Electrotaxis in American lobsters, *Homarus americanus*, and its potential use in sampling early benthic-phase animals

Peter Koeller
Invertebrates Division, Biological Sciences Branch
Department of Fisheries and Oceans
Bedford Institute of Oceanography
P.O. Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2
E-mail address: koellerp@mar.dfo-mpo.gc.ca

Gregory Crowell
Department of Electrical Engineering
Technical University of Nova Scotia
P.O. Box 1000, Halifax, Nova Scotia, Canada B3J 2X4

The American lobster, *Homarus americanus*, fishery is an important part of the economy in New England and eastern Canada. A reliable predictor of recruitment to this fishery would be useful in stock assessments and economic planning, yet no such predictors are available. The best time for a prerecruit survey is just after the stage-4 postlarva (approx. 5-mm carapace length) settles from the plankton to the benthos, after high larval mortalities have established the size of the year class, but early enough in the growth cycle to allow prediction of recruitment 4–6 years before lobsters are harvested. Unfortunately, this is also the period when lobsters are most difficult to capture. Stage-4 lobsters prefer to settle into cobble-sized rock substrate, often several layers thick, where they remain until they begin to enter commercial traps at a carapace length of about 40 mm (Lawton and Lavalli, 1995). Sampling this "early benthic phase" (EBP) of lobsters is laborious and costly. A team of divers must turn individual rocks and capture escaping animals with suction devices (e.g. Hudon, 1987, Wahle and Steneck, 1992). This method is too time consuming to permit synoptic prerecruit surveys such as are conducted for groundfish. Consequently, we sought a more efficient sampling method for EBP lobster stocks along the coast of Nova Scotia, Canada.

Several previous studies suggested that electrofishing may be a useful approach. Saila and Williams (1972) developed an electric trawl system that increased catches of commercial-size American lobsters. Stewart (1974) described the effects of electric fields on the Norway lobster (*Nephrops norvegicus*), including an induced avoidance behavior that caused animals to leave their burrows. Phillips and Scolard (1980) developed an electrofishing apparatus for juvenile rock lobsters (*Panuliris cygnus*) which looked promising, although it caught a size range similar to that taken by traps. Our approach was fundamentally different from these studies in that we intended to develop a sampling "quadrant" which electrified a small area (<1 m^2) of the substrate and took advantage of electrically induced behavior observed in our preliminary laboratory experiments. This paper presents results from these experiments and subsequent trials with several potential electrode arrangements and suggests avenues for further development.

Methods

Preliminary behavioral experiments were conducted in tanks of various sizes without shelters or substrate to determine if electrotaxis could be induced in lobsters and, if so, what pulse lengths and voltages would be most effective. Lobsters ranging in size from 5–50 mm carapace length were subjected to a wide range of electrical stimulation including voltages from 10 to 100 V and pulse frequencies from 2 to 200 Hz. Pulse lengths were varied independently of frequency during these observations, but it quickly became obvious that a square wave form (pulse duration 50% of cycle length) with a relatively high frequency was most effective in inducing the desired response. Consequently, all experiments with different electrode configurations and cobble shelters were conducted at a DC pulse frequency of 100 Hz, pulse duration of 20 milliseconds, and an input voltage of 50 V. All these experiments were also conducted in a 1.5 m^3 tank (1 m × 2 m × 0.75 m), large enough so that the walls did not distort the relatively localized electric currents produced by the apparatus. The tank was filled with sand to a depth of 10 cm, and a group of 15 cobble-size rocks (average weight 2.5 kg) of various shapes obtained from known lobster habitat were placed in the central area of the tank so that they were several layers deep and entirely contained by a 0.35 m^2 quadrant. Indirect overhead fluorescent lighting was adjusted to the natural day length. The tank was kept filled

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with 15°C seawater with a continuous flow-through system. Three EBP animals ranging from stage 4 to stage 8 (5–10 mm carapace length) were used in each trial, which is within the range of naturally occurring densities. Each animal was used only once. At least 24 hours before each trial the experimental animals were chosen randomly from a previously unused group kept in 15°C flow through holding trays. The animals were released directly above the cobble (into which they always disappeared within a few seconds) and allowed to acclimate overnight. The released animals almost always remained within the rock pile and were seen on the surrounding sand only on rare occasions. After each trial, all rocks were removed from the tank, uncaptured animals were recovered, and the rocks were replaced haphazardly. This procedure produced a different configuration of burrowing locations and shelters for each trial and simulated the varied cobble habitat that would be encountered while sampling.

The electrical apparatus (Fig. 1) consisted of a rectifier bridge, a capacitor, a 9-V battery, an opticoupler, and a power MOSFET transistor. A rheostat was used to regulate the AC power source. The bridge rectifies the current into and deposits a charge on the capacitor, thereby creating a DC source. A signal generator was used to control the opticoupler, which in turn controlled the gate of the MOSFET and primary DC source by means of the 9-V circuit. All electrodes were made of stainless steel. The only variable was the electrode configuration, each configuration consisting of a particular combination of electrode shapes and locations. These included small 6.5 cm^2 plates, 1.5-mm diameter braided wire in which a 2.5-cm length of the plastic insulation had been removed every 3 cm, or a combination of the two. The electrode configurations and the general experimental set up are shown in Figure 2.

