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Long-Term Exposure of Several Marine Benthic Animals to Static Magnetic Fields

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Electrical currents in underwater sea cables could induce magnetic fields. The sea cables lie on or within the sea bottom and this is the living area for many invertebrate and vertebrate species. North Sea prawn *Crangon crangon* (Crustacea, Decapoda), round crab *Rhithropanopeus harrisii* (Crustacea, Brachyura), glacial relict isopod *Saduria entomon* (Crustacea, Isopoda), blue mussel *Mytilus edulis* (Bivalvia), and young flounder *Plathichthys flesus* (Pisces) were exposed to a static magnetic field (MF) of 3.7 mT for several weeks. The results showed no differences in survival between experimental and control animals. Mussels *M. edulis* were kept under static magnetic field conditions for 3 months during their reproductive period in spring. The determination of gonad index and condition index revealed no significant differences to the control group. Bioelectromagnetics 25:498–502, 2004.

Key words: ***Crangon crangon*; *Rhithropanopeus harrisii*; *Saduria entomon*; *Mytilus edulis*; *Plathichthys flesus*; undersea cable**

INTRODUCTION

In the southern Baltic Sea, many underwater sea cables lie on or within a few tens of centimeters of the sea bottom. Some of these cables transmit electrical current by using high voltage direct current. These electrical currents could induce magnetic fields (MFs) with intensities up to 3.5 milliTesla (mT). MF higher than the natural geomagnetic values of approximately 50 μT is detectable within a radius of 6 m of the cable axis. The bottom of the Baltic Sea is the living area for many invertebrate and vertebrate species. The epi- and endobenthic, mobile and sessile fauna could come into contact with these artificial MFs for indefinite times. The number of underwater sea cables and therefore the area of the bottom influenced by magnetic fields could be increased in future by the construction of numerous offshore wind parks.

The influence of geomagnetic fields on orientation is evident for many marine species [Barnwell and Brown, 1964; Arendse and Kruyswijk, 1981; Lohmann, 1985; Lohmann and Willows, 1987; Lohmann and Lohmann, 1996; Taylor, 1986]. Many biological materials, for example, cells, blood, and gametes, are magneticly susceptible [Senftle and Hambright, 1969]. A few studies showed that long term exposure to steady magnetic fields could physiologically influence biological systems [Brewer, 1979; Marsh et al., 1982]. Our knowledge of long term effects of magnetic fields on marine animals is restricted to the works of Karlsen and Aristharkhov [1985] and Aristharkhov et al. [1988].

The aim of this study was to show whether exposure to magnetostatic field for several weeks could influence the survival rate and fitness of common benthic animals of the Baltic Sea.

MATERIALS AND METHODS

Test organisms were the crustacea *Crangon crangon*, *Rhithropanopeus harrisii*, and *Saduria entomon*; the mussel *Mytilus edulis*; and the flounder *Plathichthys flesus*.

C. crangon and *Plathichthys flesus* were collected in August, 2002, in the western Baltic Sea at a eulittoral station (54°01.562 N, 011°32.541 E) by using a fishing

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net with a 0.5 mm mesh size and 0.5 m in width. *R. harrisii* were obtained from docks in Gager harbor (Greifswalder Bodden; 54°18.747 N, 013°40.933 E) in September 2002 by hand sampling. *M. edulis* were collected from docks in Warnemuende harbor (54°10.901 N, 012°05.218 E) in October 2002 and February 2003 by hand sampling.

After transport to the laboratory the animals were kept in plastic aquaria, 145 × 240 × 150 mm, filled with about 10 mm natural sediment, except in the case of *M. edulis*, which had no sediment. Animals were fed twice a week with small pieces of different kinds of fish. *M. edulis* given a *Pavlova lutheri* suspension (Prymnesiophyceae) twice a week. All studies were performed in a cold room at 10 °C, a salinity of 10%, and a light/dark cycle of 13.5 h/10.5 h.

The gonad index and a condition index of *M. edulis* in both control and test were determined at monthly intervals from 6 February to 13 May 2003 [Bayne and Thompson, 1970].

Ten *M. edulis* were taken from the aquaria and a piece of mantle tissue was examined for determination of the gonad index. The tissue was squashed on a slide and graded into the following stages: (0) the mantle is thin and no gametes are visible; (1) mantle is thick but no gametes are observable; (2) sperm and oocytes are observed in the squash, but the sperm are not active in seawater and the seminal vesicle of the oocyte does not disappear on release into seawater; (3) the gametes are activated on release into seawater. The numbers of animals that fall into each category were multiplied by the number of the stage and the sum divided by the number of animals in the sample. This yields an index that ranges from 0 for unripe or spawned animals to 3 for ripe animals in the pre-spawning stage.

