

Orientation experiments in altered magnetic fields simulating geographical displacements towards N and S.

Introduction

The question is whether passerine migrants use the magnetic field of the Earth for gradient navigation.

Material and methods

In order to elucidate this question we used the same method as on Endelave in 2004 and 2005 i.e. we applied eight magnetic coil fields. In four fields a vertical vector (quadratic 2 times the intensity of the horizontal component of the Earth's field on Christiansø) directed upward was added to the Earth's magnetic field, and in the four other fields a vertical vector of the same strength directed downward was added. The resultant field intensity in the first set-up (designated **S-exp.s**) was weaker, and the inclination shallower compared with the local Earth's field, whereas the resultant field intensity in case of the latter (designated **N-exp.s**) was stronger and the inclination more steep than in case of the local Earth's field (for more details see www.jorgenrabol.dk and the doc. magnav).

From 12 Aug. and onwards we used a funnel-holder 10 cm higher than the one previously used. This means that the upper edge of the funnel is 45 cm above the level of the board, and as the 45 cm times 80 cm tree-frame containing the coils is placed on tree sticks about 2 cm above the board level the upper edge of the funnel is about two cm below the quadratic tree-frame when this is situated in the vertical field position, and in about the middle of the rectangular tree-frame when this is in the horizontal field position. Probably, this means a little more heterogeneous magnetic field within the funnel space than in the 2004 and 2005 experiments

On Endelave we used birds caged for a several days or even weeks. On Christiansø we used birds trapped on the very same or the preceding day of the experiment. The birds were transferred to cages within the altered fields one to two hours before sunset and transferred to the funnels about 2 hours after sunset. During the cage-phase the top of the cages was covered with a tree-plate because we were not interested in too much influence of the starry sky possibly masking the influence of the magnetic field. When tested in the funnels the top was uncovered leaving the sight to the starry sky thus facilitating the stars for use as a maintaining compass. On Endelave 2004/05 the birds were allowed to see the stars also when caged during sunset/early night.

Unfortunately, when after-controlling the resultant magnetic fields on 4 September field no.4 was strong and steep, and not as intended weak and shallow. Very presumably, we already made the mistake ahead of the experiments starting 9 Aug., i.e. five fields were strong and steep (N-exp.s), and only three fields were weak and shallow (S-exp.s). In order to be sure field no.4 was omitted from some samples/calculations when the N- and S-exp.s were considered separately. However, the patterns of field no.4 most resembles the N-exp.s.

Results

210 experiments on twelve nights were carried out during 9 August through 5 September 2007.

In order to investigate the possible effect of the magnetic treatment **we need a control group displaying clear uni-modal orientation**, i.e. the sample concentration should be high and significant (and preferably in about the standard direction). However, lumping all orientations of **controls** together in a single sample 9 Aug. through 5 Sep. produces dis-orientation (Fig.1): $171^\circ - 0.042$ ($n = 73$), or including two bimodal orientations and after doubling the angles $143^\circ/323^\circ - 0.171$ ($n = 75$). The same holds true for all the **N-exp.s** (Fig.2): $127^\circ - 0.085$ ($n = 41$), or – after doubling the angles - $11^\circ/191^\circ - 0.135$ ($n = 41$), and all the **field no.4 birds** (presumably N-exp.s) (Fig.3): $249^\circ - 0.244$ ($n = 8$), or – after doubling the angles - $99^\circ/279^\circ - 0.242$ ($n = 8$). However, the **S-exp.s** lumped together (Fig.4) displayed a significant orientation: $174^\circ - 0.382^{**}$ ($n = 32$). Doubling the angles leads to an insignificant pattern: $175^\circ/355^\circ - 0.206$ ($n = 32$).

However, considering single nights or few nights together the control orientation is sometimes significant or close to, and there is seasonal shift from NNW or WNW/ESE in the very start (until 14 August) and then a shift towards a more normal/standard southerly orientation during 17 through 22 August. Tab.1 informs about the sample orientation of the **controls** on the single nights, the species involved and the cloudiness.

During the three nights **9, 12 and 13 August** the **controls** were oriented bimodally towards WNW (main peak) and ESE (Fig.5, middle). We calculated a mean vector of $299^\circ/119^\circ - 0.590^{***}$ ($n = 19$). If not doubling the angles the mean vector was $310^\circ - 0.184$ ($n = 18$). The orientation of the **N-exp.s** on the same nights (Fig.5, upper) was $116^\circ - 0.192$ ($n = 12$), or if doubling the angles $73^\circ/253^\circ - 0.282$ ($n = 12$). The three single night orientations in field no.4 (included in Fig.5) were 55° , 115° and 270° . The orientation of the **S-exp.s** on the same nights (Fig.5, lower) was $223^\circ - 0.462$ ($n = 7$).

During the two nights **10 and 14 August** the **controls** were (Fig.6, middle) reversely oriented: $342^\circ - 0.728^{***}$ ($n = 13$). The orientation of the **N-exp.s** on the same nights (Fig.6, upper) was $202^\circ - 0.204$ ($n = 7$). Including the single bimodal response from a field no.4 bird and doubling the angles led to $228^\circ/48^\circ - 0.164$ ($n = 8$). The orientation of the **S-exp.s** on the same two night (Fig.6, lower) was $192^\circ - 0.629$ ($n = 5$), or – after doubling the angles - $170^\circ/350^\circ - 0.523$ ($n = 5$).

In the next period of **17 through 22 August** the orientation of the **controls** (Fig.7, middle) was significantly oriented in about the standard direction (SSW): $168^\circ - 0.396^{**}$ ($n = 33$). The orientation of the **N-exp.s** (including the **field no.4 birds**: $251^\circ - 0.536$, $n = 5$) in the same period (Fig.7, upper) was insignificantly oriented in about the same direction: $180^\circ - 0.156$ ($n = 23$). The orientation looks bimodally N/S, and doubling the angles in fact improves the description: $172^\circ/352^\circ - 0.206$ ($n = 23$). The contemporary orientation of the **S-exp.s** (Fig.7, lower) was significantly oriented in about the right angle to the standard direction: $123^\circ - 0.643^{**}$ ($n = 12$).

In the last period of **4 and 5 September** the orientation of the **controls** (Fig.8, middle) was $112^\circ - 0.394$ ($n = 9$). It looks somewhat bimodal. However, doubling the angles leads to no improvement in the concentration: $169^\circ/349^\circ - 0.287$ ($n = 9$). The orientation of the

N-exp.s (Fig.8, upper) was insignificantly northerly: $350^\circ - 0.447$ ($n = 7$), whereas the contemporary orientation of the **S-exp.s** (Fig.8, lower) was insignificant in about the standard direction: $227^\circ - 0.459$ ($n = 8$), or should perhaps be considered as bimodal (doubling the angles leads to $182^\circ/2^\circ - 0.312$ ($n = 8$)).

Discussion

If magnetic navigation is carried out – **and if the controls are oriented in about the standard direction (SSW)** – the expectation should be a significantly northerly component in the sample orientation of the S-exp.s., whereas the orientation of the N-exp.s should be the same or may be more southerly compared with the controls. In a bi-coordinate/gradient navigation system where magnetism only delivers the N/S component we should not (with a standard direction of SSW) expect reverse (i.e. NNE) but rather NNW orientation.

Because of the changing orientation of the **controls** in course of the autumn this prediction is best tested for the period a) 17 through 22 Aug. – perhaps including b) the last period 4 to 5 Sep. The mean vector of the **controls** is a) $167^\circ - 0.396^{**}$ ($n = 33$), or b) $157^\circ - 0.366^{**}$ ($n = 42$). However, the distributions look somewhat bimodal with the larger peaks more in about in the standard direction than SSE. Doubling the angles leads to a) $190^\circ/10^\circ - 0.186$ ($n = 33$), and b) $184^\circ/4^\circ - 0.197$ ($n = 42$).

The orientation of the **S-exp.s** in a) is $123^\circ - 0.643^{**}$ ($n = 12$), and b) $151^\circ - 0.386^*$ ($n = 20$). Clearly, the orientation contains no clear northerly component, and the prediction is not met.

Concerning the **N-exp.s** we should expect a higher (unimodal) concentration and a more southerly direction compared with the controls. However, at least the first expectation is not met as the a) orientation is $180^\circ - 0.156$ ($n = 23$), or if doubling the angles: $172^\circ/352^\circ - 0.206$ ($n = 23$). The b) orientation is $172^\circ/352^\circ - 0.211$ ($n = 30$).

Now the **controls** are not oriented in the standard direction in the period 9 through 14 Aug. where the orientation is about reverse (N), or bimodal NW/SE. If magnetic navigation towards a goal somewhere in the direction of NW or N we should expect about standard orientation in the N-exp.s and a strong northerly orientation in S-exp.s. However, these expectations are not fulfilled. The combined orientation in the **N-exp.s** is $146^\circ - 0.146$ ($n = 19$), and in the **S-exp.s** $205^\circ - 0.503^*$ ($n = 12$), i.e. the former group is dis-oriented, whereas the latter is significantly oriented in about the standard direction strongly opposed the expectation.

The **conclusion** should be that just like in the experiments on Endelave in autumns 2004 and 2005 there are no indications of magnetic gradient navigation. Perhaps no one should wonder as all birds tested in 2004 and 2006 were juveniles; according to Freake et al. 2006 we should only expect magnetic gradient navigation in adult birds. However, the 2005 birds were adults.

An important note should be that we do not know how the animals establish a direction in reference to a (magnetic) compass: almost surely, they do it other ways than we do (by

keeping an angle to the left or right in reference to a compass). In all probability the magnetic vector is involved as a compass reference in a way not yet understood/realized. The result is that the outcome/orientation is variable: It depends both on the vector (intensity/inclination and three-dimensional configuration) and the intrinsic state/motivation of the animal. The response also falls in between (the concepts of) compass orientation and gradient navigation.

A final note should be (compare above), that the horizontal component of the magnetic vector (i.e. the magnetic compass reference in our system) is not (normally) directed perpendicular on the isoclines of the components: a) horizontal intensity, b) vertical intensity, c) total intensity, or d) inclination.

Other papers on magnetic navigation

Dennis, T.E., M.J. Rayner & M.M. Walker 2007: Evidence that pigeons orient to geomagnetic intensity during homing. – Proc. R. Soc. B 274, 1153-1158

The **main problem with this paper** is that the randomization method is not clearly described. Therefore, it is hopeless to find out whether the conclusions of the authors are reasonable.

Adult/experienced pigeons were released in and around the Auckland Junction Magnetic Anomaly (JMA). *“The source of the JMA is a deep-seated structural dislocation app. 1.6 km below the Earth’s surface and is not correlated with surface topography”*. The peak of (total) magnetic intensity in the anomaly is said to be 400 nT above regional main-field intensity. According to Fig.1.4 in Wiltschko & Wiltschko (1995) is the latter about 55.000 nT, i.e. 400 nT is less than 1% of the regional level, probably meaning that the directions of magnetic N in reference to geographical N is barely affected (this is not presented/discussed by D. et al)..

The pigeons used have training experience from several releases up to several 100 km S of the loft. Fig.1 **implies that the birds were released “N” of the loft** (home-directions between 130° and 220° (6 out of 15 release sites are depicted), but as far as I can read the authors never explicitly inform about that.

