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Magnetic field distortions produced by protective cages around sea turtle nests: unintended consequences for orientation and navigation?

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Abstract

The Earth's magnetic field plays an important role in the orientation and navigation of sea turtles. Galvanized steel wire cages are often placed over turtle nests to protect them from predators, but the material typically used in cages has a high magnetic permeability and might therefore affect the nearby field. Here we report magnetometer measurements indicating that standard nest cages do indeed significantly alter the local magnetic field in the area where eggs develop. The mean change in total intensity was 26% at a level corresponding to the top of the egg chamber and 5% at a level corresponding to the bottom. Similarly, the mean change in field inclination was 20% for the top level and 4% for the bottom. In principle, the altered magnetic environment might affect subsequent magnetic orientation and navigation behavior in several ways, although whether turtles that develop in an unnatural magnetic field actually suffer navigational impairment has not yet been studied. Constructing protective cages out of magnetically inert materials provides a way to deter predators without risking unintended behavioral consequences of distorting the ambient field.
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1. Introduction

The Earth's magnetic field plays an important role in the orientation and navigation of sea turtles (reviewed by Lohmann and Lohmann, 1998, 2003). Hatchling loggerheads have a well-developed magnetic compass that enables them to maintain consistent headings in the absence of other cues (Lohmann, 1991; Light et al., 1993; Irwin and Lohmann, 2003), an ability that presumably helps guide them offshore during their initial seaward migration (Lohmann and Lohmann, 1996a). In addition, sea turtles are sensitive to small differences in field inclination (Lohmann and Lohmann, 1994) and intensity (Lohmann and Lohmann, 1996b) and can exploit the regional fields that exist in different locations along their migratory route as navigational markers (Lohmann et al., 2001). Finally, it has been hypothesized, though not yet demonstrated, that young turtles imprint on the magnetic fields that mark their natal beaches and use this information to return to the same region as adults (Lohmann et al., 1999).

Despite the prominent role that magnetism appears to play in the sensory world of sea turtles, little thought has been given to how anthropogenic influences in general, and conservation practices in particular, might disrupt their natural magnetic environment. A first step toward assessing possible risks is to identify circumstances in which turtles are exposed to unnatural fields that might interfere with the development of normal magnetosensory abilities or prevent the detection of important magnetic information.

A common conservation practice on many sea turtle nesting beaches is to cover turtle nests with galvanized wire mesh cages or screens to protect the eggs from raccoons, foxes, and other predators (Addison and

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Henricy, 1994; Jordan, 1994; Ratnaswamy et al., 1997; Yerli et al., 1997; Kinsella et al., 1998). Here we report, however, that wire mesh cages significantly alter the magnetic field around the eggs and developing embryos. Whether such field distortions affect the development of the turtles' navigational system is not yet known. In principle, however, the field changes produced by cages might produce effects on subsequent orientation ability and navigational performance, particularly if turtles do indeed imprint on the magnetic features of their natal beaches. The results underscore the need to consider carefully the sensory biology of animals when designing conservation practices.

2. Materials and methods

To assess the effect of protective cages on the ambient magnetic field, we measured the field distortions produced by ten cages used on south Florida beaches. Each cage was constructed in accordance with a standard cube design (Addison, 1997) and had dimensions of approximately $60 \times 60 \times 60$ cm (Fig. 1). The local magnetic field within the test area was uniform with an intensity of 39.7 μT and an inclination angle of 58.7°.

For each measurement, we placed the probe of an Applied Physics System 520 tri-axial digital fluxgate magnetometer flat on a non-magnetic platform and aligned the probe with the north–south axis of the Earth's magnetic field. We then adjusted the magnetometer offset readings for all three axes to zero so that we could measure the changes caused by the presence of a cage. The cage was then placed on a second non-magnetic platform above the probe. The cage was positioned so that one side was aligned parallel to the north–south axis and one of the test points (Fig. 1) was directly above the magnetometer probe. The magnetic field that resulted from the presence of the cage was then recorded. Because a field value could be either positive or negative depending on the direction the cage was facing, we used the absolute value of all measurements in calculations. The change in magnetic field intensity and inclination angle was then calculated for each point using standard vector addition.

