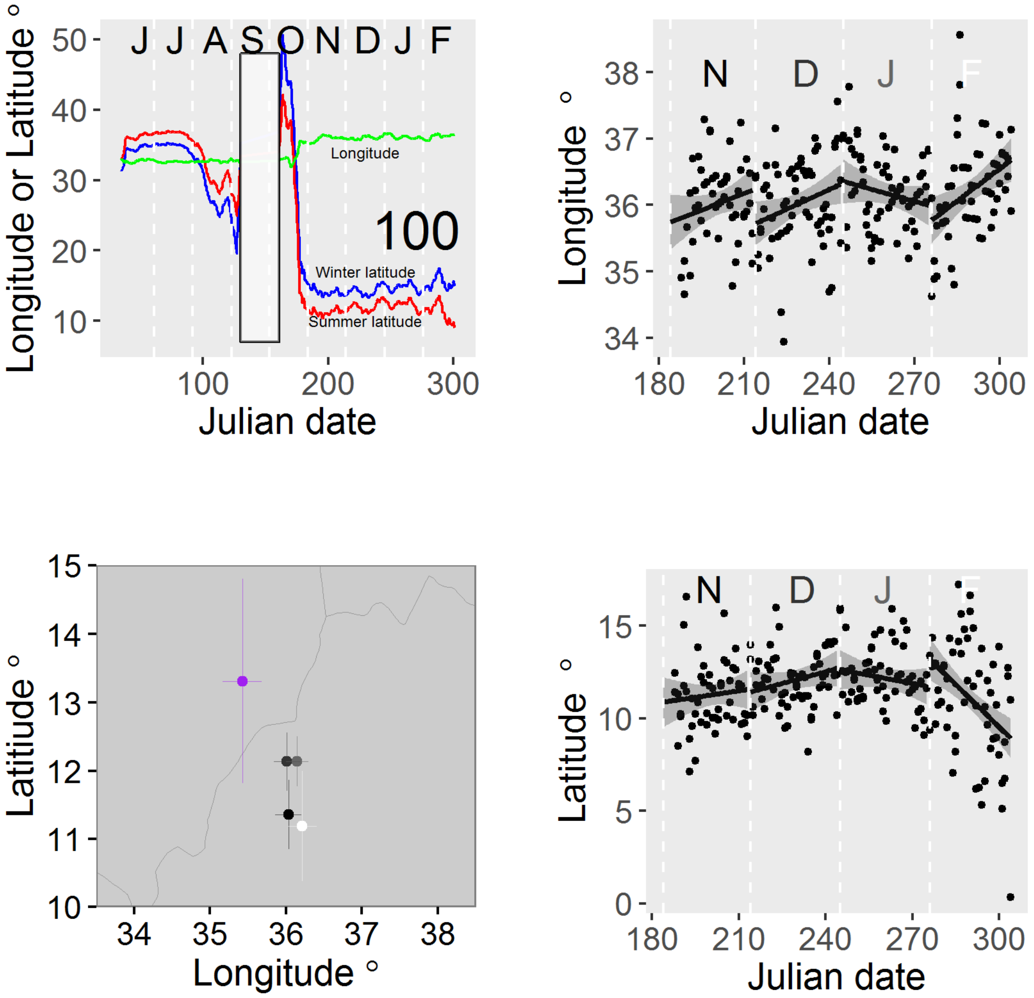

Figure A1d: Variation in latitude and longitude derived from geolocator sunrise and sunset times for Bird 107. Top left panel shows 7-day moving average values (green for longitude, red for latitude using the summer sun elevation angle and blue for latitude using the winter sun elevation angle; the shaded bar indicates when all data were broadly unreliable because of the equinox). Bottom left panel maps mean (+/- 2 SE) monthly averaged locations (Nov black, Dec dark grey, Jan light grey, Feb white). The two right hand panels show monthly variation in the raw data with fitted lines (+/- 2 SE) for the interaction term of Julian date * month to illustrate systematic deviations with time that are likely to represent errors due to environmental variation rather than actual shifts in position. Post-hoc Tukey tests showed all winter months significantly different from June, and during the winter all months differed from Feb in latitude, and all months differed significantly from Feb and Nov in longitude, suggesting a possible movement in Dec and a more likely late-winter movement in Feb.