The intensity isoclines of the anomaly looks like a lens oriented with the long axis running 150°/330°, whereas according to Wiltschko & Wiltschko (1995) Fig.1.4 the intensity isoclines in general are oriented about 110°/290° in the New Zealand area. When displaced “N” the pigeons anyway will experience increased intensities, i.e. supposedly releases within the anomaly will just increase the “feeling” of being displaced “N”. **Clearly, we need a figure of a map with the anomaly, the 15 release sites, the loft, and the magnetic intensity isoclines. Furthermore, we need to know the borders of the area from where the “randomly oriented bearings of the intensity field” are taken.**

The flight trajectories of Fig.1 are compatible with a PCD in about SE-SSE – and therefore perhaps it is only a coincidence that most flights are in parallel to the isoclines.

This is not discussed by the authors. However, an appropriate randomization procedure should compensate for such a coincidence – **but is the randomization procedure appropriate? Their probabilities of the alignment of the trajectories in parallel or perpendicular appears so low that perhaps the procedure is wrong/inappropriate.** Anyway, the randomization procedure is not described too well; we need some calculated examples of trajectories to accept the procedure.

On p.1154 right column: “*The test algorithm determined the total number of segments in a trajectory, S , in which ΔFI was less than Ac . A test distribution was generated by iteratively calculating 4999 values of S using **randomly oriented bearings of the intensity field***”. But from which intensity field (the anomaly?).

When looking at Fig.1 the circular distribution of directions at right angles towards the isoclines must be bimodal with two equally sized peaks in around 60° and 240°. Can this be confirmed by Dennis et al.?

As realized by the authors “Why pigeons initially fly after release in directions with respect to that of the local intensity field begs explanation” (p.1155, first sentence in DISCUSSION). Perhaps it is **just a spurious correlation to a general SE-SSE directed PCD?** This should be discussed.

Wiltschko, R. & W. Wiltschko 1995: Magnetic orientation in animals. – Springer, Berlin Heidelberg New York.

Freake, M.J., R. Muheim & J.B. Phillips 2006. Magnetic maps in animals: a theory comes of age? – Quart. Rev. Biol. 81, 327-347.

This is an important contribution reviewing some of the classical examples on magnetic navigation. There is a strong overall believe in the real existence of magnetic navigation, i.e. **every “something happening” is interpreted in positive terms of magnetic navigation** (such as “*Numerous studies have demonstrated that pigeons released at magnetic anomalies are disoriented, and scatter is greatest at the strongest anomalies*”, p.332 right column). Another example is found in the section MAGNETIC INCLINATION AS PART OF A MAGNETIC MAP IN ALLIGATORS “ - - “*errors*” in their homeward bearings were correlated with small deviations of inclination angle and/or horizontal intensity from the value observed during the preceding night”. It is not clear what these correlations mean. Anyway they are calculated on the basis of both data-filtration and “adaptation” to the time-values yielding the highest correlation coefficients.

In the Introduction is an interesting passage “ - - *magnetic inclination can be used as a rough measure of latitude (see below). The hope of using magnetic declination to identify longitude magnetically was dismissed, however, once people realized that declination is not constant, but steadily drifting (Pumfrey 2003)*”. Is the secular variation in magnetic declination more pronounced/unpredictable than the variation in magnetic inclination? To me it seems that the variation in both variables could be tabulated (also in animals) without problems – except of course some hard work/calculations.

The following sentences are important: 1) “*Once a gradient pattern has been learned, it may be extrapolated to unfamiliar areas far from home*” and 2) “ - - *true navigation is*

likely to be observed only in experienced adult individuals, with inexperienced juveniles relying on alternative navigational strategies such as path integration or, in case of long-distance migration, innate directional preferences". Furthermore, 3) "- - since magnetic gradients cannot be detected directly, the animal must make a series of "point samples" that are in a known spatial relationship to one another". Seemingly, Freake et al. overlook that juveniles may have an innate knowledge that (in most areas) magnetic parameters such as inclination and/or intensity are changing at a (app.) maximal rate along the magnetic N/S-axis, i.e. **scanning a gradient pattern may not be necessary**. What is needed for a N- or S-directed "navigatory" response is only an appreciation/feeling that a parameter-value has increased or decreased.

INDIRECT EVIDENCE FOR THE MAGNETIC MAP HYPOTHESIS

In this major section is reported indirect evidence from pigeons, alligators, turtles and birds (Pied Flycatcher, Beck & Wiltschko 1988, and Trush Nightingale, Fransson et al. 2001).

PIGEON HOMING DURING MAGNETIC STORMS AND AT MAGNETIC ANOMALIES

Freake et al. refer to the review of Wallcott (1991). At that time Wallcott was positive about magnetic navigation in pigeons. However, later on he changed to a much more skeptical attitude (Wallcott 1996). However, **all "evidences" presented are indirect**, and most responses to magnetic shifts are not easily understood as navigatory.

MAGNETIC MAPS IN SEA TURTLES?

The **turtling** experiments by Lohmann and co-workers are mentioned as indicative of some sort of navigatory response intended to be meaningful and adaptive in relation to the movement around in the North Atlantic gyre. **The interpretation of mine is that different magnetic treatments sometimes are followed by sample distributions which differ significantly from each other – whereas their coupling/causal relationship with the positions in the gyre is not clear.**

The hypothesis of **navigational markers** is shifted out with the **range boundary** hypothesis (- - "*critical values being genetically imprinted as "signposts" to indicate the boundaries of their range*").

The significance of the orientation of the turtlings is discussed in great length and leaves the impression that **if** the results are muddy, and **if** a clear research hypothesis is not really tested, and **if** the initial conditions for performing a navigatory act in the remote future are hopeless (the turtlings are emerging on the beach) you may always say something intelligent about how natural selection may work.

Freake et al. note “*the case for magnetic map navigation has been greatly strengthened by a more direct line of evidence: juvenile green sea turtles, Chelonia mydas, captured on feeding grounds off the coast of Florida and tested in magnetic fields found approximately 300 km north or south of the capture location, oriented themselves in the appropriate general direction that would return them to the capture site (Lohmann et al. 2004)*” I agree, but the result of this single experiment with rather few animals involved needs to be confirmed by repetition. Anyway, this experiments belongs to the next heading (**Direct evidence** for the magnetic map hypothesis).

Concerning **adult** turtles Freake et al. is much concerned about the possibility of magnetic navigation in the Ascension Island turtles. It is noted that if breeding female turtles are displaced away from the island “*individuals displaced to the northwest showed the highest homing success and tended to have straighter paths*”. Freake et al. deliver a lengthy and as far as I can see redundant set of pseudo-explanations for that rooted in a calculation that the geographical position of the magnetic coordinates of Ascension has moved steadily and about 700 km towards northwest in the period 1970 until 2005. Anyway, the distance of displacements was much shorter (Luschi et al. 2001, Hays et al. 2003) and – given the considerable age of the adult turtles in consideration - it seems difficult to figure out whether the magnetic coordinates of the island is to the NW or SE of its present position. Luschi and co-workers gives a much more reasonable reason of the high homing success from the NW: Olfactory (or auditory) orientation from the leeward site of the island (prevailing winds from the SE). This possibility is also mentioned shortly by Freake et al.

MAGNETIC CUES AS TRIGGER FOR BEHAVIORAL AND PHYSIOLOGICAL CHANGES IN BIRDS

Freake et al. mention the Pied Flycatcher case of Beck & Wiltschko (1988) – treated by me also in the Gwinner2 doc.(www.jorgenrabol.dk). Freake et al. follow Beck & Wiltschko and maintain that “*A third group held in the magnetic field found in North Africa was disoriented throughout the season*”. This is not true. The birds were oriented steadily towards NW. The conclusions of Freake et al. is that (the interpretation of) this case resembles the turtlings of Lohmann and the hypothesis of navigatory/boundary markers. However. The turtlings reacted more in the way of the Garden Warblers of Gwinner & Wiltschko (1978). This is not mentioned/appreciated by Freake et al. Anyway, the interpretation of these Pied Flycatchers and Garden Warbler experiments is not so easy, and the only safe conclusion seems to be that “some change” normally occurs in course of the season, and that the initial orientation depends on magnetic variables.

Freake et al. also mention the Trush Nightingale case of Fransson et al. (2001) – and the related case of Kullberg et al. (2003). The amount of fat deposition and feeding rate was coupled with (changes) in magnetic field values in a way leading the authors to conclude that magnetic navigation was possibly involved. Anyway, there were some significant differences between samples treated under different magnetic conditions, but certainly the interpretation of these results is not straightforward or easy.

DIRECT EVIDENCE FOR THE MAGNETIC MAP HYPOTHESIS

EASTERN RED-SPOTTED NEWTS

This case gives “*The most direct evidence for magnetic map navigation - -*”. **I agree that the results of Phillips and co-workers in course of the years have developed to confirm this conclusion.** Considered in isolation Fig.4 in Freake et al. – showing newt-orientations following real and simulated geographical displacements – confirms the hypothesis of gradient navigation in reference to magnetic inclination.

I like the last sentence of Freake et al.: “*Future work should include precise geomagnetic surveying at and around the home ponds of the newts to test for a match between the orientation behavior observed in the experiments and the actual gradient patterns*”. One may wonder why this work was not initiated long time ago. In particular we need knowledge of the gradient-axis of the inclination – in reference to both magnetic and geographical N (the declination seems to be about 8° - 10° to the W). The local axes (at the two important home-pond areas) may be different from the general gradient-axis - probably close to N/S – of the Indiana region (Phillips and co-workers give no information).

The main problem for me before accepting magnetic gradient navigation in the newts are not the experimental results but the extremely small home-range of these animals: The adult newts spend most of their time in the home-pond or in other ponds or on land up to 1 or 2 km away. **The conditions for developing a magnetic navigation system (but of course not a magnetic compass) seem totally out of context.**

Also the methods and results of these newt experiments are not easily overviewed and integrated – even after several re-readings of the many papers published. 1) At first I suspected spurious connection between shoreward and homeward orientation - i.e. the latter could – perhaps - be reduced to some (motivational conditioned) cross-axis deviant of the former, but a thorough and critical inspection of the extensive material reveals no obvious reason for such a suspicion. However, to be sure we need to see homeward orientation also after staying in a radial symmetrical outdoor water-tank where there is a shore all way around and not just in one of the long ends of a rectangular tank. 2) All displacements from the home-ponds to the laboratory area came from SSW or E-ESE. We need to see the orientation also of newts displaced from the two opposite directions – and field experiments where newts from a certain home-pond are displaced in the four cardinal directions (as in the homing pigeons of H.G. Wallraff). 3) The homeward orientation of newts from E-ESE (Phillips et al. 1995) is very difficult to understand - as the difference in inclination between the home-pond and the tank/testing area is as minute as 0.02° - 0.03° (calculation based on a said difference of 0.17° between the home-pond in SSW and the tank/testing area (Phillips et al. 2002a), and a supposed inclination gradient running about N/S). Furthermore, if the newts navigate in a mono-coordinate system by means of the inclination the response should be S and not E-ESE. 4) If the newts make use of bi-coordinate-navigation – and the declination is the other coordinate/gradient – then the homeward orientation of the E-ESE newts becomes much more understandable as the difference in declination is E-directed and about 0.1° (the sample mean vector was 126° - 0.52**, n = 19). Furthermore, in a bi-coordinate system the orientation of the

newts from the home-pond towards SSW is now expected to be SW and not S as the declination-vector is about 0.16° and directed towards W (the sample mean vector was $221^\circ - 0.59^{***}$, $n = 18$). 5) However, if we maintain the proposition of a bi-coordinate navigation system the results of the final simulated displacements of Fischer et al. (2001) and Phillips et al. (2002a) become less understandable: the orientation following the “displacement” **downward** the inclination 0.15° , 0.48° , and 2° , respectively should be about 270° , 325° , and 340° , respectively. In fact, they were random ($328^\circ - 0.08$), $25^\circ - 0.52^{***}$, and $56^\circ - 0.47^{***}$, respectively. 6) In principle the newts in the outdoor tanks should be able to “measure” the declination as the sun is available for establishing geographical N. However, the extremely small differences in declination needed seem out of context, and in fact Phillips and co-workers are not all proposing the probability. 7) One should note that the SSW- and NNE-NE orientations on a general SSW/NNE-axis in Phillips et al. (2002) come close to the bimodal “fixed-axis” orientation on SSW/NNE after exposure for long-wavelength light in the tank-phase (Phillips et al. (2002b). On the whole the different reactions/changes in orientation as the result of exposures for different wavelength of light in particular in the shoreward orientation adds to insecurity about the mechanisms behind homeward directed orientation. 8) In conclusion, the homeward orientation in the experiments performed should not be considered a proof that the newts under natural circumstances make use of magnetic navigation. In the opinion of mine too many “degrees-of-freedom” in the procedures are involved. But certainly, the results are promising.