For each cage, measurements were made on two horizontal planes. The first was immediately beneath the cage and the second was 25 cm below. These two levels correspond approximately to the top and bottom of a typical egg chamber, provided that the cage is placed correctly (Dodd, 1988). At each level, a series of nine measurements were made; these included one in the center, one in each of the four corners, and one in the midpoint of each of the four sides (Fig. 1).

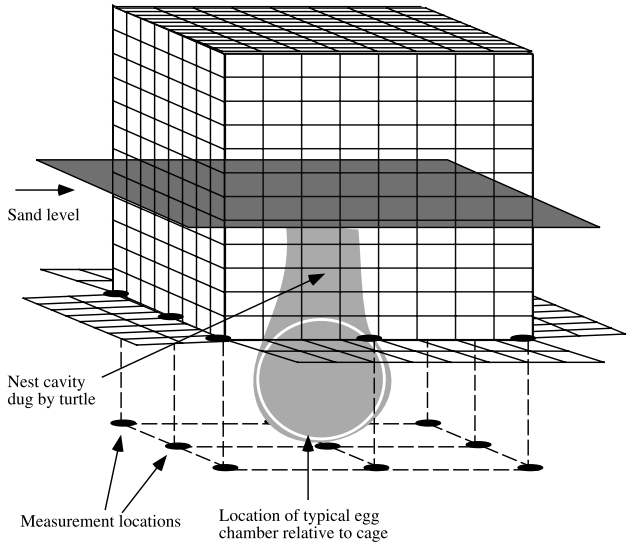

Fig. 1. Diagram of a protective wire cage and measurement locations. Measurements of the magnetic field were made 25 cm beneath each cage at a series of locations; these included sites below the center, each corner and the mid point of each side and immediately below each cage at the same 9 points. Galvanized wire protective cages are placed approximately 25 cm deep in the sand over a turtle nest. The measurement depths therefore corresponded to the average top and bottom of a loggerhead egg chamber (Dodd, 1988).

3. Results

All cages altered the local magnetic field at every position tested (Table 1). Immediately below the cages, the mean change in magnetic field intensity was 10.4 $\mu T \pm 2.4$ S.D. (26% of the ambient field) and the mean change in inclination angle was $11.6° \pm 3.0°$ S.D. (20% of the ambient field). At the level 25 cm below the cages the mean change in field intensity was $2.0\ \mu T \pm 0.4$ S.D. (5% of the ambient field) and the mean change in inclination angle was $2.2° \pm 0.7$ S.D. (4% of the ambient field).

4. Discussion

All of the cages we tested altered the inclination angle and intensity of the magnetic field at all of the test locations. Changes to the local field decreased with distance from the cages but were present throughout the area where turtle eggs develop (Table 1).

Whether developing in an altered magnetic field affects the subsequent behavior of turtles is not known. In principle, however, the field in which turtles develop might influence subsequent orientation and navigation in at least three ways. First, it might disrupt magnetic compass orientation of hatchling turtles during their offshore migration. Second, it might alter the responses of turtles to regional magnetic fields that normally serve as open-ocean navigational markers. Finally, it

Table 1
Mean and standard deviation of magnetic field changes caused by cages ($n = 10$)

	Change in intensity (μT)	% of Earth's field	Change in inclination angle (degrees)	% of Earth's field
Immediately beneath the cages				
Overall mean change	10.4 ± 2.4	26	11.6 ± 3.0	20
Mean side change	10.2 ± 2.6	26	9.9 ± 4.3	17
Mean corner change	12.3 ± 3.6	31	15.7 ± 5.1	27
Mean center change	3.0 ± 1.6	8	1.8 ± 1.6	3
25 cm below the cages				
Overall mean change	2.0 ± 0.4	5	2.2 ± 0.7	4
Mean side change	1.8 ± 0.4	5	2.0 ± 0.7	3
Mean corner change	2.3 ± 0.6	6	2.6 ± 0.8	4
Mean center change	1.1 ± 0.4	3	1.1 ± 0.7	2

Measurements were made beneath the center, each corner, and the mid-point of each side both immediately below and 25 cm below each cage. These depths correspond approximately to the top and bottom of an egg chamber if a cage is placed correctly.

might prevent turtles from relocating their natal beaches as adults. Below we briefly discuss each of these possibilities.