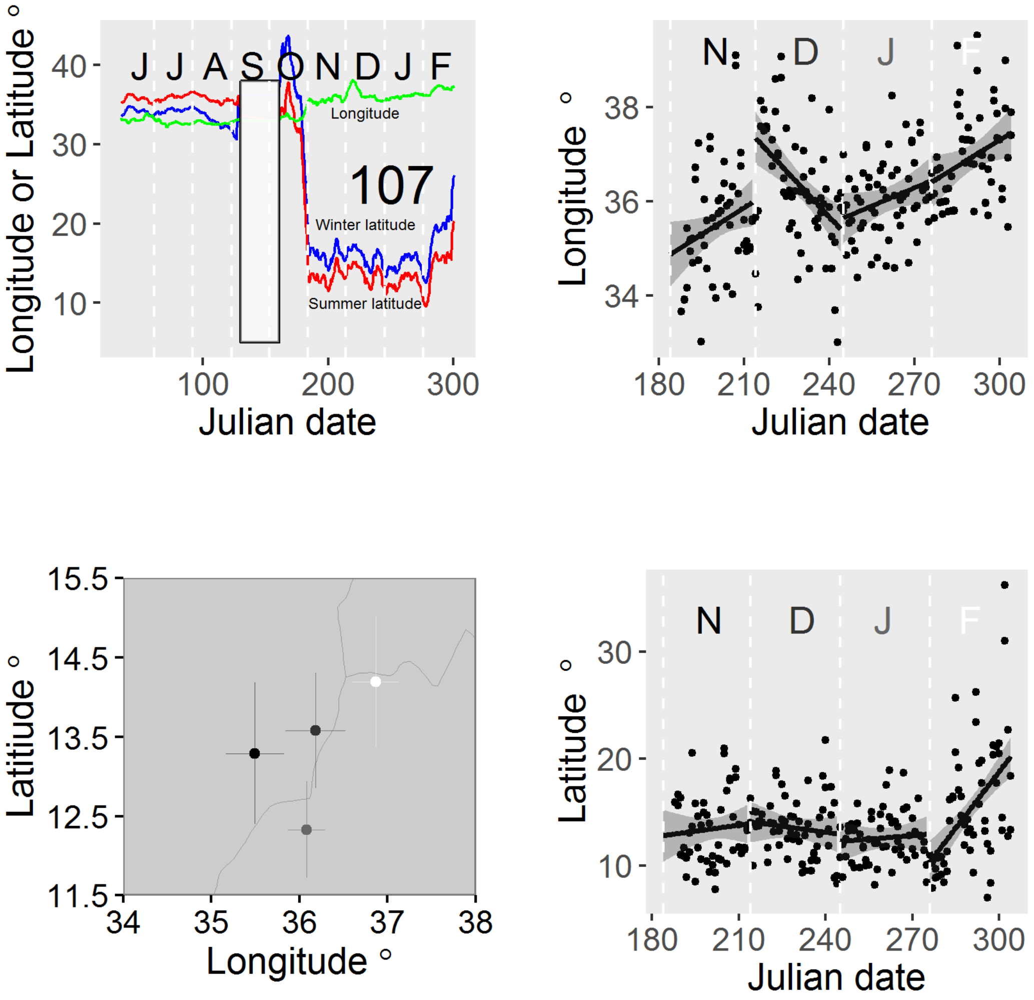

Figure A1e: Variation in latitude and longitude derived from geolocator sunrise and sunset times for Bird 123. Top left panel shows 7-day moving average values (green for longitude, red for latitude using the summer sun elevation angle and blue for latitude using the winter sun elevation angle; the shaded bar indicates when all data were broadly unreliable because of the equinox). Bottom left panel maps mean (+/- 2 SE) monthly averaged locations (Oct purple, Nov black – the geolocator failed in Nov). The two right hand panels show monthly variation in the raw data with fitted lines (+/- 2 SE) for the interaction term of Julian date * month to illustrate systematic deviations with time that are likely to represent errors due to environmental variation rather than actual shifts in position. Post-hoc Tukey tests showed all winter months significantly different from June, but no significant variation in latitude or longitude between the two months for which there were data available.

