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Cetacean live stranding sites relate to geomagnetic topography

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Summary

Live strandings of cetaceans are *exclusively* mistakes made by animals attempting to use geomagnetic topography for orientation.

Introduction

Cetacean orientation and navigation strategies are not well known (reviewed by Gaskin 1982), mainly because the release and recapture experiments which have revealed so much about these skills in other animals (examples in Schmidt-Koenig & Keeton 1978) are impractical. Essentially, however, deductions are made from such experiments through the types of mistakes made by the animals. One of the most serious orientation mistakes for an aquatic animal is to run into land, or to strand. Analysis of stranding records should therefore reveal information about the kinds of mistakes involved and hence explain orientation strategies in general.

Materials and methods

The most comprehensive cetacean stranding records are those for the United Kingdom, kept by the British Museum (Natural History). They cover many types of events, in total about 3000 over the past 70 years. From the original report files, all cases involving live animals (active strandings) and all finds of decomposed bodies (passive strandings) were noted. The 137 live strandings included 29 mass strandings (3 or more animals), 95 single and pair strandings and 13 mass near-strandings. The latter are cases with all the preliminary features of a live mass stranding, but ending with the escape of all or most animals. 968 cases where animals were clearly reported to have been dead for some time when first washed up were found. The position of each event was plotted on large scale maps and the geographical, hydrographical and geophysical characteristics of the sites compared.

Results

The live strandings are grouped at certain places, the most prominent of which are named in the small map in Figure 1, not scattered along the coast. Most sites are distinct from sites with finds of decomposed bodies (Figure 1, detailed maps) and do not reflect any known reporting biases (Easton *et al.* 1982). In contrast, the decomposed bodies are more generally distributed, the positions reflecting tides and currents, distribution of observers (represented by distribution of Coastguard establishments) and, in some cases, fishing activity. The live stranding sites have no common local geography, 49 are on steep rocky shores bordered by deep water, while 88 are on the more gently shelving shores usually associated with live strandings (Dudok van Heel 1962, Geraci 1978, Geraci & St Aubin 1979, Best 1982). The sites do not have any other features in common (Banner, Collins & Massie 1979), except for local geomagnetic topography.

Geomagnetic topography maps show how the magnetic field of the earth is distorted by local geology. Areas with rocks containing materials with magnetic properties such as iron increase the total field in their vicinity above the average or datum for that point on the earth's surface. Such areas are known as high anomalies. Areas with other geological properties distort the field below datum, forming low anomalies. The rocks causing anomalies may be at the surface of the earth or up to several kilometres below. The geomagnetic topography therefore, is not necessarily related to geography or to bathymetry (Vacquier 1972). For the present purpose it is convenient to refer to the geomagnetic topography in the same terms as geographical topography, with high anomalies as the hills and low anomalies as the valleys. Just like geographical topography (or bathymetry), very little of the earth's surface has completely flat geomagnetic topography. Figure 2, which follows this convention by representing the geomagnetic topography of the sea areas around the British Isles in three dimensions, demonstrates the general phenomenon.

Live strandings occur *exclusively* where relative low anomalies or valleys in the local geomagnetic field cross the coast or are blocked by islands. The sites are not necessarily at the exact minimum of the valley, but are arranged as if the animals—rather like a hill-walker crossing broken country—had