Hatchling loggerheads can orient using the Earth's magnetic field and are thought to use this ability as they migrate offshore soon after emerging from nests (Lohmann, 1991; Lohmann and Lohmann, 1998; Irwin and Lohmann, 2003). A similar magnetic compass sense exists in young migratory birds (reviewed by Wiltschko and Wiltschko, 1995). However, young birds that were raised in magnetic fields that differed from those they normally encounter in their natal areas oriented differently during their first migration than did birds raised in the natural field (Bingman, 1983; Weindler et al., 1995; Weindler et al., 1996). Thus, the possibility exists that sea turtles raised in fields distorted by protective cages may also orient differently during their first migration than do those that develop under natural magnetic conditions. If so, then deviations from the normal migratory direction might delay hatchlings in nearshore waters where predators are abundant or deplete their limited energy stores before they reach their normal offshore destination (Wyneken and Salmon, 1992).

A second possibility is that developing in distorted fields might alter the responses of young turtles to regional fields that serve as navigational markers along the migratory route. Young loggerheads from the east coast of Florida remain in the developmental habitat of the North Atlantic gyre for a period of years, during which time many cross to the far eastern side of the Atlantic before returning to the vicinity of the North American coast (Carr, 1987). Loggerhead hatchlings perceive different magnetic field intensities (Lohmann and Lohmann, 1996b) and inclination angles (Lohmann and Lohmann, 1994) that they encounter in different locations along the migratory route. In addition, turtles respond to the regional magnetic fields marking widely separated locations by swimming in directions that presumably help them remain within the gyre and advance along the migratory pathway (Lohmann et al., 2001). It is not known, however, if turtles respond to the actual values of the field or to *differences* between the fields that exists at the natal beach site and sites in the open ocean. For example, a turtle might recognize a particular regional field either because it has an inclination angle of 60°, or because the field has an inclination angle that is 3° greater than the 57° inclination at the natal beach. If turtles use the latter strategy, then those that develop in unnatural fields may begin life with erroneous information that might cause subsequent navigational errors.

A final possibility is that turtles that develop in distorted fields might encounter difficulty in navigating to their natal beaches years later as adults. Adult turtles are known to return to their natal areas to nest (Meylan et al., 1990; Bowen et al., 1993). It has been hypothesized, although not yet demonstrated, that turtles imprint on the magnetic features of their natal beach and use magnetic cues to return to the same geographic region later in life (Lohmann and Lohmann, 1994; Lohmann et al., 1999). If such a process occurs, then turtles that develop in a distorted magnetic environment might imprint on magnetic fields that either do not exist in nature or else occur at distant geographic locations. For example, in south Florida a change of 1° of inclination angle represents a geographic change of approximately 150 km. Given that fields in many locations beneath the cages were distorted by far greater amounts (Table 1), a turtle developing beneath a cage in south Florida might hypothetically imprint on a field that exists in an oceanic location hundreds or thousands of kilometers away, or one that exists nowhere at all. Such turtles might encounter difficulties in relocating appropriate nesting areas as adults.

Thus, in principle, the magnetic field distortions caused by wire cages might affect sea turtles in several different ways and at several different life history stages. We emphasize, however, that no experimental evidence

presently exists to confirm or refute the hypothesis that turtles are adversely affected by developing in distorted magnetic fields. Caging and screening appear to be effective means of reducing nest depredation in many geographic areas (Addison and Henricy, 1994; Jordan, 1994; Ratnaswamy et al., 1997; Yerli et al., 1997; Kinsella et al., 1998). Thus, for now, a decision about whether to use cages on a given nesting beach must balance the hypothetical possibility of adverse behavioral effects against the known threat of nest depredation. A solution worth considering is to retain cages and screens where necessary, but to avoid the use of galvanized steel wire and instead construct protective enclosures out of magnetically-inert metal, wood, or plastic materials.

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