To determine if the number of captures between electrode configurations were significantly different, each trial of three animals was treated as a replicate in a one-way analysis of variance, with the number of animals captured in each trial as the variable. Similarly, the capture time of the first, second, and third animal in each trial was treated as a replicate and a one-way analysis of variance was performed separately for each emergence. Differences between means were tested with the LSD post-hoc test.

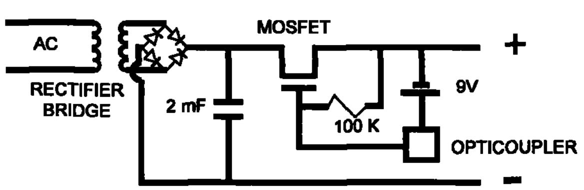

Figure 1
Circuit drawing of the electrofishing device (DC source in Fig. 2) used in experiments to determine electrotaxis and capture effciency in early benthic-phase American lobsters, *Homarus americanus*.

Results and discussion

Preliminary behavioral observations in open tanks without shelters or substrate showed that a wide size range of lobsters (5–50 mm carapace length) reacted to the electric current in a similar manner. This included an initial period of agitation of up to several seconds in which the animal appeared to become aware of the stimulus. This was followed by reorientation of the animal to face the cathode, commencement of involuntary tail flicking, and a resultant movement towards the anode. Animals of different sizes tended to react somewhat differently to the same input voltage. Larger animals (>30 mm carapace length) tended to struggle and often managed to escape the electric current. Once escaped, these animals could usually be re-entrained and induced to reach the anode by increasing the current strength and thus the tail flicking reaction. Overstimulation resulted in the animal lying motionless for several minutes after the current had been switched off. All animals that were affected in this way revived after a few minutes, apparently without ill affects. Small EBP (<10 mm) animals nearly always became motionless, usually lying on their backs, upon reaching the anode when it was situated on the substrate. If the electrode was elevated above the substrate, EBP animals gathered below it and remained motionless, but upright. When the current was switched off, they quickly escaped. EBP animals always reached the anode more quickly than large animals. In many cases the reaction was immediate and the anode was reached in less than a second. Mortalities of experimental animals (pre- and postexperimental) that could not be attributed to accidental mishandling were negligible (total of 3) during the period of observation (60 d).

We concluded that American lobsters exhibit a true electrotaxis, i.e. where an animal in a DC field is compelled to swim to the anode through involuntary muscular contractions. Electrotaxis is well known in fish (Lamarque, 1990), but has rarely been described in crustaceans. Saila and Williams (1972) observed tail muscle contractions in American lobsters subjected to currents (<38 V input), but no taxis was evident. Stewart (1974) concluded that similar tail

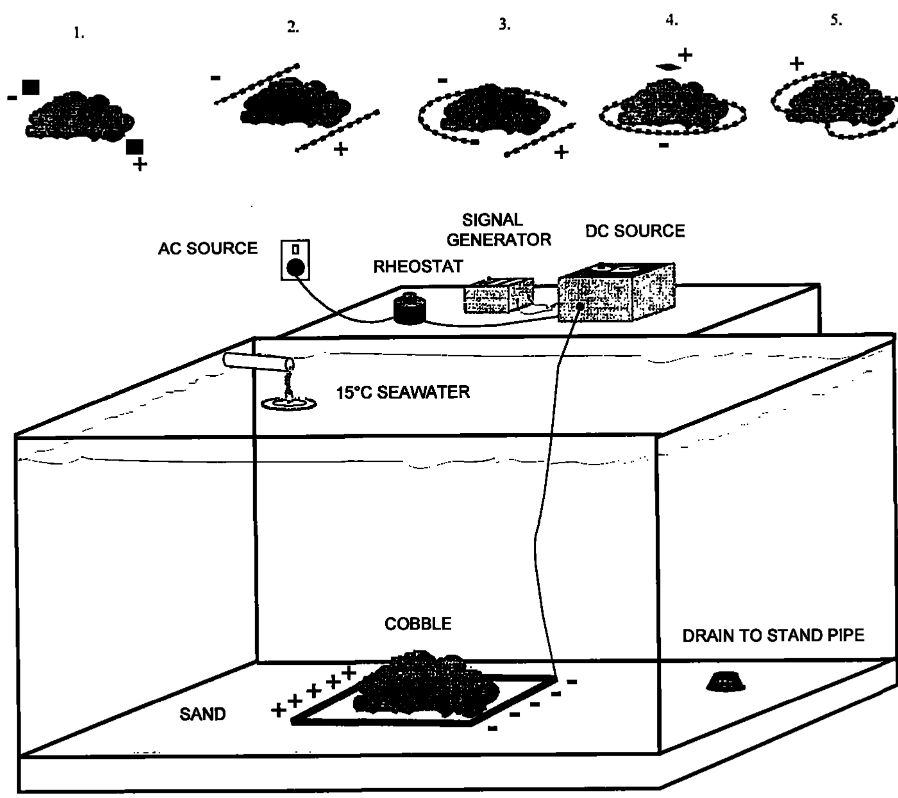

Figure 2

Laboratory setup (bottom) used to determine electrotaxis in early benthic-phase American lobsters *Homarus americanus* and capture efficiency of five electrode configurations (top).