AUSTRALIAN SILVEREYES

Freake et al. report on the investigation of Fischer et al. (2003) on **adult** Tasmanian Silvereyes *Zosterops lateralis lateralis* captured on the breeding ground and transported to Armidale within the northern part of the wintering area of the population in eastern Australia. In autumn the Silvereyes were treated in two ways; one group (SimN) were caged and tested in a magnetic field where the vertical component of the local magnetic field was **decreased** 12%, whereas the other group (SimS) experienced an **increase** of 12%. By these treatments both magnetic intensity and inclination change to simulate geographical displacements a little to the north of the wintering area and to the southern part of the wintering area, respectively. It should perhaps be emphasized – as apparent inspecting Fig.5 – that the new corresponding isoclines of intensity and inclination are not following each other to match any natural constellations: the intensities display the largest geographical about N- or S-shifts.

Fischer et al. (2003) concluded that the southeasterly orientation of the SimN birds was insignificant whereas the northnortheast orientation of the SimS birds was significant. Now Freake et al. when splitting the SimN experiments in an initial phase (first three days) and a later phase (last three days) obtain a significant orientation towards E changing to an almost significant ($P < 0.10$) orientation towards S (according to the authors because the presentation of the results in Fig.5 is obscure). The SimS birds were not changing in direction (but the concentration increased) when treated in the same way. Seemingly, Freake et al. in an unclear way takes this finding/manipulation as a strengthening of the conclusion of Fischer et al. “*that the most likely explanation was an effect on the map*”. In my opinion it changes nothing but I agree with Fischer et al.

Until now only **adult** Silvereyes were investigated. Freake et al. now writes the following (I changed two passages into **bold**): “ - - a more recent experiment (Deutschlander, Phillips, Fischer and Munro, unpublished data), in which birds were exposed to larger simulated displacements, found that the effect of the SimN condition was only observed in experienced adult birds **that use map information**. Young birds collected prior to their first migration, **which do not rely on map information**, showed no effect from the SimN or SimS treatments”. It seems that Freake et al. – as Able (2000) – know by sure that adult birds have a map, whereas young birds are only programmed to make use of compass orientation.

The final observation of Freake et al. – based on experiments with Silvereyes of the Wiltschkos and Munro – is, that “ - - pulse remagnetization experiments have also provided evidence that Silvereyes use magnetic map information”. However, this “evidence” (a right angle response) – only found in adult birds – is not clearly understood and at best gives indirect evidence of magnetic gradient navigation.

SPINY LOBSTERS

The well known experiment by Boles & Lohmann (2003) is referred to and my comment should be that also Freake et al. seem unaware of the possibility of chemical/olfactory navigation in the displaced lobsters*. Concerning the simulated displacements the following orientations certainly look like at least mono-coordinate magnetic map responses – just like the newts of Phillips and friends.

Freake et al. write the following wise words: “A criticism common to both the newt and lobster studies is that the simulated displacement distances exceed the distances over which they are known to perform true navigation and, therefore, are not representative of the real world”.

10 March 2003 I commented in my note-book: Alerstam (2003) writes: “Sometimes an idea is so irresistible that it is revisited over and over again. One such is the notion that Earth’s magnetic field provides guidance for orientation and even true navigation”. The point of mine is that because of this irresistibility the magnetic people have to be challenged. Otherwise, there is a risk that the field develops into a disharmonic mixture of facts and fiction.

The conclusion of the authors is “our results demonstrate for the first time that an invertebrate animal is capable of true navigation”. Furthermore, “These results provide the most direct evidence yet that animals possess and use magnetic maps”.

However, whereas true navigation is probably involved, the indications of the use a magnetic map could be challenged.

First, **if** the displaced lobsters (Figure 1 and 2) have been **tested in local water**, “olfactory” (chemical) navigation may be involved in much the same way as demonstrated in pigeons by Benvenuti & Wallraff (1985). If so the magnetic field was probably involved only as a compass reference. The authors are aware – and mention - that magnetic navigation may be difficult because the displacements are closer to an E/W-axis than a N/S-axis and the isoclines of both magnetic inclination and intensity are running close to E/W in the area of investigation.

This leads to the next point: Fig.3 is depicting simulated magnetic displacements to two **positions** about 400 km N and S of home. The two mean vectors calculated are pointing close towards home, so the combination of Figs.1, 2 and 3 appears very convincingly explained as guided by magnetic navigation. However, the longitude – 80.5° W – given in the “Experimental protocol” for both positions of displacement is bound to be very uncertain. Both magnetic inclination and intensity vary “much” with latitude but close to nothing with longitude, so the simulated displacement is not towards a position in N but towards a long row of “positions” between – say – WNW and ENE as seen from the home position. In the same way the position in S is a long row of “positions” between ESE and WSW. In short, the homeward orientations as depicted are maximum solutions to the hypothesis in charge. The figure may also be misleading in another aspect: If navigating in a close-range magnetic system the orientation depicted may or may not be home-directed.

Now, the lobsters on Fig.3 was captured at CS2 and tested in TS1, and clearly there is no significant difference between the orientation of the lobsters “displaced” 400 km to the “N” (199° - 0.51) and the other(?) sample of lobsters displaced from CS2 to TS1 depicted in the lower right of Fig.1 (222° - 0.65). This leaves the possibility that the orientation of the lobsters “displaced” 400 km to the “S” is not a navigatory response but only reverse orientation in compass system elicited by “something” that of course in principle could be the magnetic inclination and/or intensity and if so could be considered (it is mostly a matter of words) as a simple form of uni-coordinate navigation.

Further comments 16 Sep. 2003. I contacted Boles (with the text above) several times on email. He never answered. I then contacted Hans Wallraff and wrote “*If the displaced lobsters (Figures 1-2) were tested in local seawater (they probably were!), olfactory/chemical navigation may be involved*”. Now Wallraff already in Jan. contacted Boles and on basis of Boles’ answer he concluded to me “*that in this case olfaction is sufficiently excluded*”. However, Wallraff’s conclusion could be wrong. Probably, he misunderstood something about the words “tank” and “arena”, which for Boles are clearly the same thing, or the word “laboratory”. Boles wrote that “*The water for the tanks was filtered sea-water from the laboratory’s flow through system*”. Furthermore, “*The water comes from the nearby ocean*”. This probably means that the lobsters were tested in the local water of TS1 when displaced to TS1, and in the local water of TS2 when displaced to TS2, and if the water was only mechanically filtered and not charcoal filtered (or something like that as in the pigeons of Wallraff) the chemical composition of the water was not changed.

At last two further observations. 1) The orientation of the lobsters “displaced” 400 km to the S is significantly bimodal. Doubling the angles leads to $-17^\circ/163^\circ - 0.66^{***}$ (n = 16), and 2) there is no significant difference between the orientation of these and the CS1 displacements to TS1 (Fig.1). Of course, these observations are not at all incompatible with the hypothesis of a magnetic navigation system, but they suggest a simple sign system, which perhaps also could be understood in terms of a standard (“nonsense”)/reverse compass system.

SOME THOUGHTS ON DESIGNING EXPERIMENTS

Freake et al. maintain that “ - - *the ability to produce precise alterations in the magnetic field to simulate artificial displacements and exclude alternative cues is essential*”.

Furthermore “*It is also important to test whether manipulations of the geomagnetic field act on the map step of homing, rather than exerting a nonspecific effect on the compass step*”. This sounds wise but **what is meant by a nonspecific effect on the compass step?** It is just words coming out from a scenario with a clear distinction and separation of compasses and maps/gradient navigation.

The following sentence is typical for supporters of magnetic gradient navigation “ - - *alternative cues may suffice to mediate homeward orientation when reliable magnetic information is unavailable, but this does not demonstrate that a magnetic map is nonexistent*”. This is true but this kind of argumentation resembles “***There is no need invoking the Good Lord in the process of creation/development of life, but this does not demonstrate that he/she is nonexistent***”.

The problems by demonstrating magnetic navigation in long-distance migrants like albatrosses and turtles is met by a predictable warning – which of course may be true in all cases reported until now: “*It is essential to consider whether the presence of a satellite transmitter attached to the animal distorts the geomagnetic field sufficiently to render a magnetic map sense inoperable*”

The final words of mine should be that there are so many people fond of and believing (and publishing successfully) in magnetic navigation that the society is almost immune for criticism. There is a clear feeling that magnetic navigation must be working because the field is always there and available for use.

Able, K.P. 2000: The concepts and terminology of bird navigation. – J. Avian Biol. 32: 174-183.

Alerstam, T. 2003: The lobster navigators. - Nature 421: 27-28.

Beck, W. & W. Wiltschko 1988: Magnetic factors control the migratory direction of Pied Flycatchers (*Ficedula hypoleuca* Pallas). – In Quillet, H. (ed.) Acta XIX Congr. Int. Ornith., Vol.II, pp.1955-1962.

Benvenuti, S. & H.G. Wallraff 1985: Pigeon navigation: site simulation by means of atmospheric odours. – J. Comp. Physiol. A 156, 737-746.

Boles, L.C. & K.J. Lohmann 2003: True navigation and magnetic maps in spiny lobsters. – Nature 421, 60-63.

Fischer, J.H., M.J. Freake, S.C. Borland & J.B. Phillips 2001: Evidence for the use of magnetic map information by an amphibian. – Anim. Behav. 62: 1-10.

Fischer, J.H., U. Munro & J.B. Phillips 2003: Magnetic navigation by an avian migrant? In: Berthold, P., E. Gwinner & E. Sonnenschein (eds.) Avian Migration. Springer-Verlag, Berlin and New York, pp.423-432.

Fransson, T., S. Jakobsson, P. Johansson, C. Kullberg, J. Lind & A. Vallin 2001: Bird migration – magnetic cues trigger extensive refueling. – Nature 414: 35-36.

Gwinner, E. & W. Wiltschko 1978: Endogenously controlled changes in the migratory direction of garden warbler, *Sylvia borin*. – J. Comp. Physiol. 125-273.

Hays, G.C., S. Åkesson, A.C. Broderick, F. Glen, B.J. Godley, F. Papi & P. Luschi 2003: Island-finding ability of marine turtles. – Proc. R. Soc. London B 270: S5-S7.

