EFFECTS OF MAGNETIC FIELD ON THE DIRECTION OF FISH MOVEMENT UNDER NATURAL CONDITIONS

Krzysztof Formicki, Adam Tański, Aleksander Winnicki

Department of Fish Anatomy and Embryology, Agricultural University of Szczecin, ul. K. Królewicza 4, 71-550 Szczecin, Poland, E-mail: kformicki@fish.ar.szczecin.pl

ABSTRACT

Locomotory responses of fish in the presence of magnetic fields generated by permanent magnets placed in stationary fishing gear (fyke nets) were studied. The fyke nets used allowed the fish to select the direction in which to move: into the trap or out of it. Three fyke sets were used. A set consisted of two fykes equipped with permanent magnets (with their N or S poles directed into the trap) and one rigged with magnet dummies; the latter fyke served as a control in each set. The traps were deployed in the littoral of a lake; each time the fykes were emptied, their deployment site was changed by moving them along the shore to another site. The magnet-rigged fyke nets were found to catch by 70-90% more fish (depending on the magnet pole location) than control traps, rigged with magnet dummies, did.

INTRODUCTION

Behavioural responses of living organisms are greatly dependent on the ambient magnetic field [1, 2, 3]. Magnetic field has been found to affect the selection of migration direction and navigation of numerous fish species. Such responses were found in, i.a., salmonids such as smolts and juveniles of sockeye salmon (*Oncorhynchus nerka*) [4, 5, 6, 7], chum salmon (*O. keta*) [7, 8], rainbow trout (*O. mykiss*) [9, 10], Atlantic salmon (*Salmo salar*) [11, 12], European eel (*Anguilla anguilla*) [13, 14], American eel (*A. rostrata*) [11, 15], yellowfin tuna (*Thunnus albacares*) [16] as well as sharks and rays [17]. The fish are capable of developing conditional responses to magnetic field [16, 18]. Those findings prompted us to study responses of adult freshwater fish to magnetic field generated by permanent magnets placed in stationary fish traps (fyke nets). Trapping fishing gear offer a fish a possibility to choose a behaviour mode, i.e., a fish may either move into the trap or turn back and swim away. To study this behaviour, it was decided to rig the fyke net openings with magnets to find our if, and how, the artificially generated magnetic field would affect the number of actually trapped fish. Should the presence of magnets increase the number of fish caught, the results—in addition to providing new data on fish behavioural responses—would be of a practical importance as well.

MATERIALS AND METHODS

The study spanned the period of 3 years and was conducted in the vegetated littoral of an 80 hectare lake, oval in shape. The forest-surrounded lake is situated in a rural area, away from the nearest village. It is inhabited by more than 20 fish species.

During the experiment, the fish were caught with fyke nets, a type of stationary trapping fishing gear, 80 cm in height and 6 m in wing length, rigged with permanent magnets and their dummies (magnet imitations).

Three fyke sets were used. A set consisted of two fykes equipped with permanent magnets and one rigged with magnet dummies (control). The magnets and dummies were mounted to the net just behind the first and in front of the second ring of each trap in the following manner: 12 magnets had their S poles directed into the trap, while the 8 magnets mounted next to the second ring had their N poles facing into the trap. The magnets in the second fyke were arranged in the identical way, except that their poles showed a reverse orientation. The third trap, serving as a control, was rigged with magnet dummies identical in appearance as the actual magnets.

The magnets (Polfer, Warsaw) and their dummies were 11.6 mm diameter, 4.6 mm long cylinders. The magnetic field generated by a single magnet, perpendicularly to its surface, was 0.1 mT at a distance of 10 cm away from the poles, as measured with an HTM-12 halotronic teslameter (Institute of Telecommunications and Acoustics, Technical University of Wrocław).

Three sets of fykes, three fyke nets each were deployed in the lake, along the shore, their inlets facing the shore (the axis of symmetry was perpendicular to the shore). The fyke sets were deployed several hundred metres apart. The three fykes within a set were separated by a several metre distance from one another.

The deployment site of each fyke in a set was changed; they were moved clockwise following retrieval and fish collection. The fykes were emptied at 2-day intervals; at each retrieval, the number of fish trapped was recorded and the fish were identified to species. During the period of study, every set was retrieved 24 times, i.e., a total of 216 samples were examined.

The statistical treatment of data involved the χ^2 test run with the Statistica software.