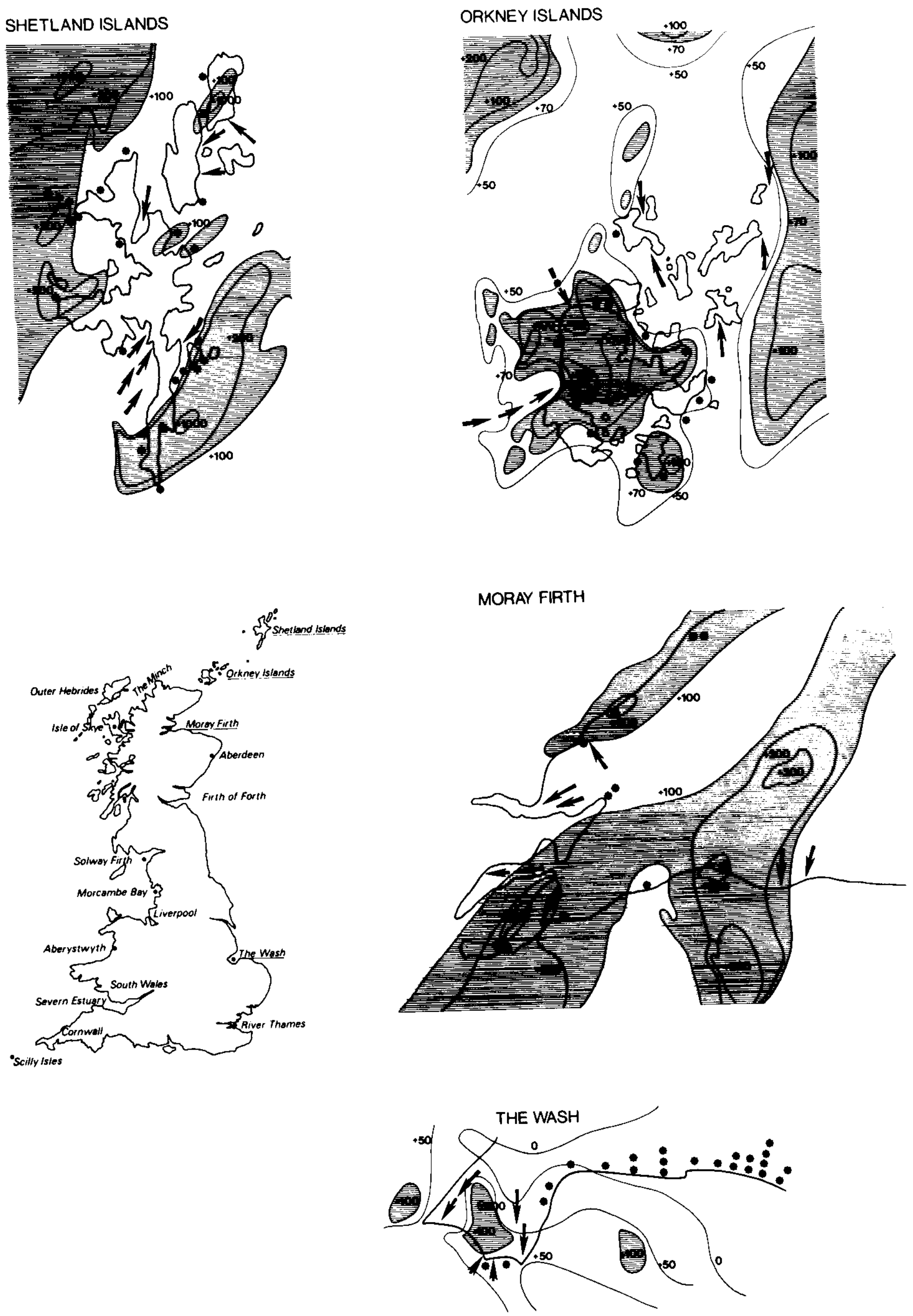

Figure 1. Major live stranding sites are named on the small map; the dots are intended to aid location of small areas. Four sites are shown in more detail. The tips of the arrows indicate sites of individual live strandings, circles indicate finds of decomposed bodies. Symbols follow each other where there is more than one event at a given site. The important areas of high local geomagnetic anomaly are hatched: contours are marked in nano Tesla. Even on this scale, the topography is complicated, therefore for simplicity, only a minimum of contours above datum are shown and those below datum omitted. No single contour adequately characterizes all sites, indicating that it is the shape of the field, not the absolute field strength which is of importance for the distribution of live strandings. In Shetland, the live strandings are in two groups, north and south of the main island, just where animals attempting to pass along the valley would meet land, whereas the decomposed bodies are scattered widely around the coasts. Many Orkney live strandings are associated with the small islands blocking the eastern valley. (This valley does not show well on the scale of Figure 2.) The Moray Firth area is a good example of a long valley leading to and across land (compare Figure 2). In the Wash, the live strandings are near the only high anomaly and its associated valley in a rather geomagnetically featureless area.

Figure 2. Local geomagnetic field for sea areas around the British Isles. Adapted from maps compiled by the Institute of Geological Sciences (1972) and displayed using the ASPEX computer graphics package. The land and areas outside the survey are shown as zero or datum. It is important to note that the land/sea border represents an artificial division as far as geomagnetic topography is concerned (see Figure 1). To display the topography on a single map, the data have been smoothed and truncated. No survey was available for the sea areas off the east coast. The angle of projection was chosen both to give an overall impression of the field and to illustrate as many as possible of the sites not shown in Figure 1.