Kullberg, C., T. Fransson, S. Jakobsson & A. Vallin 2003: Magnetic cues and time of season affect fule deposition in migratory trush nightingales (*Luscinia luscinia*). – Proc. R. Soc. B 263: 1671-1675.

Lohmann, K.J., M.F. Lohmann, L.M. Erhart, D.A. Bagley, and T. Swing 2004. Geomagnetic map used in sea-turtle navigation. – Nature 428: 909-910.

Luschi, P., S Åkesson, A.C. Broderick, F. Glen, B.J. Godley, F. Papi & G. Hays 2001: Testing the navigational abilities of ocean migrants: displacement experiments on green sea turtles (*Chelonia mydas*). – Behav Ecol Sociobiol 50: 528-534.

Phillips, J.B., K. Adler & S.C. Borland 1995: True navigation by an amphibian. – Anim. Behav. 50: 855-858.

Phillips, J.B., M.J. Freake, J.H. Fischer & S.C. Borland 2002a: Behavioural titration of a magnetic map coordinate. – J. Comp. Physiol. 188: 157-160.

Phillips, J.B., S.C. Borland, M.J.Freake, J. Brassart & J Kirschvink 2002b. `Fixed-axis`magnetic orientation by an amphibian: non-shoreward-directed compass orientation, misdirected homing or positioning a magnetite-based map detector in a consistent alignment relative to the magnetic field? – J. Exp. Biol. 205, 3903-3914.

Pumfrey, S. 2003. Latitude and the Magnetic Earth. – Cambridge and New York: Icon Books.

Walcott, C. 1991: Magnetic maps in pigeons. In: Berthold, P. (ed.) Orientation in Birds. Birkhäuser Verlag, Basel, pp.38-51.

Walcott, C. 1996: Pigeon homing: Observations, experiments and confusions. – J. Exp. Biol. 199: 21-27.

Alerstam, T. 2006. *Conflicting evidence about long-distance animal navigation.* – *Science* 313, 791-794.

Alerstam starts with an important observation/statement – not normally shared by other bird migration/orientation people: “*Until recently, it was believed that juvenile birds (among species traveling solitarily) on their first journeys relied solely on an endogenous spatiotemporal program, defining the journey in terms of direction and distance along one or a few main legs*”. The reason for this acknowledgement is that “*- migration patterns converging toward narrowly defined species-specific passage or wintering areas can hardly be the result of such simple endogenous control (5, 6)*”. 5 and 6 are Thorup & Rabøl 2001 and Fransson et al. (2005).

Alerstam – in the spirit of most contemporary scientists - focuses much on the **earth magnetic field** as the possible agent behind gradient navigation. Fransson et al. (2001) is (implicitly) mentioned as a possible example on magnetic **regional markers**, and says that the best example on these “*comes from experiments with hatchling loggerhead sea turtles*” (Lohmann). Alerstam mentions a serious problem with the magnetic field acting as regional markers: the field is changing (rather) fast in time and “*how is it possible for evolutionary change in the animals’ genetic migration program to keep pace with such secular changes in the Earth’s magnetic field*”.

Alerstam continues his busyness of magnetic navigation by mention the (claimed – and for an at least superficial consideration reasonable) examples of magnetic navigation: 1) the newts of Phillips and friends, 2) the spiny lobsters of Boles & Lohmann (2003), and 3) the juvenile turtles of Lohmann et al. (2004). However, he notes the problem that only simulated N/S-displacements have been demonstrated (this is not true in case of the newts), and the further problem that “*It also remains to be shown whether geomagnetic gradients allowing unambiguous navigation are actually available within the local natural homing ranges of the experimental animals*”. Furthermore “*An even more serious difficulty for the magnetic navigation hypothesis is the failure reported in several experimental attempts to disrupt homing success by attaching magnets to the animals*”.

The conclusion of Alerstam is that “*These results imply that magnetic cues are not essential for successful homing if alternative navigation cues are available*”. Here Alerstam is very diplomatic and friendly with his “if”.

The next point of Alerstam is also a courtesy to the dominating magnetic paradigm when he says that “*A possible alternative homing mechanism is olfactory navigation*” and “*For homing pigeons, olfactory navigation remains theoretically possible on the basis of observed large-scale gradients of atmospheric chemical substances*”. In the advanced year of 2006 no serious scientist can doubt the significance of olfactory navigation in homing pigeons, and consider it a very probable agent also in other animals like seabird, turtles and spiny lobsters.

Alerstam writes nothing about the possibility of celestial/stellar navigation. One may wonder why – because Alerstam knows the planetary simulated displacements of mine.

So in short – and after the opinion of mine – Alerstam exaggerates/over-estimates the navigatory influence from the Earth’s magnetic field; under-estimates the importance of chemical/olfactory navigation; and totally forgets – or ignores – celestial navigation.

Until now Alerstam considered gradient/coordinate navigation. He then turns to “*the intercalibration between different compass mechanisms - - in cue-conflict cage experiments in which birds are exposed to both celestial and magnetic cues, with one or both of these cues manipulated such that they give conflicting compass information*”.

Alerstam mentions the traditional perception of the Wiltschko & Wiltschko (1995) with the distinction between what going in the **pre-migratory period** (celestial rotation calibrates the magnetic compass), and later on **during actual migratory progress** (the magnetic compass dominates/calibrates the celestial compasses). However, this generalization (which already was challenged by Able 1995, 1996 (not mentioned by A)) has been broken by the Catharus-releases of Cochran et al., and the survey by Muheim et al. (2006) indicating that a sunset compass calibrates the magnetic compass – at least under conditions when the birds are able too see the twilight sky down to the horizon.

According to Alerstam “*New studies, particularly of birds under natural free-flying conditions, are now needed for a reevaluation of the compass calibration*”. The problem here – not mentioned by Alerstam - is that manipulations of the different compasses under free-flying conditions are difficult or mostly impossible. However, another approach emphasized by Alerstam is that migratory courses/flight trajectories may reveal whether or not magnetic or celestial compass references are in use.

The last focus of Alerstam is on “*individual-based tracking data of increasing spatial resolution and prolonged coverage during multiple years and journeys. This will be crucial to understand how migration is organized into phases of dispersal, exploration, compass orientation, and homing, and how learning during one journey affects succeeding journeys*”. Furthermore “*Analyses of the variability in individual migration history within and between populations with different migratory habits will be important to understand the evolution of new migration patterns*”. And finally “- - we are still far from understanding how animals integrate different cues for long-distance navigation under natural conditions”.

Able, K.P. & M.A. Able 1995: Interactions in the flexible orientation system of a migratory bird. – Nature 375-232.

Able, K.P. & M.A. Able 1996: Orientation cues used by migratory birds: A review of cue-conflicts experiments. – Trends Ecol. Evol. 8: 367-371.

Boles, L.C. & K.J. Lohmann 2003: True navigation and magnetic maps in spiny lobsters. – Nature 421, 60-63.

Cochran, W.W., H. Mouritsen & H. Wikelski 2004: Migrating songbirds recalibrate their magnetic compass daily from twilight cues. – Science 304: 405-408.

Fransson, T., S. Jakobsson & C. Kullberg 2005: Non-random distribution of ring recoveries from trans-Saharan migrants indicates species-specific stopover areas. – J. Avian Biol. 36: 6-11.

Lohmann, K.J., M.F. Lohmann, L.M. Erhart, D.A. Bagley, and T. Swing 2004. Geomagnetic map used in sea-turtle navigation. – *Nature* 428: 909-910.

Muheim, R., J.B. Phillips & S. Åkesson 2006: Polarized light cues underlie compass calibration in migratory songbirds. – *Science* 313: 837-839.

Thorup, K. & J. Rabøl 2001: The orientation system and migration pattern of long-distance migrants: conflict between model predictions and observed patterns. – *J. Avian Biol.* 32: 111-119.

Wiltschko, R. & W. Wiltschko 1995: *Magnetic orientation in animals.* – Springer-Verlag, Berlin.

Avens, L. and K.J. Lohmann 2004. Navigation and seasonal migratory orientation in juvenile turtles. J. exp. Biol. 207, 1771–1778.

Juvenile loggerhead and green turtles inhabiting inshore waters of North Carolina, US are tested after displacements 30 – 168 km along circuitous routes while deprived of visual cues. Juvenile turtles are several years old and are supposed – starting as hatchlings – to have undertaken and terminated the long gyre migration round in the Atlantic Ocean.

Turtles were displaced to the oceanic laboratory in Beaufort from two main areas 1) Core Sound and Pamlico Sound towards ENE (74°), and 2) an area WSW (255°) as seen from Beaufort. At Beaufort they were tested – tethered in the same way as the hatchling turtles – in a circular arena (6 m in diameter and a water depth of 0.75 m). Obviously the local seawater of the testing site was used (and "the water was stirred prior to each trial to ensure that no chemical gradients existed in the tank"). The walls of the tank blocked the view of the horizons and surrounding things.

During summer (i.e. May to Sep.) both species show reasonably clear homeward orientation, in particular towards ENE (loggerheads 83° – 0.29***, n = 122, and green turtles 50° – 0.71**, n = 9). Only loggerheads were displaced from WSW, and the westerly orientation (271° – 0.43, n = 11) is only significant in context of the V test and not the Rayleigh test.

Avens and Lohmann considers these results as indicative of homing towards the capture grounds towards ENE and WSW. They are more cautious about which compasses and maps may be involved. The **magnetic compass** and a compass based on the **sun** or patterns of skylight polarisation (the exp.s were carried out during daylight hours) are mentioned. "Among several potential sources of **positional information** are **location-specific chemical cues** – – and information from the **Earth's magnetic field** – – (and) from celestial cues such as the elevation (height above the horizon) of the **sun** at specific times of the day" (my underlings). The last possibility is considered unlikely.

My comments: The authors forget to tell or recognize that magnetic map navigation is also rather unlikely as the magnetic gradients in the region all (except declination) run

about NNW–SSE i.e. perpendicular to the displacement directions. The same point was made by me in case of the Spiny Lobster displacements (Boles and Lohmann 2003). On the other side, Avens and Lohmann should be acknowledged for mentioning the chemical/"olfactory" possibility. Boles and Lohmann never did that (probably it never occurred to them).

Avens and Lohmann also tested both species during autumn (i.e. Oct. and Nov.) where the turtles are supposed to migrate somewhere around south out in the Atlantic Ocean. At this time of the year the displaced loggerheads oriented $190^\circ - 0.61^{**}$, $n = 15$, and the greens $199^\circ - 0.76^*$, $n = 7$.

As far as I can see the conditions for chemical navigation must be rather perfect as seawater is probably running up and down along the coast and sounds, and the testing site is placed at the coast and local seawater is used in the test arena.

Boles, L.C. & K.J. Lohmann 2003: True navigation and magnetic maps in spiny lobsters. – *Nature* 421, 60-63.

Lohmann, K.J., M.F. Lohmann, L.M. Erhart, D.A. Bagley, and T. Swing 2004. Geomagnetic map used in sea-turtle navigation. – Nature 428: 909-910.