RESULTS AND DISCUSSION

The study yielded a total of 2658 fish individuals belonging to various species. The controls (magnet dummy-rigged) fykes attracted 21.0% of all the fish caught. Those fykes rigged with inward-facing N pole magnets on the first ring were observed to have attracted 37.6% of all the fish caught, while 41.4% of all the fish were trapped by the fykes equipped with the inward-facing S pole magnets (Fig. 1A). The differences became still more evident when the number of fish caught by the magnet-rigged fykes is standardised by the number of fish trapped by the controls: the first and the second fyke type attracted 179.0 and 197.3% of the fish caught by the control, respectively (Fig. 1B). The differences with respect to the controls were statistically significant. In addition to the pike, eel, and burbot, the catches contained cyprinids and percids. The most pronounced response was observed among the cyprinids.

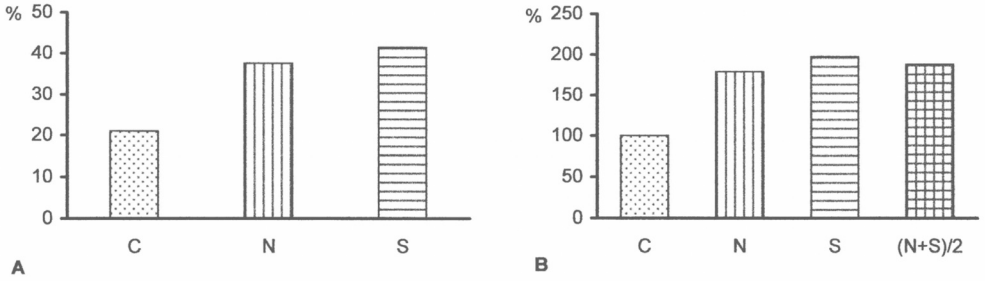

Fig. 1. Number of fish entering the fyke nets; C, control: traps rigged with constant magnet dummies; N, traps with inward-facing N poles of magnets mounted by the first ring; S, traps with inward-facing S poles of magnets mounted by the first ring; (N+S)/2 = mean of magnet-rigged traps; **A**, traps catches as proportion of all the fish caught; **B**, trap catches as standardised by the control trap catch (100%), ($\chi^2 = 157.16$, $p < 0.001$)

Having encountered an obstacle in the form of the fyke net wing when swimming freely in the lake littoral, the fish could choose a direction in which to proceed and either enter the trap or turn back and move away from it. It seems that the magnetic field generated by the magnets mounted around the fyke inlet induced the fish to move into the trap. A change in magnetic field direction near the second ring strengthened the response, as a result of which the fish moved on farther into the trap. Such a behavioural response is most probably related to the presence of a magnetic material in the fish body, as found in many species, not only those dwelling exclusively in the sea. The magnetic material was found in, i.a., *Thunnus albacares*, *T. alalunga*, *Sarda sarda* [19], *Clupea harengus* and *Scomber scombrus* [20], in species migrating from brackish to freshwater and back: *Oncorhynchus tschawytscha* [21], *O. nerka* [22, 23, 24], *O. keta* [25], *Anguilla anguilla* [26], and in species inhabiting inland water bodies: *Cyprinus carpio* and *Perca fluviatilis* [20].

ACKNOWLEDGEMENTS

The study was supported by the State Committee for Scientific Research grant No. 5 P06D 024 19.

REFERENCES

[1] T.S. Tenforde (ed.), *Magnetic Field Effect in Biological Systems*, Plenum Press, New York–London, 1979.
[2] M. Blank (ed.), *Electricity and Magnetism in Biology and Medicine*, San Francisco Press, San Francisco, 1993.
[3] R. Wiltschko and W. Wiltschko, *Magnetic orientation in animals*. Springer Verlag, Berlin, 1995.
[4] T.P. Quinn, "Evidence of celestial and magnetic compass orientation in lake migrating sockeye salmon fry", *J. Comp. Physiol.*, vol. 137A, pp. 243-248, 1980.