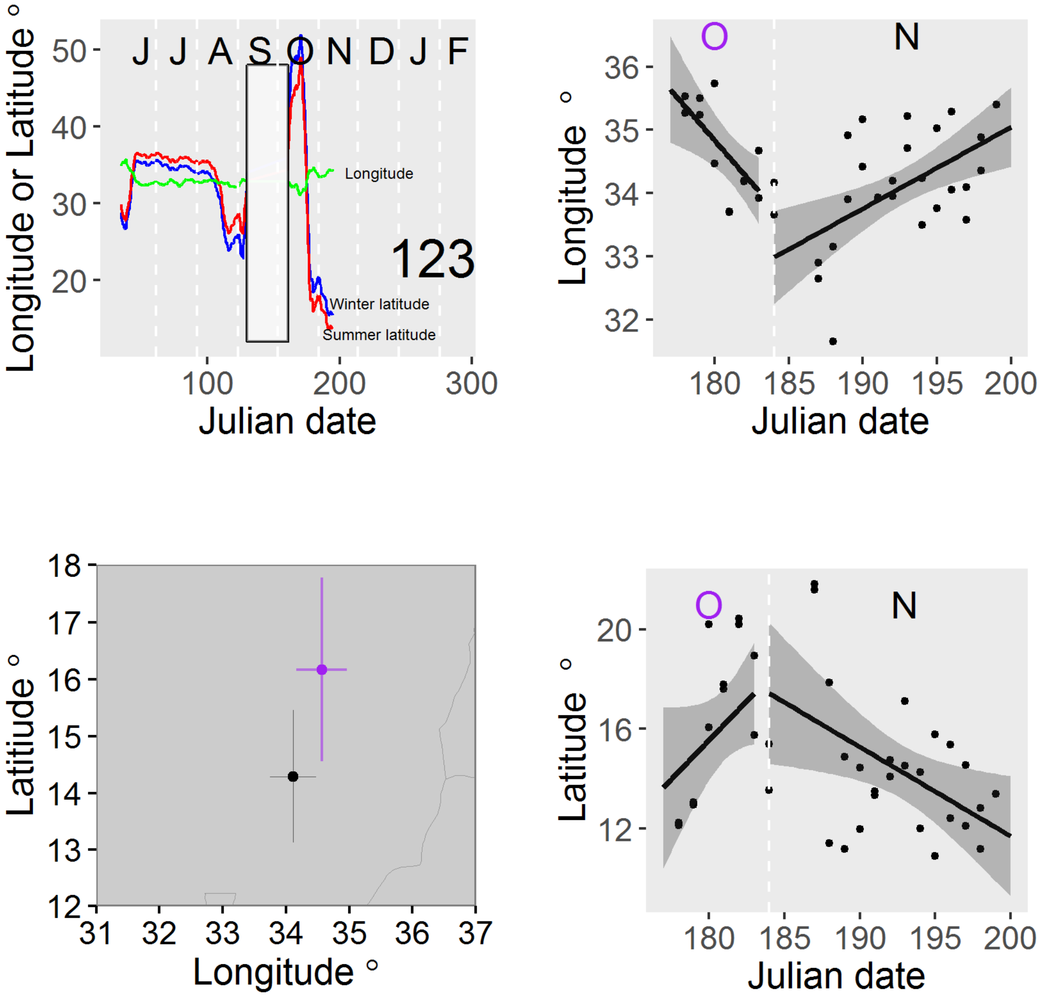

Figure A1f: Variation in latitude and longitude derived from geolocator sunrise and sunset times for Bird 126. Top left panel shows 7-day moving average values (green for longitude, red for latitude using the summer sun elevation angle and blue for latitude using the winter sun elevation angle; the shaded bar indicates when all data were broadly unreliable because of the equinox). Bottom left panel maps mean (+/- 2 SE) monthly averaged locations (Oct purple, Nov black, Dec dark grey, Jan light grey, Feb white). The two right hand panels show monthly variation in the raw data with fitted lines (+/- 2 SE) for the interaction term of Julian date * month to illustrate systematic deviations with time that are likely to represent errors due to environmental variation rather than actual shifts in position. Post-hoc Tukey tests showed all winter months significantly different from June, and during the winter Dec & Jan differed from Nov & Feb in latitude, but there was no significant within-winter variation in longitude, suggesting that there was only weak evidence for any within-winter movement.

