

Impacts of Remotely Operated Vehicles (ROVs) on the behavior of marine animals: an example using American lobsters

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ABSTRACT: The effects of Remotely Operated Vehicles (ROVs) on the behavior of marine animals have not been thoroughly studied despite the increasing use of these systems in depths beyond those that can be safely reached with SCUBA. We studied the effects of an ROV on the feeding behavior of juvenile clawed American lobsters *Homarus americanus* under laboratory and field conditions. The presence of the ROV in an operational state significantly reduced feeding activities. ROV lights and the sounds produced by electric thrusters, presented separately to the laboratory-held lobsters, reduced some feeding activities. Simultaneous presentation of the thruster sound and the lights was even more effective in diminishing feeding activities. Outputs of the camera and electronic flash inhibited feeding activities and occasionally initiated an escape response. In the field, feeding activities in the presence of an ROV with lights and thrusters off were not significantly different from those observed by a small stationary video camera with no lights. If an ROV is to be used for obtaining behavioral data, we suggest it be held stationary, without strobe flashes. The sound and light associated with normal operation should be minimized, perhaps by using quieter thruster motors and either infrared illumination or low-light cameras.

KEY WORDS: Lobster · ROV · *Homarus americanus* · Feeding behavior

INTRODUCTION

Direct observations of marine organisms had been limited, until recent years, to the very shallow margins of the ocean. These observations were done by snorkeling or SCUBA diving techniques and rarely exceeded 30 m depth. Duration of observation was also limited by air supply and water temperature. Yet, the average depth of the world's oceans is 3814 m (Kennish 1989) and many parts are too deep and cold to allow conventional diving for any length of time. The use of manned research submersibles has solved some of these problems (Stone & Busch 1991). However, manned submersibles are very expensive to operate and their operation must involve the use of large and sophisticated support ships. Unmanned submersibles and especially low-cost Remotely Operated Vehicles (ROVs), on the other hand, are considerably less expensive than manned submersibles (Smith 1989).

They are small, light, and can be operated from relatively small and unspecialized vessels by a small crew. ROVs are controlled from the surface vessel via a tether, are maneuverable with thrusters, and are equipped with still and video cameras. ROVs also can be equipped with accessories such as oceanographic sensors, depth gauges, manipulators, and sampling devices without considerably altering the low operating cost of the units (e.g. Hardin et al. 1992, Sprunk et al. 1992). These ROVs have been successfully used in recent years in a variety of marine habitats around the world to study the taxonomy, distribution, and ecology of marine organisms in pelagic as well as benthic environments deeper than SCUBA diving depth range (e.g. Bergström et al. 1987, Auster et al. 1991, Greene et al. 1991, Hamner & Robison 1992).

ROVs may also be ideal platforms for making *in situ* long-term behavioral observations of megafaunal marine animals such as fish, crustaceans, and molluscs

(Auster et al. 1990). However, the presence of even an unmanned artificial object such as an ROV may alter the natural conditions. Local conditions may change due to illumination, sounds, and currents created by the thrusters of the ROV, and the physical presence of a relatively large object. The need for an underwater light source to make observations by the human eye can greatly affect the behaviors of interest to the observer. Although no ROV project has been specifically designed to study the effect of the ROV on behavior, Auster et al. (1990) reported that white light attracted large swarms of shrimps thus altering the behavior of predatory fish. Similarly, Spanier et al. (1991) reported the attraction of deep-water shrimps and their predators to ROV lights.

We observed feeding behavior of juvenile American lobsters *Homarus americanus* Milne Edwards which are common in the coastal waters of New England, USA. Molluscs, crustaceans, echinoderms, polychaete worms, and fishes have been shown to be major components of the lobster diet (e.g. Squires 1969, Weiss 1970, Miller et al. 1971). Lawton (1987) and McKenzie (1989) demonstrated that laboratory-held juvenile lobsters readily consume blue mussels *Mytilus edulis* after being deprived of food in the absence of predators. *M. edulis* is common in the natural habitats of juvenile *H. americanus*. Captive *H. americanus* will walk upstream towards the source of food odors (McLeese 1973a). Chemical stimuli are important cues in mediating predator-prey interactions in aquatic organisms (e.g. Peckarsky 1980, Sih & Moore 1980, Croll 1983, Zimmer-Faust 1989), and this is certainly true in the American lobster, which is very sensitive to odors in the marine environment (McLeese 1973b, Atema 1986). Thus, due to the wealth of information and its importance for lobsters' biology, feeding behavior was selected in the present study to examine the effects of the ROV in the laboratory and in the field. This study was designed to determine the effects of an ROV and some of its component stimuli on the behavior of individual animals.

METHODS

We tested the effects of a Benthos MiniRover MK II ROV (henceforth 'MiniRover') on lobster behavior in the laboratory and in the field. In large laboratory tanks, we presented both the entire MiniRover in an operational state (called 'fully operational' below) and elements of the MiniRover stimuli to individual lobsters. In the field, we placed the MiniRover in front of an occupied burrow and observed behavior in response to a food stimulus.

Laboratory experiments. Specimens: The lobsters used in the laboratory experiments were obtained by divers from Narragansett Bay, Rhode Island, USA, and maintained in individual mesh cages in tanks of running filtered seawater at 16 to 19°C. The artificial light regime was 12 h dark, 10 h light and 2 h crepuscular. The lobsters were fed blue mussels *Mytilus edulis* ad libitum until 60 h before the experiment. Intact juvenile lobsters in the intermolt stage of both sexes (41 to 58 mm carapace length, CL) were used. The same individuals were used in test and control trials.

