were found to contain less than 0.5 ppm of Hg, with average values as indicated in Table 1. The total Hg loss in the ash and water streams from the furnace totaled approximately 250 g/day. About 10 percent of the Hg input is disposed of in these waste products.

The average Hg vapor concentration in the flue-gas discharge was 31 $\mu g/m^3$ (range, 6 to 82 $\mu g/m^3$ on four samples). On the basis of data on the flow rates of furnace flue gas, the average Hg discharge rate is approximately 2500 g/day. Most of the Hg appears to be discharged from the plant as vapor in the flue gas, as hypothesized by Bertine and Goldberg (*2*). The total Hg flow rate from the entire plant (three stacks, 2100 Mw) is estimated to be approximately 7.5 kg/day. The annual plant load factor, based on previous operating experience, is 0.72. The total amount of Hg emitted annually into the U.S. atmosphere from this source (10^{15} g of coal per year, 0.3 ppm of Hg) is estimated to be of the order of 10^3 metric tons.

Because of the small number of samples obtained in this preliminary study, the differing analytical methods used, and the range of the data used in averages, the overall average Hg balance (input versus output) does not check exactly. Apart from further extended sampling and analysis of fuels and emissions, there are several aspects of the problem of environmental Hg from fossil fuels that require further consideration. The fate of the vapor in the stack plume and its partitioning characteristics with respect to chemical constituents and attachment to aerosol particle during cooling will affect downwind Hg deposition and inhalation patterns. Atmospheric concentrations of Hg associated with suspended particulate matter have been reported to range from 1 to 5 ng per cubic meter of air (*9*). The biological consequences of the transport of airborne Hg are unknown. Technology for the control of Hg emissions from these large sources has not been developed, although Hg has been observed in effluent liquid from a flue-gas scrubber for sulfur oxides.

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Oceanic Electric Fields: Perception by American Eels?

Abstract. *American eels, long-distance migrating fish, consistently exhibited conditioned cardiac deceleration responses to electric fields as small as* 0.167×10^{-2} *microampere per square centimeter in water of resistivity 4000 ohm centimeters (6.7 microvolts per centimeter) and 400 ohm centimeters (0.67 microvolt per centimeter). Fewer responses were shown at this current density* (0.167×10^{-2} *microampere per square centimeter) in more saline water (40 ohm centimeters, 0.067 microvolt per centimeter) and at a lower current density* (0.167×10^{-3} *microampere per square centimeter) in fresh water. Thus, eels have sufficient sensitivity to utilize geoelectric information for orientation.*

Royce, Smith, and Hartt (*1*) have revived the suggestion that aquatic animals might use the weak electric fields generated in the ocean by water currents moving through the geomagnetic field for orientation or navigation. They suggested that Pacific salmon (*Oncorhynchus*), which migrate along ocean currents, may determine the direction of the water currents by means of this geoelectric field. Others have made similar hypotheses (*2, 3*); Deelder (*4*) offered electric field detection as one possible means by which migrating elvers of the European eel (*Anguilla anguilla*) orient themselves in tidal streams.

Several groups of essentially nonmigratory fish have been shown to have sensitivity to very weak electric fields, for example, the weakly electric fish (Gymnotidae, Mormyridae) to 0.03 $\mu v/cm$ (*3, 5*), sharks (*Scyliorhinus canicula*) and skates (*Raja clavata*) to 0.01 $\mu v/cm$ (*6*), and bullheads (*Ictalurus nebulosus*) to 30 $\mu v/cm$ (*7*). However, determination of the electric current density to which the fish were exposed is not possible, since a nonuniform field was applied to known re-