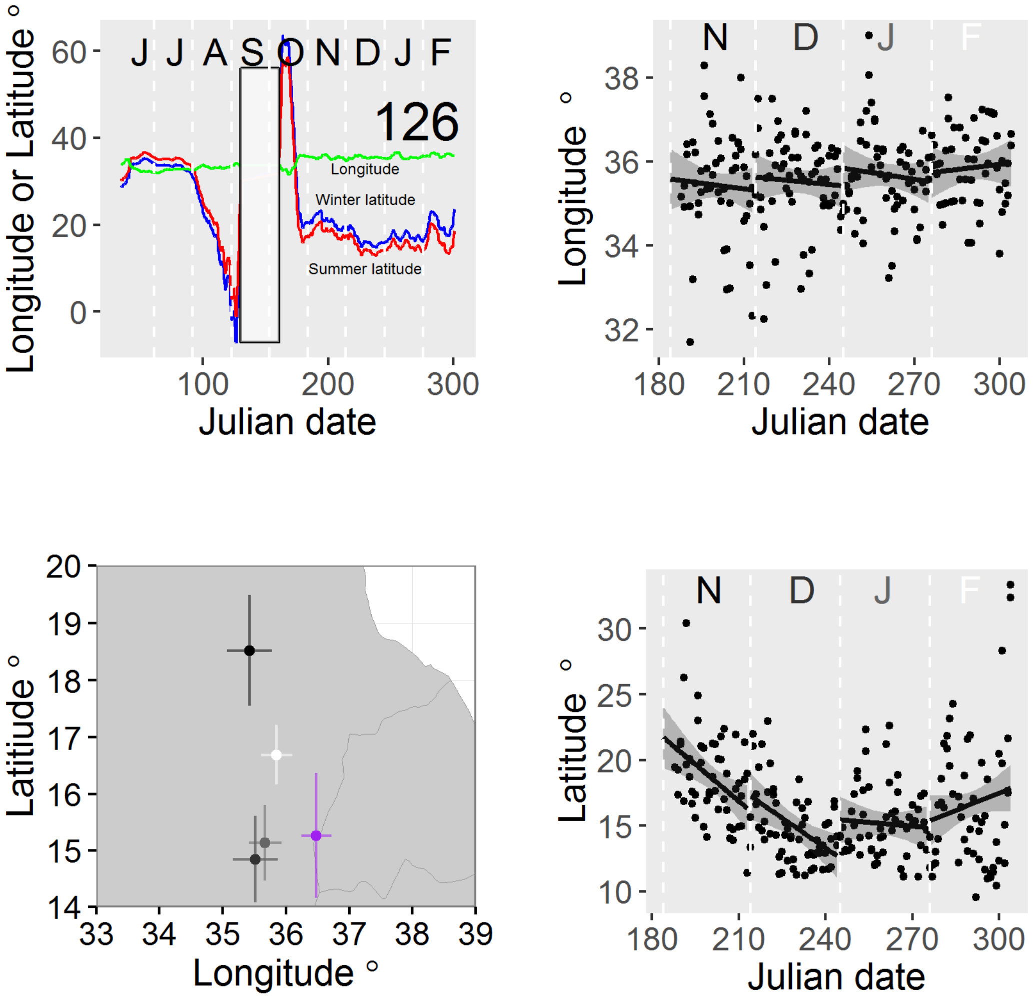

Figure A2a: Results for Bird 57 of the changeLight function analysis in the R package geolight to show the mismatch between its automated identification of points of likely change in position (top and bottom graph) and those obtained from visual examination of the raw sunrise and sunset times (middle graph with points of greatest change indicative of migration identified from manual inspection marked with bold arrows). Note that Cyprus Wheatears were known to be on the study site (i.e. stationary) from May until late September in all cases. Outputs are from default settings with a specified 5 day stationary period and 0.9 quantile, and with identified outliers; varying these from 3 to 14 days, or 0.75 to 0.95 quantiles, or without outliers, made little difference as to whether any of movement periods identified actually coincided with those identified from manual inspection, and whether stationary periods coincided with the periods that Cyprus Wheatears were known to be stationary.