Six *M. edulis* were taken from the aquaria to test condition and opened by cutting the adductor muscle. They were placed in an oven at 50 °C for 10 min and then weighed (total weight). The flesh was then excised and weighed (flesh weight). Flesh weight as a percentage of total weight was used as an estimate of condition.

Magnetic Coil System

The investigations were performed with a Helmholtz coil system (ELWE GmbH, Germany) consisting of a vertical pair of coils connected in series, each coil 300 mm in diameter. The distance between the coils was 150 mm. A DC power source DF 3010 10A generated a variable static MF up to 3.7 mT. The artificial MF was considerably higher than the geomagnetic total field of about 49 μT at Rostock (54°10.756 N, 012°04.804 E) with horizontal intensity of about 18 μT and a vertical component of about 46 μT. The magnetic flux density (*B*) was measured by using a Model Koshava 4-magnetometer (Wuntronic GmbH, Germany). The maximal magnetic flux density was generated at the coil planes and values decreased to the middle between both coils. A mean magnetic intensity was calculated, and values between the two single coils ranged about ±8% around the mean. All measurements were performed at the axial center of the coil system, where MF is highly homogenous.

Statistical Analysis

Statistical analysis was performed by the U-test of Mann and Withney. A statistical level of $P < 0.05$ was considered significant.

RESULTS

Long-Term Survival

C. crangon were kept under the test condition (3.7 mT static magnetic field) for 7 weeks. The number of animals decreased linearly after the first week from 10 animals to 1–2 animals at the end (Fig. 1a). In the first 3 weeks, no differences could be observed between the three test groups and two control groups. During the later course of the experiment, the survival of test animals was slightly higher than control group. These differences were not statistically significant.

Three test groups and one control group (eight animals each) of *S. entomon* were tested for 3 months. After the first week, the survival of the test group became lower than control (Fig. 1b) and remained lower to the end of experiment: the mean number of survivors decreased to five animals. The first and only animal of the control group died between the 40th and 60th day. After 2 months, a mean of six test animals survived, but after 83 days the mean mortality increased till the end of experiment. These differences were not statistically significant.

Three test groups and one control group (each 10 animals) of *R. harrisii* were cultured under test conditions for 57 days (Fig. 1c). No animals died in the first month. Only animal of the control group died between the 30th and 40th day. The mean number of survivors in the test group decreased linearly after the first month. At the end of the experiment, a mean of eight test animals survived. There is no statistical significance in these differences.

Three test groups of each 20 individuals of *M. edulis* were compared against two control groups. Most of the animals survived for 5 weeks in both groups (Fig. 1d). At the end of the experiment, the mean number of survivors in test group (18 animals) was higher than in control (16 animals). But these differences were not statistically significant.