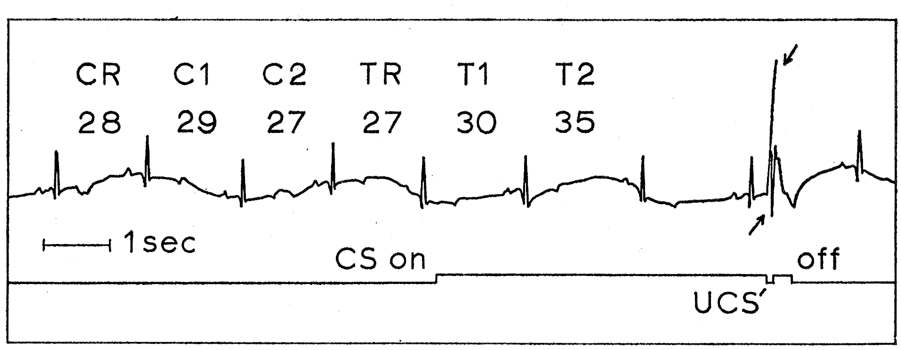

Fig. 1. Electrocardiogram of an American eel (number 73 in Table 2) during one training trial, showing apparent conditioned cardiac deceleration, presentation of weak electric field (*CS*) (0.167×10^{-2} $\mu amp/cm^2$), unconditioned stimulus (*UCS*), and designation of test and control heartbeats. *CR*, control reference beat; *C1* and *C2*, control beats; *TR*, test reference beat; *T1* and *T2*, test beats. The numbers are interbeat intervals in millimeters from the original EKG record. The arrows mark artifacts caused by UCS interference in the recording system. The EKG electrodes were disconnected from the recording circuit during UCS presentation.

Table 1. Number of American eels showing conditioned cardiac deceleration to weak electric fields at various electric current densities and water resistivities. The symbol ⊥ designates a field applied perpendicular to the body axis; ||, a field applied parallel to the body axis. The significance criterion is a one-tailed t-test, $P < .05$.

Current density (μamp/cm^2)	Water resistivity (ohm-cm)	Potential gradient (μv/cm)	Number significant ⊥	Number significant ||
0.167	4000	668	4 of 5	0 of 5
0.167×10^{-1}	4000	66.8	5 of 6	
0.167×10^{-2}	4000	6.68	7 of 8	0 of 4
	400	0.668	8 of 8	0 of 4
	40	0.0668	4 of 8	
0.167×10^{-3}	4000	0.668	2 of 8	
	400	0.0668	0 of 8	
0.167×10^{-4}	4000	0.0668	0 of 8	

ceptor organs, and the resistivity of the water was not stated.

A complete lack of data on electrosensitivity of migratory fish species prompted us to study responses of American eels (*Anguilla rostrata*) exposed to uniform weak electric fields. During preliminary experiments we found eels to be sensitive to uniform d-c fields of 0.167 μamp/cm^2 (668 μv/cm) in fresh water (*8*). However, in the ocean an eel would encounter electric fields with current densities at least two orders of magnitude smaller and potential gradients four orders of magnitude smaller. Here we report the responses of eels to these weaker fields both in fresh water (resistivity 4000 ohm cm) and salt water (400 ohm cm, 40 ohm cm).

Classical conditioning of cardiac deceleration (*9*) was attempted on 72 eels at various combinations of electric current density and water resistivity (Table 1). The weak electric field was the conditioned stimulus (CS), and a strong a-c electric shock was the unconditioned stimulus (UCS). The conditioned response (CR) was a slowdown of one or two heartbeats following application of the CS. Eels captured in fresh and estuarine waters were obtained from a commercial dealer who was holding them in fresh water. For saltwater experiments eels were held at the test salinity for at least 5 days prior to experimentation. The eels ranged in body length from 37 to 52 cm.

Two fine, Teflon coated, stainless steel wires were tied around the eel's body just posterior to the pectoral fins (*8*). The tips were implanted anterior and posterior to the pericardial region to serve as cardiac electrodes. Implantation was performed in late afternoon or evening under light anesthesia (2 liters of crushed ice, 1 liter of water, 3 ml of 2-phenoxyethanol). Immediately after the implantation the eel was placed in a Plexiglas aquarium 100 cm long, 30 cm wide, and 37 cm deep, and allowed to recover overnight. The eels were gently restrained by a U-shaped, plastic mesh trough suspended along the long axis of the tank. The mesh distorted the electric field very little (less than 1 percent). A pair of stainless steel plates along each side or at each end of the tank served to impose a weak horizontal electric field either perpendicular or parallel to the eel's body. Field uniformity was within ± 1 percent inside the mesh trough. The same plates were used to deliver both the CS and the UCS. The aquarium was located on a vibration-damping mount inside a darkened, sound-deadening chamber. All recording and operating equipment was outside the chamber.