tried to follow lines avoiding high peaks and unnecessary descents into the deepest valleys. By comparing the small map in Figure 1 with the 3-dimensional presentation in Figure 2, a general impression of this arrangement may be gained. From the north, 9 live strandings are in Shetland, 9 in Orkney and there are 3 more associated with small valleys ending in high anomalies along the north Scottish coast between Orkney and The Minch. The Moray Firth has 8. In the Firth of Forth there are 13 plus another in a side-branch of the valley at Aberdeen. In the Wash itself there are 6, plus another 5 along a northern extension of that valley. In the Thames area there are 14 live strandings. There is a large valley extending from the continental shelf edge which branches at the tip of Cornwall. The southern branch runs up to the Channel while the northern branch extends to the Severn Estuary and south Wales (Vacquier 1972). Sixteen of the live strandings are in the main Cornwall/Scilly Isles valley with another 9 in the northern branch to the Severn estuary and south Wales. There are 3 live strandings in the Aberystwyth valley and 5 in the Liverpool valley with another 6 in the extension to Morcambe Bay. Three incidents are associated with the Solway Firth valley and 3 with the valley running down The Minch which is blocked by the Isle of Skye and continues east of the Outer Hebrides.

Fourteen live strandings occur on that part of the east coast lacking offshore survey data, and although the sites look similar with respect to geomagnetic topography, further consideration of these cases must await publication of the appropriate maps. The remaining live strandings are associated with small geomagnetic topographical features, mainly on the south coast between the Thames and Cornwall. In general, about half of the sites are valleys ending with high coastal anomalies. 85% of near-strandings occur at sites without such high anomalies.

Analysis of the species involved confirms that inshore species (eg harbour porpoise *Phocoena phocoena* 6%) have few live strandings in comparison with the number of decomposed bodies found whereas offshore species (eg false killer whale *Pseudorca crassidens* 67%) live strand much more frequently (Geraci 1978, Geraci & St Aubin 1979, Best 1982, Sergeant 1982).

The live stranding sites are not characterized by absolute field strength, but by the relative topography, as can be seen from the detailed maps in Figure 1. Even within a small area no one contour describes every site, but a general strategy of valley following (even where the equivalent of a fairly high mountain pass is involved) does cover all cases. This interpretation can be expressed in a simpler way, by describing the animals as following the geomagnetic contours. Thus areas with contours perpendicular to the coast should be associated with live strandings, while areas with magnetic contours parallel to the coast should not. All the live stranding points for which survey data are available are where contours are perpendicular to the coast (the scale of the Figures is not fine enough to demonstrate this in all cases), but the relative general frequency of such sites is of interest in estimating the importance of such a relationship. The coast from the Wash to the Solway Firth was described in terms of 5 km grid squares for the preparation of Figure 2. This area covers 70 live strandings, 672 decomposed strandings and 292 Coastguard establishments. (The rest of the coast was too complex or contained too few strandings for adequate analysis in this manner or lacked survey data.) Each of the 600 grid squares was scored as to whether the geomagnetic contours were in general perpendicular (P–407 or 68%) or parallel (H–193 or 32%) to the coast in that area. Grid squares containing one or more live strandings were 100% P (55); those containing one or more decomposed strandings 37% H (95), 63% P (162) and those containing Coastguard establishments (representing observer distribution) 35% H (65), 65% P (119). The relationship of live strandings to the perpendicular contour squares (chi sq. 47, 1 df, $p > 0.00001$) was most unlikely to have been a chance result, while the distribution of squares containing passive strandings (chi sq. 1.15, 1 df, $p = 0.25$) or coastguard establishments (chi sq. 0.43, 1 df, $p = 0.5$) was not different from the general distribution of P and H squares. From the same grid, but counting events per 20 squares (to give adequate cell frequencies for analysis) a correlation of 0.73 (28 df, $p < 0.01$) was obtained between decomposed strandings and Coastguard establishments. Live strandings were not correlated to decomposed strandings ($r = 0.25$) nor to Coastguard establishments ($r = 0.10$). The same 600 grid squares were also assessed for average geomagnetic field strength in 50 nano Tesla steps (again to give adequate cell frequencies for analysis). The range was from −200 to +300 nano Tesla. Correlations were calculated between the total frequency distribution of grid squares in terms of field strength and the frequency distributions of those containing one or more live strandings, decomposed strandings or Coastguard establishments. All three categories were highly correlated ($p < 0.001$) with the general field and with each other. However, this relationship is spurious and results from the fact that all three categories are at sites with geomagnetic field variations. This can be demonstrated by calculating partial correlations, controlling for geomagnetic field distribution. The correlation between the distributions of live and decomposed strandings now falls from 0.9391 to −0.1984 and that between live strandings and Coastguard establishments falls from 0.8938 to −0.1252. The correlation between the distribution of decomposed strandings and Coastguard establishments (0.9855) is hardly affected (0.9697). Clearly, live strandings are distributed only in relation to the local geomagnetic field. Decomposed strandings are not, although they are strongly related to observer distribution as represented by Coastguard establishments.