Juvenile (several years old, after completion of at least one gyre tour) Green Turtles *Chelonia mydas* were trapped on the foraging grounds on the eastern/mid Florida coast, where experiments were carried out in the local laboratory water following simulated displacement about 337 km to the N and S (shifted magnetic fields to 61.2° , 49.2 mikroT and 55.4° , 45.4 microT. The sample orientations were $172^\circ - 0.70^{**}$ ($n = 11$), and $16^\circ - 0.54^*$ ($n = 12$), i.e. **it looks like magnetic navigation – as in the N/S-“displaced” Spiny Lobsters and Newts (and as in the prism-experiments of mine).**

I should like to see this experiment repeated. Also on the map shown in Lohmann et al. (2004) two dots denote to where the turtles were “displaced”. However, these dots are not too well defined, as the isoclines of magnetic intensity and inclination are running almost in parallel (the same problem as in previous experiments).

Lohmann, K.J. 2007. Sea Turtles: Navigating with magnetism. – Current Biology 17, R102-R104.

This is a more relaxed/cautious paper compared with his first/earlier papers – and the turtlings are now not supposed to be able to navigate in a magnetic gradient system, but the inclination and intensity “only” serve as **navigatory markers** eliciting “changes in swimming direction at crucial points in the migratory route where the turtles might otherwise stray off course”. Later on in the text it grows even less precise “when exposed to regional magnetic fields that exist in widely separated locations along the their migratory route, turtles that had never before been in the ocean responded by swimming in directions that would, in each case, facilitate movement along the migratory pathway”. The problems for Lohmann is 1) there is no clear testable research/null-hypothesis (by

keeping it loose he may “adapt” his results), and 2) he made all too few experiments – in particular with combinations of intensity and inclination.

In this paper Lohmann relies much on the navigatory responses of 1) simulated magnetic “displacement” with juvenile turtles (reported in Lohmann et al. 2004), and in particular by the 2) Luschi et al. (2007) experiments with geographically displaced adult turtles.

- 1) Reported above and looks convincing, but we need to see such simulated displacements repeated before making generalizations.
- 2) Reported in the file **Paolo** (see below, Luschi et al. 2007) and the conclusion of both Luschi (in litt.) and me is that there is no direct indication of magnetic navigation, but certainly the results are indicative of something else that just simple magnetic compass orientation. But this something may be navigation in another system than a magnetic one.

Lohmann, K.J., M.F. Lohmann, L.M. Erhart, D.A. Bagley, and T. Swing 2004.
Geomagnetic map used in sea-turtle navigation. – *Nature* 428: 909-910.

Luschi, P., S. Benhamou, C. Girard, S. Ciccione, D. Roos, J. Sudre & S. Benvenuti 2007.
Marine turtles use geomagnetic cues during open-sea homing. – *Current Biology* 17, 126-133

Luschi, P., S. Benhamou, C. Girard, S. Ciccione, D. Roos, J. Sudre & S. Benvenuti 2007. Marine turtles use geomagnetic cues during open-sea homing. – *Current Biology* 17, 126-133

20 Green Turtles *Chelonia mydas* were displaced about 100 km from Mayotte to three areas to the SE, SW and NE.

The turtles were divided in three groups: 1) **C**, Controls (7), 2) **MH**, Magnet Homing (7), i.e. turtles equipped with a strong and movable bar-magnet on head at the release site, and 3) **MT**, Magnet Transport (6), i.e. turtles disturbed by a strong and movable bar-magnet under the transport from Mayotte to the release site. I.e. there was no fourth group carrying magnets both when displaced and when released.

C and **MH** turtles were displaced to NE (2), SE (3) and SW (2).

MT turtles were displaced to SE only.

The SW and NE transports were in one year (2004), and the SE transports in another year (2005). I.e. the MH and MT turtles were mostly displaced in different directions and in different years making comparisons between the two experimental groups difficult.

Therefore the applied three-sample ANOVA testing including all turtles is perhaps not very rewarding/appropriate. It seems better just to compare the SE releases.

All turtles – except one – actually homed to Mayotte, i.e. **the magnetic treatments did not destroy the homing process** to the same extent as cutting the olfactory nerves in pigeons. However, certainly the magnetic treatments have some effects.

The main effect – when looking at Fig.1 - is that the **homing tracks of the HM and HT turtles are much longer than in case of the C turtles.**

However, there are also important **similarities** between the controls and the exp.s. All turtles released from SE departed more or less NNE-NE and then bended N and finally approached Mayotte from NE. A mirror image of this pattern was seen in (at least 3 out of 4) turtles released from SW: The departure direction was about NW then bending N and Mayotte was finally approached from the NW. The four C and MH turtles released in NE approached the island on more straight courses.

If distinguishing in the traditional black-and-white way between a magnetic compass **or** magnetic gradient navigation without considering processes in between, the conclusion of mine – based on the patterns of MH and MT turtles considered in concert - should be that probably only the magnetic **compass** is influenced by the two treatments.

However, the authors – otherwise presumably rooted in the tradition – moved in between, e.g. in their final words “- - *geomagnetic information has a major, albeit still not exclusive, role in pinpointing isolated targets*”. Certainly, the authors with the words “*major*” and “*pinpointing*” infer a significant kind of something more “*navigatory*” than just simple compass orientation. But perhaps they just felt tempted (in an understandable opportunistic way to obtain approval from the referees, and not because of scientific insight) to be positive about the possibility of magnetic gradient navigation.

Cain, S.D., L.C. Boles, J.H. Wang & K.J. Lohmann 2005. *Magnetic orientation and navigation in marine turtles, lobsters, and molluscs: Concepts and conundrums.* – *Integr. Comp. Biol.* 45, 539-546.

In case of the turtlings the results of Lohmann et al. (2001) is given as the most prominent example of the magnetic field delivering information as **navigational markers** (Fig.1).

The following quotations are interesting: “*straying beyond the latitudinal extremes of the gyre is often fatal*”, and “*An ability to recognize the latitudinal extremes of the gyre, and to respond by orienting in an appropriate direction, might therefore have considerable adaptive value*”. We could all agree and then **wonder about the disorientation shown by turtlings “displaced” to the inclinations of 75° and 15°** (Fig.2, Lohmann & Lohmann 1994).

Cain et al. also maintain that “- - *hatchling loggerheads evidently emerge from their nests already capable of detecting two different magnetic field elements that vary across the Earth’s surface and might provide positional information useful in guiding a long-distance migration*”. If one is very friendly this is perhaps vaguely correct in an indirect way but using the word “*evidently*” is far too much. **Remember that the hatchlings are not even endowed with a magnetic “standard direction” when emerging on the beach. What is the reality of a scenario where the turtlings are struggling towards the light of the sea transferring this direction to a magnetic compass reference and simultaneous with attacks from voracious ghost crabs they start looking in the**

remote future reacting in a meaningful way on specific values of intensity and inclination of the Earth's magnetic field?

Lohmann, K.J., S.D. Cain, A.A. Dodge & C.M.F. Lohmann 2001: Regional magnetic fields as navigational markers for sea turtles. – *Science* 294: 364-366.

Lohmann, K.J. & C.M.F. Lohmann 1994: Detection of magnetic inclination angle by sea turtles: a possible mechanism for determining latitude. – *J. Exp. Biol.* 194: 23-32.

Lohmann, K.J., P. Luschi & G.C. Hays 2008. Goal navigation and island-finding in sea turtles. – j. Exp. Mar. Biol. Ecol. 356: 83-95

This clear survey refers to many of the papers above. According to the Abstract “- a reasonable hypothesis is that sea turtles use multiple cues to navigate in the marine environment, perhaps relying on a magnetic map to navigate into the vicinity of a distant target and then use non-magnetic cues to guide themselves to the final goal”. Thus the paper seems a Lohmann/Luschi-mixture with dominance of the former.

Wiltschko, W., H. Ford, U. Munro, M. Winklhofer & R. Wiltschko 2007. Magnetite-based magnetoreception: the effect of repeated pulsing on the orientation of migratory birds. – J. Comp. Physiol. A 193: 515-522.

Together with the findings of R. Wiltschko et al. (2007) on the influence of wavelength and intensity of light on migratory orientation, the pulse-paper of W. Wiltschko et al. (2007) add to the general confusion/complexity. Furthermore (as in the newts of Phillips and friends) there seems to be some interaction/inter-connection between the two kinds of magnetoreceptions.

The indoor orientation at sunset time of Tasmanian Silvereyes trapped in the wintering area around Armidale, NSW, Australia and tested during spring was southerly (grand mean vector based on 5-6 individual headings $198^\circ - 0.93^{***}$, $n = 12$).

When a strong magnetic pulse (“intensity $0.5T$ and a duration of about $4-5ms$ ”) was applied the subsequent orientation on the first evening shifted 127° CCW (sample mean vector $71^\circ - 0.64^{**}$). Such a significant (about 90°) CW or CCW response following a strong magnetic pulse is well known – at least in adult birds and Silvereyes (W. Wiltschko et al. 1997). After disorientation on evenings 2, 4 and 6 following the pulse, the sample mean vector approaches southerly significance on evening 8, and attains southerly significance on evenings 10 and 12 after the pulse. This development in orientation following a single strong pulse is well known from earlier experiments (Munro et al. 1997, W. Wiltschko & R. Wiltschko 1995, W. Wiltschko et al. 1994, W. Wiltschko et al. 1997, 1998).

The new approach is to give the recovered birds a second pulse on day 16. This time the normal southerly spring orientation is already significant on the second evening (and in fact fairly close to already on the very first evening; sample mean vector $190^\circ - 0.42$, $n = 11$).

W. Wiltschko et al. (2007) give a lot of discussion and speculation for “explaining” this new result in terms of the receptor mechanism and the motivational state. However, together with the well known temporal development following the first pulse (at least in the Silvereye), the responses are considered to originate in a **magnetic navigational map system**. W. Wiltschko et al. (2007) write “- - the observation that the pulse affected only experienced birds, but not inexperienced youngsters (Munro et al. 1997) points to a learned system like the navigation ‘map’ (see Perdeck 1958), the part of the navigational system that indicates position”.

Clearly, the implicit scenario of the W. Wiltschko et al. (2007) is that the (experienced) birds (in their experiments) display **magnetic gradient navigation** from Armidale towards Tasmania, but something goes wrong during the first week or so – at least following the first pulse – when a **magnetic gradient-value of the map changes and slowly recovers**. Clearly, W. Wiltschko et al. (2007) are not thinking in magnetic compasses, i.e. neither a polarized nor the inclination-based magnetic compasses for alignment of the map nor a light-based magnetic compass reference for compass orientation in the standard direction).

Furthermore, Wiltschko et al. (1998) emphasize that the orientation change towards E of adult Silvereyes in both spring and autumn following the same oriented magnetic pulse is an indication that a navigational gradient/coordinate is involved and not just simple compass orientation. If the latter the changes in orientation spring/autumn should had been CW/CCW or CCW/CW. W. et al (1998) write “In both seasons, despite the 180° difference in migratory direction, adult silvereyes responded to the pulse with oriented behaviour towards east. This is in agreement with an effect on the position finding system, because the same pulse treatment should induce the same changes, leading to a similar response”. For a superficial consideration this argumentation seems reasonable. However, in Australia no magnetic gradients are oriented about E/W (clearly the declination could not be involved as the indoor birds have no possibility for establishing the direction towards geographical N).