The electric field was produced by a 1.5-volt dry cell, reduced by a voltage divider, and adjusted by a potentiometer in series with the tank electrodes and a microammeter. Each field presentation was monitored by the microammeter. The various water resistivities were made from well water and synthetic sea salts.

An electrocardiogram (EKG) was made on one channel of a physiological recorder from amplified signals from the cardiac electrodes. Another channel simultaneously recorded presentation of the CS and UCS. The EKG electrodes were disconnected during brief presentations of the UCS.

Eight sets of ten training trials, each set separated by about 1 hour, were attempted on each eel. In many cases the EKG implant pulled out before 80 trials could be given, but only those eels on which at least 50 trials were completed are included. The CS was presented for a duration of three heartbeats and followed by the UCS; then both stimuli were turned off. An interval of 40 to 80 seconds was allowed before the next trial began.

The beat immediately prior to the CS was designated the test reference beat, and the percentage changes in the interbeat intervals between the reference beat, test beat 1, and test beat 2 during the CS presentation were computed (Fig. 1). Similarly, three beats prior to the test reference beat were used as control reference beat, control beat 1, and control beat 2, with changes in interbeat intervals also computed. One-tailed t-tests ($P < .05$) were used to test the hypothesis that there was no decrease in heart rate of test beat 1 compared to control beat 1 and test beat 2 compared to control beat 2. The alternate hypothesis was that test means were greater than control means, if conditioning had occurred. The t values

Table 2. Responses of American eels to an electric current density of 0.167×10^{-2} μamp/cm^2, in water of resistivity 400 ohm-cm, applied perpendicular and parallel to the body axis. The significance criterion is a one-tailed t-test between the percentage change in the test beat mean and the control beat mean at $P < .05$ and $P < .01$. The control and test values are means and standard deviations; N is the number of trials.

Fish	N	Change in first beat (%) Control	Change in first beat (%) Test	t value	Change in second beat (%) Control	Change in second beat (%) Test	t value
			Field perpendicular to body				
73	80	−6.0 ± 9.5	4.6 ± 15.2	5.28*	−4.7 ± 10.3	5.7 ± 13.4	5.50*
75	70	−1.0 ± 9.2	4.4 ± 10.2	3.28*	−0.4 ± 10.8	4.6 ± 9.6	2.89*
76	60	−3.1 ± 16.8	9.8 ± 24.9	3.33*	−3.9 ± 18.5	7.4 ± 16.0	3.59*
77	50	−0.4 ± 15.8	12.9 ± 28.5	2.89*	0.7 ± 21.3	6.6 ± 22.3	1.36
80	60	−0.6 ± 37.2	10.1 ± 42.2	1.48	1.5 ± 36.7	16.5 ± 51.2	1.84†
81	60	2.5 ± 15.2	6.9 ± 16.4	1.51	1.1 ± 14.5	9.2 ± 18.7	2.67*
84	80	−1.8 ± 14.9	1.2 ± 16.5	1.23	−1.7 ± 20.7	5.4 ± 23.4	2.02†
85	80	−4.4 ± 24.7	5.2 ± 15.4	2.96*	−6.8 ± 21.2	14.4 ± 55.4	3.21*
			Field parallel to body				
86	80	1.9 ± 9.8	−0.1 ± 14.1	<0	0.2 ± 10.6	−2.0 ± 11.3	<0
87	60	2.3 ± 8.5	4.7 ± 29.3	0.63	3.2 ± 10.5	0.6 ± 9.9	<0
91	60	0.9 ± 8.3	−0.1 ± 7.1	<0	0.1 ± 9.2	−0.5 ± 8.7	<0
92	60	9.1 ± 43.8	7.1 ± 29.7	<0	4.2 ± 33.3	3.9 ± 16.3	<0

* $P < .01$. † $P < .05$.

were also calculated cumulatively in increments of ten trials. For each field intensity and orientation, learning curves of mean t values against the number of trials were then plotted for fish significantly conditioned and for nonsignificant fish.