Discussion

The distinction between active strandings and passive strandings emerged during this analysis. Initially, only mass strandings—defined as events involving three or more animals regardless of condition—were considered, because such obvious events are least subject to reporting biases (Easton *et al.* 1982). Several such mass strandings were not related to the geomagnetic topography: these were groups of decomposed animals washed up together. The same pattern was found when the samples were extended to include single and pair strandings and mass near strandings; only incidents involving live animals were consistently related to geomagnetic topography.

Similar use of geomagnetic topography is known, particularly from work with pigeons (for example Walcott 1978, Graue 1965, Talkington 1967, Wagner 1976, Gould 1980), which clearly indicates that flight paths tend to be parallel to geomagnetic contours and to follow valleys in local geomagnetic topography, with avoidance of, and disorientation by, high anomalies. Since 11 of the 13 mass near-strandings occurred at sites without high coastal anomalies, it would appear that the cetacean system for following geomagnetic topography is also adversely affected by high anomalies (Walcott 1978).

The topography, being related to the local geology, does not end or usually change at the land-sea border: the coast is an artificial barrier. In the open ocean, however, the geomagnetic anomalies, particularly the regular groups produced by continental drift, provide a clear and safe set of permanent orientation cues (Vacquier 1972). The geomagnetic field would appear to be the most convenient permanent cue for an aquatic animal, obviating any need to surface to observe astronomical or geographical (Gaskin 1982, Kirschvink 1982) cues. Echo-location (Dudok van Heel 1962) and other sound production, often cited as a major cetacean orientation system, now appears only suitable for very short ranges (Gaskin 1982, Geraci 1978).

Distribution, migration and some strandings of cetaceans have been linked to movements of food species (Gaskin 1982, Geraci 1978, Geraci & St Aubin 1979). But although less well documented, fish seem to make the same kinds of orientation mistakes as cetaceans. Many cetacean stranding sites are also fish (including sharks and squid) stranding sites eg Wellfleet, Cape Cod, USA (Geraci & St Aubin 1979), an area with the same kind of geomagnetic topography as the British live stranding sites. If both the predator and the food species use the same orientation system, they are likely to use the same routes.

Since offshore species live strand more frequently than inshore species, live stranded animals are likely to be outside their usual areas and hence exposed, perhaps for the first time, to the problems involved in following geomagnetic topography in coastal waters. Inshore species could learn the topography, but they must use such cues since they live strand at the same sites. In most cases even animals unfamiliar with the area are obviously able to deal with the problems: live strandings are very rare events. In 70 years only 137 incidents have been recorded for 14 100 km of coastline. In comparison with almost 3000 strandings of all types so far recorded, and with the hundreds of thousands of animals alive at sea, live strandings, or major orientation mistakes, are rare indeed. It is remarkable that when mistakes are made, they are all related to the geomagnetic topography. This must either imply that the animals are unable to use any other orientation information at that time—perhaps because of illness—or that they have not paid sufficient attention to other available information. In the latter context, the mass near strandings may well represent last-moment error corrections. The geomagnetic topography thus appears to be dangerous to inexperienced animals in coastal waters, but not overwhelmingly so—otherwise there would be more live strandings.

If strandings really do represent mistakes through inappropriate following of a general orientation strategy, it is important to show that such a strategy is in fact used by animals in normal circumstances. Comparing what is known of cetacean migration routes with maps of oceanic geomagnetic anomalies (Vacquier 1972, Lockyer & Brown 1981), some similarity is obvious. I have also recently been informed that tracks of radio-tagged wild animals tend to follow geomagnetic topography (Evans 1984). This is encouraging, since the strategy suggested by the strandings is simple and robust (and has recently been confirmed for other areas (Dawson *et al.* in press, Cornwell-Huston 1984, Fraser 1984, Kirschvink 1984). Employing neither compass nor grid map, it is proof against secular geomagnetic field variations (even polar reversals) and demands only sensitivity to relative field strength sufficient to keep higher field to one side and lower to the other during travel (although there must, of course, be points where animals move perpendicular to contours in order to change from one valley system to the next). The ability to learn and remember such routes would increase the efficiency of the system. Such a strategy is applicable all over the earth, and it is possible that further study will reveal many more animals using geomagnetic topography as a basic aid to their travels (Klinowska 1983).

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