flicking in *N. norvegicus* was not involuntary, but rather the animal's natural escape reaction induced by the electric stimulation. We have found only two reports of electrotaxis in crustaceans in which tail flicking and movement toward the anode were observed: one for the penaeid shrimp Penaeus duorarum (Higman, 1956) and the other for the rock lobster, *Panulirus cygnus* (Phillips and Scolaro, 1980).

It was apparent from these observations that the strong electrotactic response of EBP lobsters could be used to develop a quadrant-like field-sampling device. Table 1 gives the results of experiments with five different electrode configurations and EBP animals sheltered under cobble on sand substrate. These tests confirmed the unidirectional nature of the electrotaxis. Of the 81 (59%, n=137) animals that emerged from the cobble shelters, all moved directly to the anode. There was a significant difference between electrode configurations in the mean number of animals caught (ANOVA, P<0.001). The best capture rate (2.6 animals per trial, or 85% of the total population) was obtained with a semicircular cathode, straight anode and horizontal configuration (configuration 3 in Fig. 2), and the worst capture rate (0.8 animals, 25% of the population) was obtained with the circular cathode, plate anode, and vertical configuration (configuration 4 in Fig. 2). There was a significant difference between electrode configurations in mean capture time for the first animal (ANOVA, P=0.008, LSD post-hoc test) but no significant differences in capture times for the other two animals in each trial. Animals tended not to emerge at the same time but in sequence, with the first, second, and third animals emerging after an overall average of 26.3, 51.6, and 64.5 seconds. In all trials combined, one animal was caught in 91%, two in 60%, and all three in 23% of the trials. The lower and slower capture rate of the second and third animals in each test is probably related to the position of the animals in the rock pile. The EBP lobsters placed in close proximity exhibit intense aggressive behavior (Lawton and Lavalli 1995), which would tend to result in an overdispersed distribution within a bounded habitat like the test rock pile. In this situation some animals will be closer to the anode, and

Table 1

Results of electrofishing experiments with the five electrode configurations and cobble shelters on sand shown in Figure 2. The pulse frequency, duty cycle, and input voltage was 100 Hz, 50%, and 50 V, respectively, in all cases.

Electrode configuration	No. of animals[1]	No. of trials[1] (n)	Percent moving to		Mean no. captured	Percent captured	% of trials capturing			Mean capture time (sec) by order of appearance		
			anode	cathode			1 animal	2 animals	3 animals	1st animal	2nd animal	3rd animal
1	39	13	100	0	1.23 ± 0.60	41	92	31	0	66.8 ± 75.2	72.5 ± 73.7	n/a
2	39	13	100	0	2.08 ± 0.76	74	100	85	31	4.4 ± 6.1	57.5 ± 50.4	24.0 ± 19.8
3	27	9	100	0	2.56 ± 0.73	85	100	89	67	13.3 ± 12.0	42.6 ± 40.5	102.0 ± 60.4
4	24	8	100	0	0.75 ± 0.89	25	50	25	0	37.0 ± 34.5	80.0 ± 99.0	n/a
5	9	3	100	0	2.33 ± 0.58	78	100	100	33	1.0 ± 0	7.3 ± 11.0	1
Overall average						59	91	60	23	26.3	51.6	64.5

[1] Note that three animals were used in each trial.

these would tend to be caught more quickly than those farther away. Animals farther from the anode have a lower probability of a clear passage through crevices and a greater probability of being caught in a "dead end" before emerging from the rock pile.

It is apparent that electrofishing is a potentially useful method for sampling EBP lobsters. However, some additional research is necessary before a practical field sampler can be developed and tested successfully. Our study, although using the most common EBP lobster habitat, did not examine other habitats (e.g. eelgrass, mud) or variations of the common habitat, such as different rock sizes and associated crevices, or different thicknesses of cobble. Although the tedium associated with the existing sampling methods could be reduced significantly by using a diver-operated electrosampler, the most cost-effective and efficient sampler would be operated from a small boat without the need for divers. Conceivably, a sampling device that combines the electrotactic response of EBP lobsters with a bottom-to-surface water pump (e.g. Bergstedt and Genovese, 1994) could fulfill these requirements. Finally, it should be noted that the device described was designed only for use in test tanks insulated from the operator. The use of electrofishing devices in saltwater by divers, although quite safe (Stewart and Cameron, 1974), does require special precautions from an engineering as well as a personal safety perspective.

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