I am not convinced that this Wiltschkonean scenario is the correct one. 1) Perhaps the birds are not navigating but only carry out simple compass orientation/one-direction orientation. The problem here is that following the traditional scenario of the Wiltsckos we all pretend to know and accept that the magnetic compass for carrying out simple compass/one-direction orientation is light/retina-based and not influenced by strong magnetic pulses. Another possibility is that **the magnetic compass for aligning of the magnetic gradients is of the polarity type**. However, Wiltschko & Wiltschko (1995a, pp. 64-65) do not seem to share this scenario of Phillips (1986): Newts from about 20 km E-ESE of the laboratory displayed **shoreward** orientation established in reference to a magnetic inclination compass – as inversion of the inclination (without changing the polarity) in the test-phase leads to an orientation shifted about 180° . On the other hand, the **homeward** orientation is unaffected by the inversion and this leads Phillips to the obvious conclusion that the newts for navigation make use of a compass steered by the polarity of the magnetic vector – with the words of Phillips “a distinct magnetoreception

pathway with polar response properties is involved in homing and is possibly linked in some way to the navigational map". The comments of mine should be that the navigational map of the newts needs (integration with) a compass and this compass is a polarity compass if the gradients are based in the magnetic field. When the homeward orientation is unaffected this also means that there is no transference from the polarity compass to an inclination/axial compass in the test-phase.

Finally, there is a problem with this generalization of the experiments with Silvereyes: Garden Warblers and Robins seemingly react somewhat different (Wiltschko & Wiltschko 1995b, and W. Wiltschko et al. 1997).

Munro, U., J.A. Munro, J.B. Phillips & W. Wiltschko 1997: Effect of light and pulse magnetisation on different magnetoreception systems in a migratory bird. – Australian Journal of Zoology 45: 189-198.

Phillips, J.B. 1986. Two magnetoreception pathways in a migratory salamander. Science 233, 765–767.

Wiltschko, R. & W. Wiltschko 1995a: Magnetic orientation in animals. – Springer, Berlin.

Wiltschko, W. & R. Wiltschko 1995b: Migratory orientation of European Robins is affected by the wavelength of light as well as by a magnetic pulse. – J. Comp. Physiol. A 177: 363-369.

Wiltschko, W., U. Munro, R.C. Beason, H. Ford & R. Wiltschko 1994: A magnetic pulse leads to a temporary deflection in the orientation of migratory birds. – Experientia 50: 697-700.

Wiltschko, W., U. Munro & R. Wiltschko 1997: Magnetoreception in migratory birds: Light-mediated and magnetite-mediated processes? – RIN 1997: Orientation & Navigation – birds, humans and other animals. The Royal Institut of Navigation, Oxford 1997, pp. 1-1 – 1-9.

Wiltschko, W., U. Munro, H. Ford & R. Wiltschko 1998: Effect of a magnetic pulse on the orientation of Silvereyes, *Zosterops l. lateralis*, during spring migration. – J. Exp. Biol. 201: 3257-3261.

Wiltschko, R., K Stapput, H.-J. Bischof & W. Wiltschko 2007: Light-dependent magnetoreception in birds: increasing intensity of monochromatic light changes the nature of the response. – Frontiers in Zoology 4: 5.

Beason, R.C., R. Wiltschko and W. Wiltschko 1997. Pigeon homing: Effects of magnetic pulses on initial orientation. *Auk* 114, 405–415.

"ABSTRACT. – After treatment with a 0.5-T magnetic pulse, homing pigeons (*Columbia livia*) showed headings that deviated from the mean direction of untreated controls. (1) These deviations ranged up to 60° and were most pronounced at distances beyond 100 km from the home loft. (2) When birds treated with a pulse south–anterior and birds treated with south–left were released together, they deviated to opposite sides of the untreated controls, indicating that the direction of the pulse determined its specific effects. (3) On the day of treatment, a south–left pulse caused a significantly larger deflection than a south–anterior pulse. (4) The duration of the effects was not entirely clear; the number of releases with significant deflections seemed to decrease as time passed and birds had made additional homing flights. (5) Our findings agree with the hypothesis that magnetite–based receptors provide the pigeons with orientational information. (6) The manifestations of the effect indicate that the magnetic "map" rather than the magnetic compass is involved. (7) Apparently, the pulse alters map information".

The markings (1) to (7) are mine and considered below.

Commentary to Beason et al. (1997).

In short almost nothing – but probably a little more than may be ascribed to stochastic variation only – happens. With this marginal evidence on the influence of the applied magnetic pulses on the homeward orientation and by means of various enforcements and biased announcements – and referring to a multivariate navigational system and by means of explaining everything in a positive direction and explaining all negative things away –Beason et al. create a story/"scientific paper".

Put a little differently. Something happens. This something cannot be ascribed to the magnetic compass mechanism, because as we all know (we do?) that the compass mechanism is light/retina based and therefore should not be influenced by the pulse treatment (furthermore, the exp.s are carried out under the sun where the dominant sun compass is working). An obvious problem, is that there is no expectation of what should happen following the two different magnetic pulses. The authors simply wait to see what happen, then overrate these tendencies and finally make an interpretation in favour of magnetic map navigation. This is simply bad science.

Beason et al. never set up a clear prediction of what to expect following the two different kind of pulses. Are we expecting small directional deflections, about 90° deflections (as in case of experienced passerine migrants) or increased or decreased sample concentrations or degree of homeward orientations? Nothing is clear in beforehand and the authors just cling to some more or less significant tendencies and these are then interpreted in the maximal way for the influence of a magnetic map factor.

(1). The 60° is almost true. 59° is correct, whereas the mean numerical deviation are 32° and 17° for controls/south–left (n = 10) and controls/south–anterior (n = 21), resp. (in these as in the following only data from Table 1 and Table 2 (once before homers) are included. The corresponding mean vectors are 13° – 0.843*** and –2° – 0.933***, resp. Clearly, there is no directional differences between the controls and the two sets of exp.s,

i.e. the orientations of the latter are within the 5% confidence limits of the controls. Furthermore, the difference (15°) between the two sample mean vectors is not significant (W/W/test, $0.10 < P < 20$). It is true that the deflections were significantly most pronounced at distances beyond 100 km from the home loft – in case of controls/south–anterior. The opposite tendency is found in controls/south–left.

(2). This is right. However, the deviation was sometimes to the right and sometimes to the left and there was no systems in the deviations in relation to the homeward direction. Comparing south–left/south–anterior 4 deviations are to the left and 6 to the right. The mean vector is $27^\circ - 0.535$ ($n = 10$). The deviation from 0° is far from statistical significance (confidence interval test). Now one of deviations (180°) was rooted in a very small mean vector concentration (0.21) in south–anterior. If this deviation is omitted the mean vector becomes $23^\circ - 0.695^{**}$ ($n = 9$). Also in this case the deviation from 0° is far from statistical significance. Summing up, Beason et al. is right in their statement but their focus is one–sided and insufficient. By using a more reasonable data treatment their point crumbles.

(3). This is right 5 times out of 6 (Tab.1). Including Tab.2 (once before homers) the statement is right 7 times out of 10. Clearly, this is not a significant tendency.

(4). There is no such general tendency. Considering south–anterior and omitting the three deviations (-102° , -36° , -127°) based on very small sample concentrations (0.10, 0.26, 0.21) the correlations coefficient (Pearson) is 0.087 ($n = 27$), whereas the corr.coeff. (-0.682^{***} , $n = 14$) is significant in the subsample of south–left. Taken the two subsamples together there is no significant tendency ($r = -0.217$, $n = 41$).

(5). This is not clear, because Beason et al. make no clear predictions.

(6). This is not clear. As far as I know a light/retina dependent magnetic compass is strongly inferred in passerine birds but not in pigeons. Perhaps pigeons has a compass based on magnetite – or both kind of magnetic compasses as claimed in newts (Phillips, J.B. 1986. Two magnetoreception pathways in a migratory salamander. *Science* 233, 765–767(see also the book of Wiltschko & Wiltschko 1995 p.64 og 65)

(7). We do not know. Perhaps.

Fleissner, G., B. Stahl, P. Thalau, G. Falkenberg & G. Fleissner 2008: A novel concept of Fe-mineral-based magnetoreception: histological and physicochemical data from the upper beak of homing pigeons. – Naturwissenschaften DOI 10.1007/s00114-007-0236-0

The **Abstract** starts with the “fact”: “*Animals make use of the Earth`s magnetic field for navigation - - -*”, and “*Our recent results from histology and X-ray analyses support the hypothesis that delicate iron-containing structures in the skin of the upper beak of homing pigeons might serve as a biological magnetometer. Histology has revealed various iron sites within dendrites of the trigeminal nerve, their arrangement along strands of axons, the existence of three dendritic fields in each side of the beak with specific 3D-orientations, and the bilateral symmetry of the whole system*”. The Abstract ends with “*Due to its 3D architecture and physiochemical nature, the dendritic system should be able to separately sense the three vector components of the Earth`s local field,*

simultaneously---allowing birds to detect their geographic position by the magnetic vector, i.e., amplitude and direction of the local magnetic field, irrespective of the animal's posture or movement and photoreception”.

It seems like the Germans have finally solved the mystery of pigeon-homing/navigation.

However, shortly afterwards Winklhofer & Kirschvink (2008) as a comment to the paper above concluded *“In this short communication we point out that the novel concept propagated is based on conclusions that are not supported by data and, in fact, stand in contradiction to previously published crystallographic and magnetic data”.*

So it looks like the usual mixture between fact and fiction within the field of magnetic gradient navigation.

Winklhofer, M. & J. Kirschvink 2008: Does avian magnetoreception rely on both magnetite and maghemite. – arXiv:0805.2249v1

Final statement of JR

First, I am not at all against magnetic orientation or navigation. In fact, I am convinced that the magnetic field of the Earth has significant and important influences on the orientation of migrant birds, pigeons and other animals.

Second, this is not a crusade against persons like Phillips who I do not know personally, nor the Wiltschkos who I like very much as persons.

However, I have a strong feeling (and I think also a lot of documentation) that **magnetic gradient navigation** is an overrated and misunderstood phenomenon. Furthermore, the significance of **magnetic compass orientation** is biased and certainly needs reconsideration.

During recent years the significance and importance of magnetic orientation and navigation has developed in the scientific journals and public media to be a magic concept/policy almost on the level of global warming or biodiversity. This means that we now have a large and increasing tribe of magnetic people who share their object and belief in an upward spiral of confirmation and confidence. Even the weakest possible signal of magnetic navigation (e.g. Wiltschko & Wiltschko 2003 and Mora et al.2004) is now published in the leading and distinguished scientific journals. Clearly the area is open for invasion of fiction and data adaptations. Very often the conclusions are not supported by the experimental results, and everything is explained or explained away and always to the positive side of magnetic importance and significance (e.g. Walker 1998, Beason et al. 1997*). People are not following common rules for logical treatment and models are proposed which first **describe** and then later on are used to **explain** a certain system or mechanism (e.g. Phillips et al. 2002, Fig.2).

Beason, R.C., R. Wiltschko and W. Wiltschko 1997. Pigeon homing: Effects of magnetic pulses on initial orientation. Auk 114, 405–415.

Mora, C.V., M. Davison, J.M. Wild and M.M. Walker 2004. Magnetoreception and its trigeminal mediation in the homing pigeons. - Nature 432: 508-511.

Walker, M.M. 1998: On a wing and a vector: a model for magnetic navigation by homing pigeons. J. Theor. Biol. 192: 342-349.