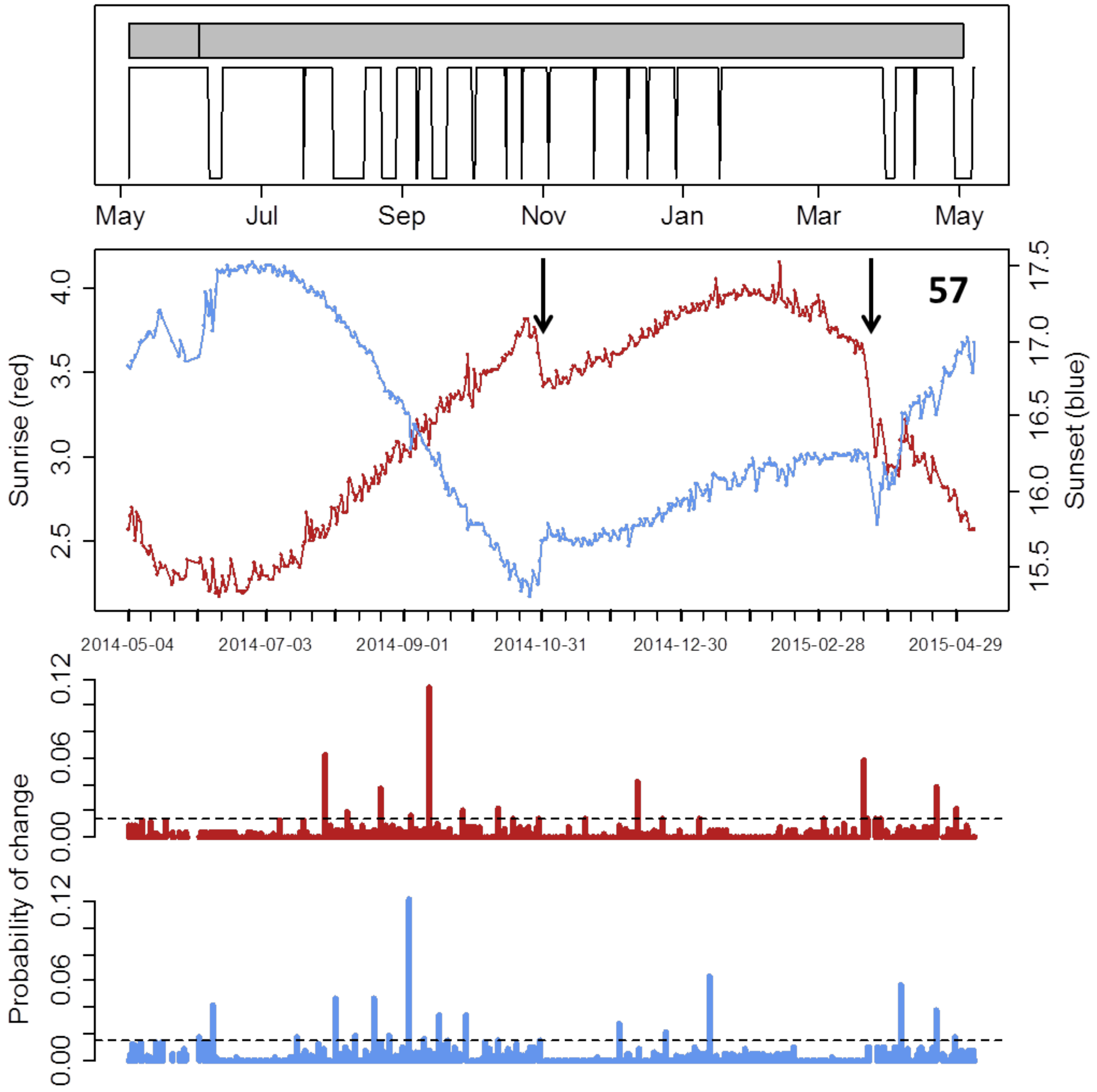

Figure A2e: Results for Bird 123 of the changeLight function analysis in the R package geolight to show the mismatch between its automated identification of points of likely change in position (top and bottom graph) and those obtained from visual examination of the raw sunrise and sunset times (middle graph with points of greatest change indicative of migration identified from manual inspection marked with bold arrows). Note that Cyprus Wheatears were known to be on the study site (i.e. stationary) from May until late September in all cases. Outputs are from default settings with a specified 5 day stationary period and 0.9 quantile, and with identified outliers; varying these from 3 to 14 days, or 0.75 to 0.95 quantiles, or without outliers, made little difference as to whether any of movement periods identified actually coincided with those identified from manual inspection, and whether stationary periods coincided with the periods that Cyprus Wheatears were known to be stationary.

Figure A2f: Results for Bird 126 of the changeLight function analysis in the R package geolight to show the mismatch between its automated identification of points of likely change in position (top and bottom graph) and those obtained from visual examination of the raw sunrise and sunset times (middle graph with points of greatest change indicative of migration identified from manual inspection marked with bold arrows). Note that Cyprus Wheatears were known to be on the study site (i.e. stationary) from May until late September in all cases. Outputs are from default settings with a specified 5 day stationary period and 0.9 quantile, and with identified outliers; varying these from 3 to 14 days, or 0.75 to 0.95 quantiles, or without outliers, made little difference as to whether any of movement periods identified actually coincided with those identified from manual inspection, and whether stationary periods coincided with the periods that Cyprus Wheatears were known to be stationary.