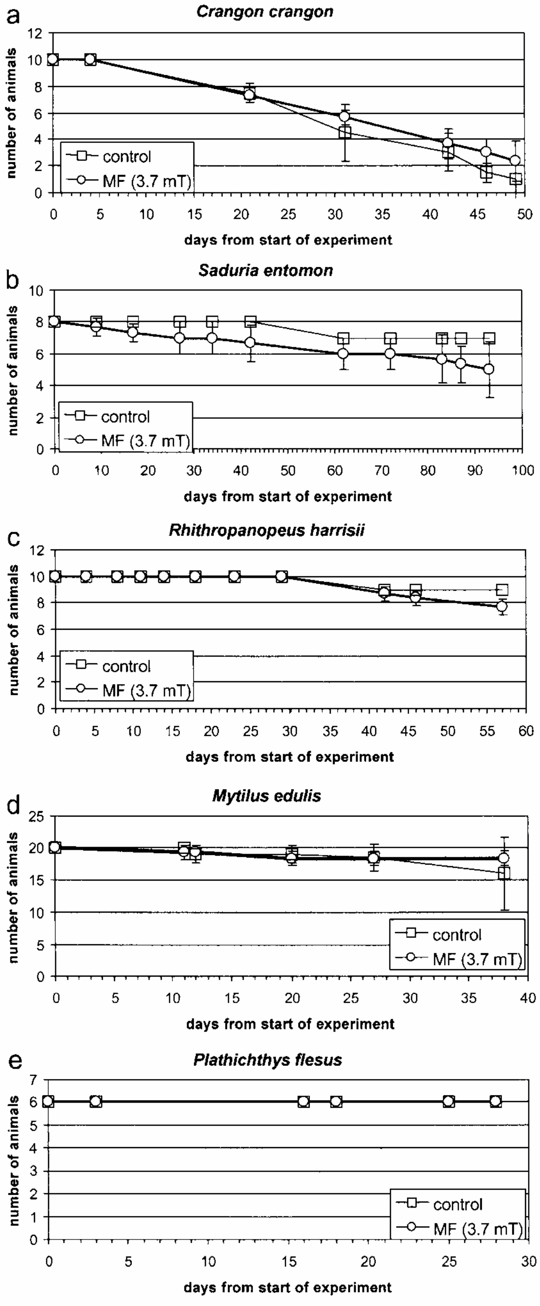

Fig. 1. Survival of prawn *Crangon crangon* (**a**), isopod *Saduria entomon* (**b**), crab *Rhithropanopeus harrisii* (**c**), mussel *Mytilus edulis* (**d**), and young flounder *Plathichthys flesus* (**e**) during experimental duration in control cultures (squares) and with static magnetic field conditions (circles). Mean number of animals ± SD.

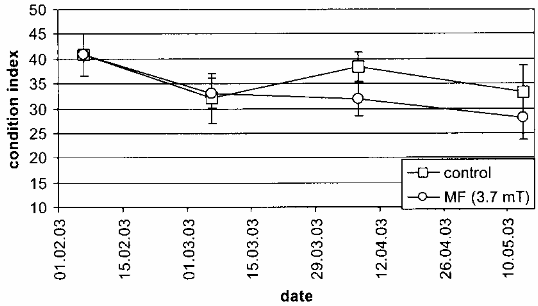

Fig. 2. Condition index of mussel *Mytilus edulis* during experimental duration in control cultures (squares) and with static magnetic field conditions (circles). Mean ± SD.

Three test groups each of six individuals of young flounder *Plathichthys flesus* (2–5 cm in length) were compared against one control group. All animals survived the experimental time of 4 weeks (Fig. 1e).

Fitness

At the beginning of the experiment, the condition index (CI) (flesh weight as a percentage of total weight) of *M. edulis* was about 40. CI declined in control and test groups to about 33 (Fig. 2). At the end of the experiment, the condition of test animals decreased further to a CI of about 28, whereas the CI of the control group remained over 33. But these differences were not statistically significant.

Gonad index (GI) was about 2.2 at the beginning of the experiment, which revealed that all animals were in the gonad development reproductive stage. GI reached 2.6 one month later and 2.7 after two and three months, showing further development of the gametes (Fig. 3). There was no visible difference between the control and test groups.

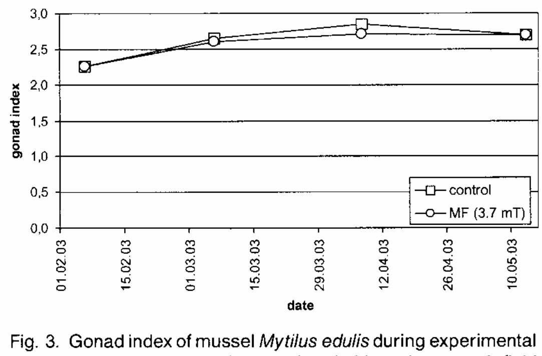

Fig. 3. Gonad index of mussel *Mytilus edulis* during experimental duration in control cultures (squares) and with static magnetic field conditions (circles). Mean ± SD.

DISCUSSION

We tested the survival of prawn *Crangon crangon*, crab *Rhithropanopeus harrisii*, isopod *Saduria entomon*, mussel *Mytilus edulis*, and young flounder *Plathichthys flesus* during exposure to a static magnetic field of 3.7 mT for several weeks. All species are able to survive test conditions for at least 1 month and up to 3 months in case of the isopod *S. entomon*. For all experiments, there were only relatively low, not statistically significant variations between control and test animals.

The exploration of sea areas for construction of offshore wind parks in the North Sea and the Baltic leads to a higher amount of sea cables in connection with wiring of these plants. Energy transport could be performed by means of direct (DC) or alternating current (AC). An artificial magnetic field of different strength results during operation in both cases. The values of artificial magnetic fields of these cables could reach approximately 3700 μT and are therefore about 70 times higher than the natural values of approximately 50 μT in the southern Baltic.

The influence of static magnetic fields on aquatic organisms has been little studied. In the hydroid *Clava multicornis*, authors tested the production of zooids at 10, 20, and 40 mT for 12 days [Karlsen and Aristharkhov, 1985]. The results show faster reproduction at 10 and 20 mT than in control and at 40 mT. Investigations on *M. edulis* also showed effects of magnetic fields on biochemical parameters [Aristharkhov et al., 1988]. Magnetic field action of 5.8, 8, and 80 mT leads, regardless of the induction value, to 20% decrease in hydration and 15% decrease in amine nitrogen values. Magnetic values of both studies are two to 20 times higher than in our investigation.