Wiltschko, R. and W. Wiltschko 2003. Orientation behavior of homing pigeons at the Gernsheim anomaly. Behav Ecol Sociobiol 54, 562–572

Tab 1: Orientation of controls. **9 Aug.:** 277° - 0.751* (7), PF (GW), 8/8 (but sunset visible), **10 Aug.:** 352° - 0.676* (7), GW (PF), changing 8-6-8/8 (sunset visible), **12 Aug.:** Looks bimodal ESE/NW-NNW, 51° - 0.324 (6), or 125°/305° - 0.485, PF, changing 7-8/8 (sunset visible). **13 Aug.:** 119°/299° - 0.603 (6), WT (GW, PF), changing 3 to 8/8 (+ sunset), **14 Aug.:** 333° - 0.807* (6), PF, GW, 1/8, **17 Aug.:** 143° - 0.556 (8), PF, 0/8, **18 Aug.:** 206°/26° - 0.570 (7), PF, 0/8, **20 Aug.:** Appears bimodal E/SSW-SW, 54°/234° - 0.409 (7), PF, changing 5 to 8/8, **21 Aug.:** 174° - 0.641 (6), PF, changing 7-8/8 to 3-4/8 (+ sunset), **22 Aug.:** 194° - 0.467 (5), PF, GW, changing 8 to 3/8 (no visible sunset), **4 Sep.:** bimodal 190° (2)/340° (1), BC, PF, 0-1/8, **5 Sep.:** 96° - 0.662 (6), RB, RS, PF (BC), 0/8. PF = Pied Flycatcher, GW = Garden Warbler, WT = Whitethroat *Sylvia communis*, BC = Blackcap *Sylvia atricapilla*, RB = Robin.

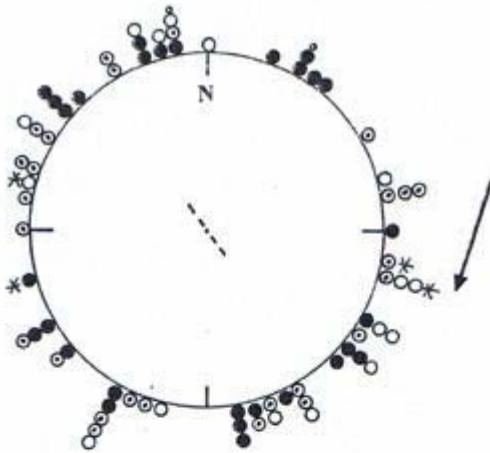


Fig.1: The orientations of all **controls** 9 Aug. through 5 Sep. shows dis-orientation: $171^\circ - 0.042$ ($n = 73$), or including two bimodal orientations and after doubling the angles $143^\circ/323^\circ - 0.171$ ($n = 75$). The length and steepness of the arrow to the right is a measure of the magnetic intensity and inclination, respectively.

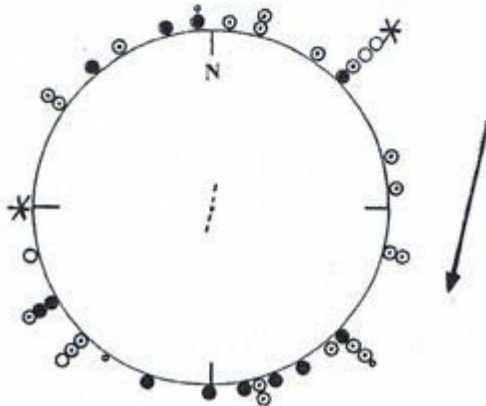


Fig.2: The orientations of all the **N-exps.**: $127^\circ - 0.085$ ($n = 41$), or – after doubling the angles - $11^\circ/191^\circ - 0.135$ ($n = 41$)

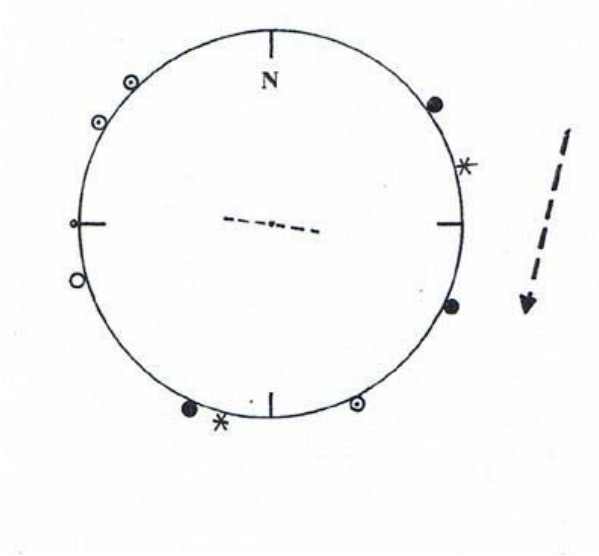


Fig.3: The orientations of all the **field no.4 birds** (presumably N-exp.s, therefore the broken arrow): $249^\circ - 0.244$ ($n = 8$), or – after doubling the angles - $99^\circ/279^\circ - 0.242$ ($n = 8$).

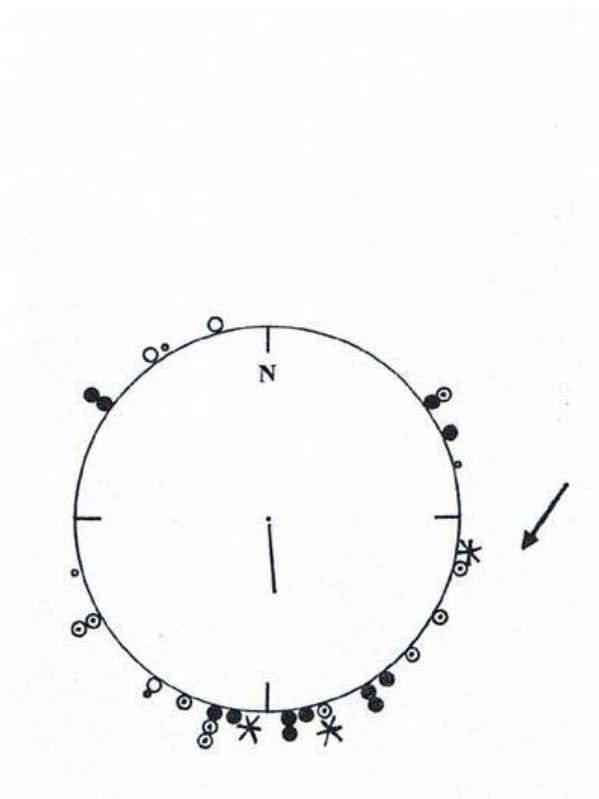


Fig.4: The orientations of all the **S-exp.s** lumped together displayed a significant orientation: $174^\circ - 0.382^{**}$ ($n = 32$).

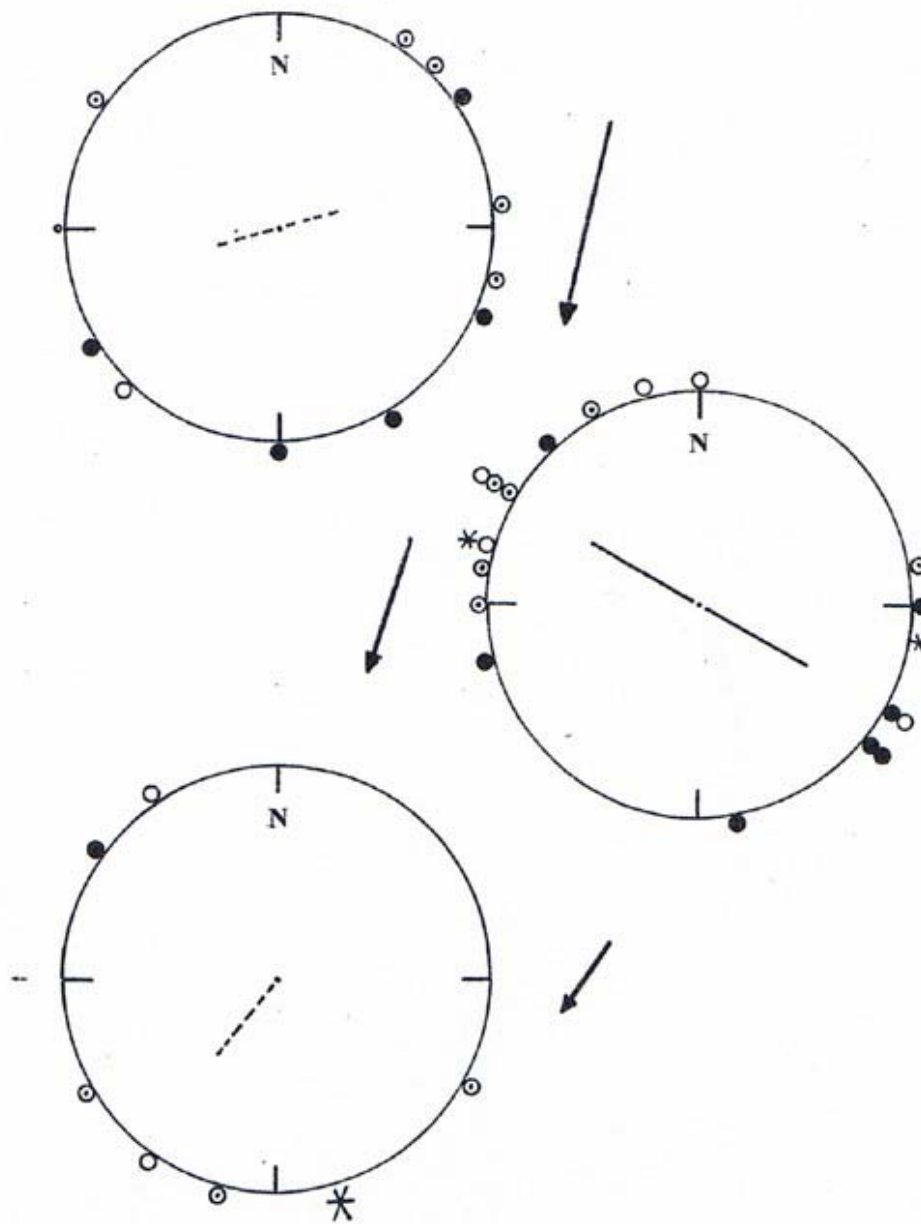


Fig.5: The orientations 9, 12 and 13 August. The controls are shown in the middle figure, (mean vector of $299^{\circ}/119^{\circ} - 0.590^{***}$, $n = 19$), the N-exp.s (including the no.4 birds) in the upper figure ($73^{\circ}/253^{\circ} - 0.282$, $n = 12$), and the S-exp.s in the lower figure ($223^{\circ} - 0.462$, $n = 7$).