[5] T.P. Quinn, R.T. Merrill, and E.L. Brannon, "Magnetic field detection in sockeye salmon", *J. Exp. Zool.*, vol. 217, pp. 137-142, 1981.
[6] T.P. Quinn and E.L. Brannon, "The use of celestial and magnetic cues by orienting sockeye salmon smolts", *J. Comp. Physiol.*, vol. 147A, pp. 137-142, 1982.
[7] T.P. Quinn and C. Groot, "Orientation of chum salmon (*Oncorhynchus keta*) after internal and external magnetic field alteration", *Can. J. Fish. Aquat. Sci.*, vol. 40, pp. 1598-1606, 1983.
[8] A. Yano, M. Ogura, A. Sato, Y. Sakaka, Y. Shimizu, N. Baba, and K. Nagasawa, "Effect of modified magnetic field on the ocean migration of maturing chum salmon, *Oncorhynchus keta*", *Mar. Biol.*, vol. 129, 3, pp. 523-530. 1997.
[9] M.M. Walker, C.E. Diebel, C.V. Haugh, P.M. Pankhurst, J.C. Montgomery, and C.R. Green, "Structure and function of the vertebrate magnetic sense", *Nature*, vol. 390, pp. 371-376, 1997.
[10] G.L. Chew and G.E. Brown, "Orientation of rainbow trout (*Salmo gairdneri*) in normal and null magnetic fields", *Can. J. Zool.*, vol. 67, 3, pp. 641-643, 1989.
[11] S.A. Rommel and J.D. McCleave, "Sensitivity of American eels (*Anguilla rostrata*) and Atlantic salmon (*Salmo salar*) to weak electric and magnetic fields", *J. Fish. Res. Bd Can.*, vol. 30, pp. 657-663, 1973.
[12] C.C. Varanelli and J.D. McCleave, "Locomotor activity of Atlantic salmon parr (*Salmo salar*) in various light conditions and in weak magnetic fields", *Anim. Behav*., vol. 22., pp. 178-186, 1974.
[13] F.W. Tesch and A. Lelek, "Influence of geomagnetism and salinity on the directional choice of eels", *Helgolander wiss. Meeresuners.*, vol. 26, pp. 382-395, 1974.
[14] F.W. Tesch, T. Wendt, and L. Karlsson, "Influence of geomagnetism and salinity on orientation of the eel *Anguilla anguilla* L., as evident from laboratory experiments", *Ecol. Freshwat. Fish.*, vol. 1, 1, pp. 52-60, 1992.
[15] J.D. McCleave and J.H. Power, "Influence of weak electric and magnetic fields on turning behaviour in elvers of the American eel *Anguilla rostrata*", *Mar. Biol.*, vol. 46, pp. 29-34, 1978.
[16] M.M. Walker, "Learned magnetic field discrimination in yellowfin tuna, *Thunnus albacares*", *J. Comp. Physiol.*, vol. 155A, pp. 673-679, 1984.
[17] A.J. Kalmijn, "Electric and magnetic field detection in elasmobranch fishes", *Science*, vol. 218, pp. 916-918, 1982.
[18] A.J. Kalmijn, "Experimental evidence of geomagnetic orientation in elasmobranch fishes", in *Animal Migration and Homing*, K. Schmidt-Koenig and W.T. Keeton, Eds., Springer Verlag, Berlin, pp. 347-353, 1978.
[19] M.M. Walker, J.L. Kirschvink, and A.E. Dizon, "Magnetoreception and biomineralization of magnetite in fish", in *Magnetite Biomineralization in Organisms*, J.L. Kirschvink, W.J Jones, and B.J. McFadden, (Eds. Plenum Publ. Corp., pp. 417-497, 1985.
[20] M. Hanson and H. Westerberg, "Occurrence of magnetic material in teleosts", *Comp. Biochem. Physiol.*, vol. 86A, pp. 169-172, 1986.
[21] J.L. Kirschvink, M.M. Walker, S.-B. Chang, A.E. Dizon, and K.A. Peterson, "Chains of single-domain magnetite particles in chinook salmon, *Oncorhynchus tschawytscha*", *J. Comp. Physiol.*, vol. 157A, pp. 375-381, 1985.
[22] S. Mann, N.H.C. Sparks, M.M. Walker, and J.L. Kirschvink, "Ultrastructure, morphology and organizationin biogenic magnetite from sockeye salmon, *Oncorhynchus nerka*: implications for magnetoreception", *J. Exp. Biol.*, vol. 140, pp. 35-49, 1988.
[23] M.M. Walker, T.P. Quinn, J.L. Kirschvink, and A.E. Dizon, "Production of single-domain magnetite throughout life by sockeye salmon, *Oncorhynchus nerka*", *J. Exp. Biol.*, vol. 140, pp. 51-63, 1988.
[24] Y. Sakaki, T. Motomiya, M. Kato, and M. Ogura, "Possible mechanism of biomagnetic sense organ extracted from sockeye salmon", *IEEE Trans. Magn.*, vol. 26, pp. 1554-1556, 1990.
[25] M. Ogura, M. Kato, N. Arai, T. Sasada, and Y. Sakaki, "Magnetic particles in chum salmon (*Oncorhynchus keta*): extraction and transmission electron microscopy", *Can. J. Zool.*, vol. 70, pp. 874-877, 1992.
[26] M. Hanson, L. Karlsson, and H. Westerberg, "Magnetic material in European eel (*Anguilla anguilla* L.)", *Comp. Biochem. Physiol.*, vol. 77A, pp. 221-224, 1984.