Guppies *Lebistes reticulatus* survived a continuous magnetic treatment of 50 mT for 200 days and three generations [Brewer, 1979]. In the first generation, the brood size was normal but the gestation period was reduced by 30%. The second generation had an average reduction of spawn rate of 50%; and in the third generation, reproduction was completely inhibited as long as the fish remained within the magnetic field. This study revealed a clearly visible influence of an artificial magnetic field. Field strengths are considerably higher than in our study and therefore not comparable.

In the terrestrial arthropod, the American cockroach *Periplaneta americana*, Russel [1969] determined a significant inhibition in spontaneous activity of neurons. Magnetic field of 66 mT was used in this study to expose the ganglion for 90 min. In this case, a short term effect could be shown, but the tested magnetic values are also much higher. Marsh et al. [1982] performed a study on human workers who were exposed to a steady magnetic field up to 1.4 mT during working day. Physiological parameters were measured, and the authors found a slight increase in blood pressure and a decrease in white cell count.

There was a sharp decline in CI during first weeks. This drop was also observed in other *M. edulis* laboratory cultures [Bayne and Thompson, 1970].

Maintaining of animals in captivity for the purpose of cultivation in artificial or semi-artificial conditions leads to physiological responses of the individuals to abnormal environments. Cultivation conditions represent a stress on the animal that may be reflected in an altered maintenance energy requirement for the animal and consequent physiological responses. Therefore, a higher mortality of animals in captivity could be observed compared to natural environments.

The increase of GI describes the growth of gametes. Our results of development of gonad index and condition index revealed no influence of the artificial magnetic field on fitness and production of gametes to *M. edulis*. Bayne and Thompson [1970] ascertained a different GI in the presence of a stress factor (unfed *vs.* fed animals). An external magnetic field like that in our investigation did not cause similar results.

Studies of possible effects of static magnetic field have been carried out in different systematic groups and with diverse experimental conditions. It has shown that externally applied magnetic fields could interact with biological systems to produce detectable changes. Often these findings are very slight differences from control groups and clear-cut effects of steady magnetic fields are missing. Nevertheless our study produced new information for some marine animals.

The practicable possibility for wiring offshore wind parks by means of alternating current sea cable gives a basis for further studies, because static magnetic field from DC cables is not comparable with time-varying fields from AC power transmission.

REFERENCES

Arendse MC, Kruyswijk CJ. 1981. Orientation of *Talitrus saltator* to magnetic fields. Neth J Sea Res 15(1):23–32.

Aristharkhov VM, Arkhipova GV, Pashkova GK. 1988. Changes in common mussel biochemical parameters at combined action of hypoxia, temperature and magnetic field. Seria biologisceskaja 2:238–245.

Barnwell FH, Brown FA. 1964. Responses of planarians and snails. In: Barnothy MF, editor. Biological effects of magnetic field, Vol. 1. New York, NY: Plenum Press, pp 263–278.

Bayne BL, Thompson RJ. 1970. Some physiological consequences of keeping *Mytilus edulis* in the laboratory. Helgoländer wiss. Meeresunters 20:526–552.

Brewer HB. 1979. Some preliminary studies of the effects of a static magnetic field on the life cycle of the *Lebistes reticulatus* (Guppy). Biophys J 28:305–314.

Karlsen AG, Aristharkhov VM. 1985. The effect of constant magnetic field on the rate of morphogenesis in a hydroid *Clava multicornis* (Forskal). Zurnal obscej biologii 5:686–690.

Lohmann KJ. 1985. Geomagnetic field detection by the western Atlantic spiny lobster, *Panulirus argus*. Mar Behav Physiol 12(1):1–17.

Lohmann KJ, Lohmann CMF. 1996. Orientation and open-sea navigation in sea turtles. J Exp Biol 199(1):73–81.

Lohmann KJ, Willows AOD. 1987. Lunar-modulated geomagnetic orientation by a marine mollusk. Science (Wash) 235(4786): 331–333.

Marsh JL, Armstrong TJ, Jacobson AP, Smith RG. 1982. Health effect of occupational exposure to steady magnetic fields. Am Ind Hyg Assoc J 43(6):387–394.

Russel DR. 1969. Effect of a constant magnetic field on invertebrate neurons. In: Barnothy MF, editor. Biological effects of magnetic fields, Vol. 2. New York, NY: Plenum Press, pp 227–232.

Senftle FE, Hambright WP. 1969. Magnetic susceptibility of biological materials. In Barnothy MF, editor. Biological effects of magnetic field, Vol. 2. New York, NY: Plenum Press, pp 261–306.

Taylor PB. 1986. Experimental evidence for geomagnetic orientation in juvenile salmon, *Oncorhynchus tshawytscha* Walbaum. J Fish Biol 28(4):607–623.