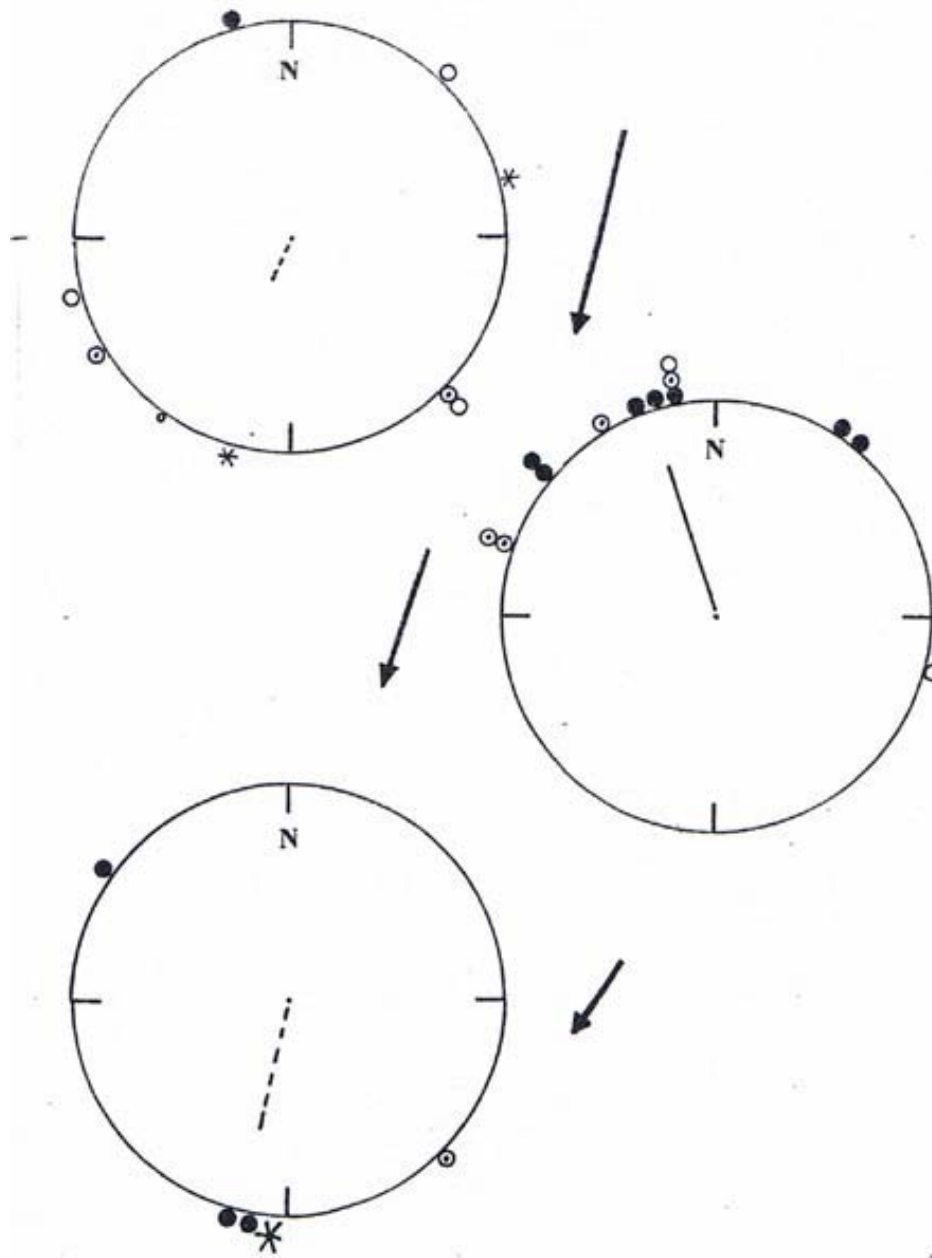


Fig.6: The orientations 10 and 14 August. The controls shown in the middle figure were reversely oriented: $342^\circ - 0.728^{***}$ ($n = 13$). The N-exp.s (upper figure) were disoriented: $202^\circ - 0.204$ ($n = 7$). The S-exp.s (lower figure) were insignificantly oriented in about the standard direction: $192^\circ - 0.629$ ($n = 5$).

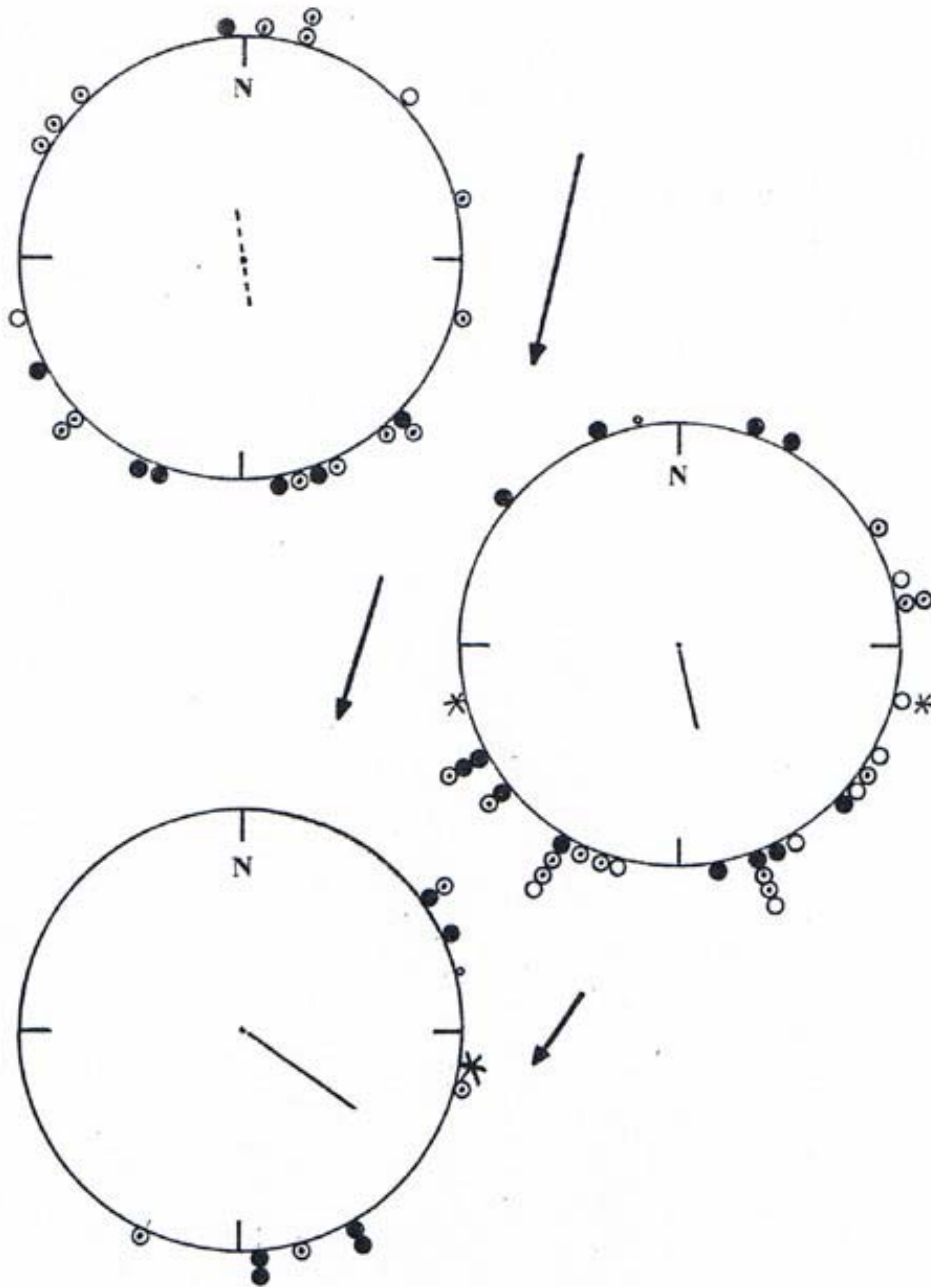


Fig.7: The orientations 17 through 22 August. The controls shown in the middle figure were significantly oriented: $168^\circ - 0.396^{**}$ ($n = 33$). The N-exp.s (upper figure) were insignificantly oriented: $172^\circ/352^\circ - 0.206$ ($n = 23$). The S-exp.s (lower figure) were significantly oriented: $123^\circ - 0.643^{**}$ ($n = 12$).

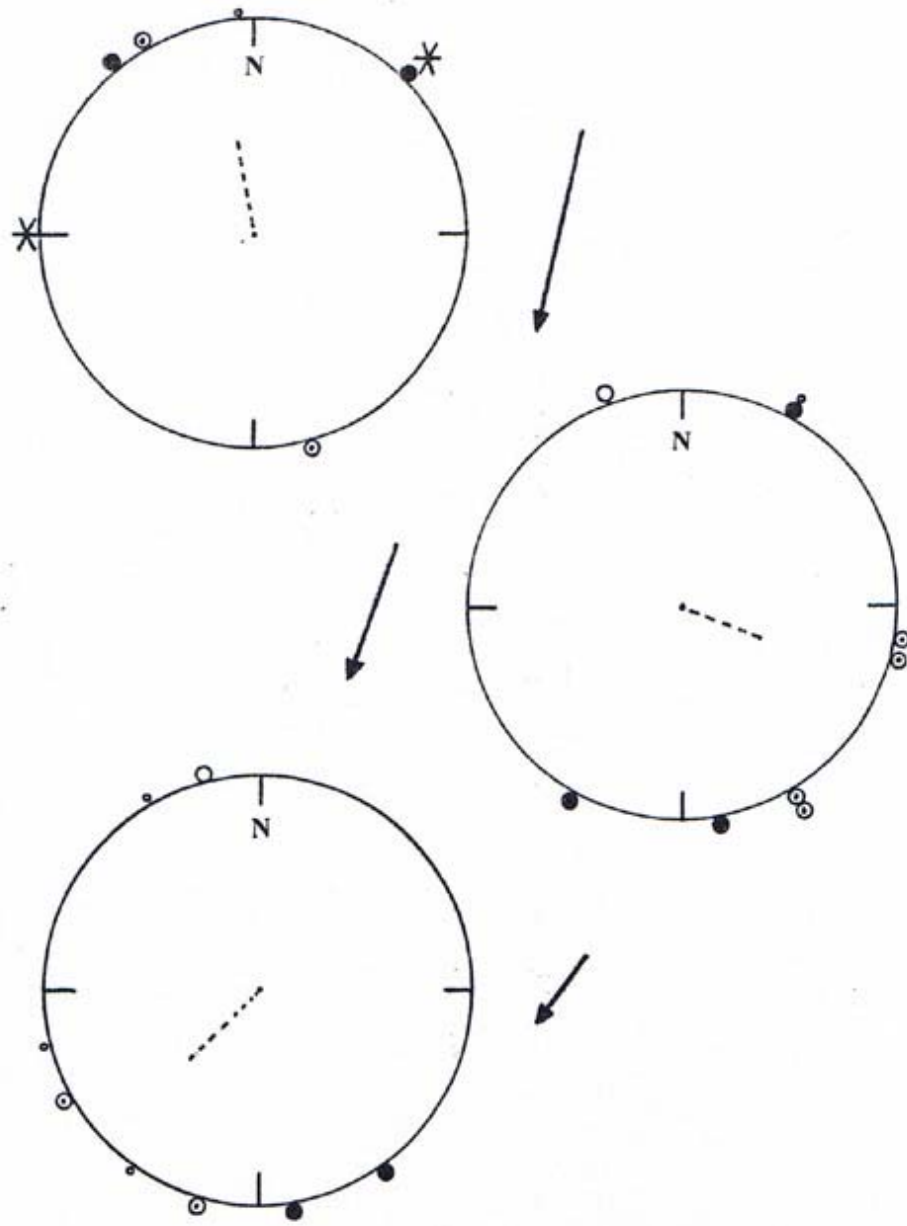


Fig.8: The orientations 4 and 5 September. The controls (middle figure) were disoriented: $112^\circ - 0.394$ ($n = 9$).. The N-exp.s (upper figure) were insignificantly northerly: $350^\circ - 0.447$ ($n = 7$), whereas the S-exp.s (lower figure) were insignificantly oriented in about the standard direction: $227^\circ - 0.459$ ($n = 8$).