Nearly all eels exhibited a conditioned response to perpendicular fields as low as 0.167×10^{-2} μamp/cm^2 in fresh water (Table 1). Fewer responses were observed at 0.167×10^{-3} μamp/cm^2 and none were observed at 0.167×10^{-4} μamp/cm^2. At 0.167×10^{-2} μamp/cm^2 in water of resistivity 400 ohm-cm (0.67 μv/cm) all eels responded (Table 2), and in water of resistivity 40 ohm-cm (0.067 μv/cm) (approximately 17 per mil salinity) about half responded. The response was absent at 0.167×10^{-3} μamp/cm^2 and resistivity 400 ohm-cm. No eels responded to fields applied parallel to their bodies (Table 1).

The learning curves substantiated these findings. In all cases of parallel fields and at the lowest perpendicular field intensity at each water resistivity the nonsignificant groups gave no indication that any learning had occurred. At 0.167×10^{-2} and 0.167×10^{-3} μamp/cm^2 in fresh water the nonsignificant groups had learning curves which suggested that some learning occurred; however, our criterion of significance was not reached.

The eel's sensitivity is well within the range of naturally occurring oceanic electric fields. For example, in certain study sections of the Gulf Stream we have predicted values of up to 0.016 μamp/cm^2 (0.46 μv/cm) (*10*). Electric fields are at a maximum in the Gulf Stream, but surface potential gradients of at least 0.10 μv/cm also occur, for example, in the Labrador, West Greenland, North Atlantic, Irminger, and Antilles currents (*11*). All of these are almost certainly involved in migration routes of American and European eels.

While demonstration of a sensitivity does not prove its use in orientation, the fact that the eel is sensitive to perpendicular fields, but not parallel fields, provides a mechanism by which water current direction can be determined. Interaction of moving water with the vertical component of the geomagnetic field would generate a potential gradient perpendicular to the body axis, if the eel were oriented upstream or downstream. The potential gradient would be parallel to the body, if the eel were oriented across the water current. By simply aligning the body to sense the electric current the eel could remain oriented to the water current. If it can also sense polarity, it could discriminate upstream from downstream. The horizontal component of the geomagnetic field interacting with moving water produces vertical fields, which would provide no directional information to the fish. However, most migratory fish, such as salmon and eels, have routes distinctly north of the equatorial region, where the vertical component is the major portion of the total geomagnetic field.

This method does not distinguish between conditioning to the d-c field itself and conditioning to the change in electric field at the onset of the CS. However, since it is sensitive perpendicular but not parallel to its body, an eel in a natural water current system would experience a rapid change in electric field when it turned its body from side to side as in its swimming movements.

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Ultrasonic Doppler Technique for Imaging Blood Vessels

Abstract. *Present ultrasonic Doppler flow detectors that use the Doppler effect on waves scattered from moving blood have provided useful information when directed by hand to trace the circulation of animals and man. By scanning with a highly directive flow detector, the areas of flow can be localized. Images can be formed of the interior of blood vessels. These images have the appearance of arteriograms and venograms made by dye contrast radiography, but have none of its hazards. The resolution appears adequate for useful images.*

We have found that the scanning techniques can be used with a continuous-wave ultrasonic Doppler flow detector (*1*) to produce images of blood flow within vessels. This technique appears to extend the usefulness of these very sensitive devices by adding spatial information. Similar additions have been found invaluable in other fields. For example, ultrasonic diagnostic apparatus was not widely used until scanning techniques had been demonstrated (*2*).

It is necessary to scan the Doppler transducer over the surface of the patient or animal to be examined. The detector must have a narrow sensitive area so that areas of flow can be accurately localized. Figure 1 illustrates the principle and suggests how a film might be exposed directly by a bulb mounted on the transducer in the man-

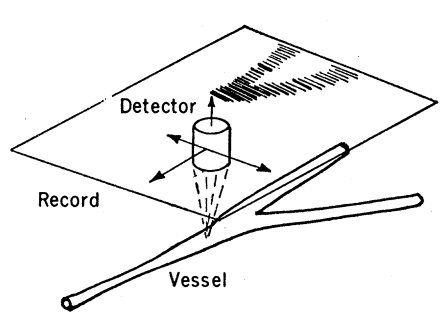

Fig. 1. Representation of the use of a focused Doppler detector to image flow within a blood vessel. The acoustic transducer was coupled to the test object or subject by immersion in a shallow water bath with sound transparent bottom. Display of the images is made electronically on an oscilloscope for convenience.