Fully operational MiniRover: The behavior of individual lobsters ($n = 7$) in the presence (treatment) or absence (control) of an operational MiniRover was observed in a large cylindrical tank (3.2 m diameter, 0.9 m water depth). The bottom of the tank was covered with a 3 cm layer of white marble chips 1.2 to 2.5 cm diameter. Heated, filtered seawater at 16.5 to 18.5°C entered close to the bottom of the tank at a rate of 20 l min⁻¹ and drained through a screened opening at the opposite side of the tank. Black plastic sheeting was hung around the tank to reduce external disturbance and illumination.

Lobsters were introduced in a 30 × 12.5 cm clay pipe shelter which was placed in front of a drain facing into the current. Between each trial the shelters were washed with detergent, rinsed in hot and cold fresh water and seawater and then dried (for explanation see Spanier & Zimmer-Faust 1988). The lobster was allowed to habituate to the tank for 1 h before each experiment began. Each trial lasted 4 h, thus the lobster was in the tank for a total of 5 h. At the beginning of the 4 h observation, 15 mussels were placed in the tank in 3 rows. The first row, 2.8 m upstream from the shelter, was of small mussels (16 to 25 mm shell length, SL), the second row, 5 cm closer to the shelter, held medium mussels 26 to 35 mm SL, and the third row, 5 cm closer, was of large mussels 36 to 45 mm SL. Two mussels of each size group were crushed just before placement to provide an odor stimulant.

Two lights (150 W quartz lamps) were installed in the front of the MiniRover, 25 cm above the bottom and 32 cm from the center line on each side. An electronic flash (used for the still camera) also was located on the front of the MiniRover. Throughout the experiment, the lights were on and the vertical thrusters were operated at 50% power. This would be a typical operating condition when the ROV is stationary on the bottom. Every 15 min, or whenever the lobster emerged from its shelter the camera (and electronic flash) was triggered. Every 20 min the mechanical arm at the base of the MiniRover was opened and closed once. Ambient illumination, measured at the bottom of the tank with a LI-COR 185A radiometer with a spherical sensor, was 0.4 to 0.7 mE m⁻² s⁻¹. Illumination 1 m from the MiniRover when the lights were on was 15 mE m⁻² s⁻¹.

All lobster activity was recorded for the full 5 h of habitation and trial in both control and experimental sessions using a low-light video camera with a wide-angle lens mounted 2 m above the bottom of the tank. The ROV video camera also was operated during the experimental trials.

At the end of each session the number of mussels moved and/or consumed was noted. The video tapes were analyzed using a VCR with fast, slow, and still-frame capabilities. We measured the time lobsters spent inside and outside of shelter. Data were analyzed with a Mann-Whitney *U*-test (Sokal & Rohlf 1981).

Elements of the MiniRover: To test the component stimuli of the MiniRover, we presented lights, sound, or lights and sound together to individual lobsters and observed their foraging behavior. A treatment with no lights or sound provided a control. These experiments were conducted in a 1.2 × 3.2 m tank (Fig. 1) supplied with filtered, heated seawater at a rate of 11 to 17 l min⁻¹. Water entered close to the bottom of the tank and drained through overflows at the surface at the opposite end of the tank. Water depth was 26 cm, and temperature ranged from 15 to 20°C. The bottom of the tank was covered with a 3 cm layer of white marble chips (1.2 to 2.5 cm diameter), with a 1 cm layer of fine white gravel (0.1 to 0.4 cm diameter) on top of it. The upstream area close to the water supply was blocked from access by the lobsters with a black plastic mesh screen. The stimuli (ROV lights, and sound from an underwater speaker) were presented from this area. Ambient illumination (6 to 8 mE m⁻² s⁻¹) was provided by incandescent light bulbs. Experimental illumination was provided by 2 MiniRover lights placed behind the screen 20 cm above the bottom and each 32 cm from the center line of the tank. As in the previous experiment, the MiniRover lights produced 15 mE m⁻² s⁻¹

1 m from the source. The sound of the ROV was recorded in an acoustic tank, 1 m from the source, when thrusters were operated at 50% power. This sound was played back through an Electrovoice DU-30 underwater loudspeaker hung behind the screen 20 cm above the bottom. Sound levels were adjusted before the experiment using a Benthos Aquadyne AQ 17 hydrophone placed at the opening of the shelter. A preamplifier and sound meter allowed us to match the sound level recorded with the same equipment 1 m from the MiniRover. The sounds were later analyzed with a Kay BSF 5500 Sonograph.

All sessions were conducted between 07:30 and 18:30 h. Each trial included 1 h of habituation and 4 h of stimulus presentation. Lobsters were placed in the tank inside a clay pipe shelter 1 m from the screen (and the stimulus source). Shelters were cleaned between trials as described previously. After 1 h habituation, 15 mussels in 3 size groups (as before) were placed in rows, with the row of small mussels placed touching the screen. There were 4 treatments in this experiment: lights only, sound only, lights and sound together, and control (lamps and speaker in the tank but not activated). Each individual lobster was subjected to each treatment once. The order of presentation of treatments to each individual was randomized. At the end of the experiment we counted the number of mussels moved and the number consumed. We also noted the location of any alternative shelter dug by the lobster. Video recording and analyses were carried out as described above. The following activities were measured from the videotapes: time spent in shelter, time spent walking, and time spent at the food patch (foraging). We used a Wilcoxon signed rank test to analyze the results (Sokal & Rohlf 1981).

Field experiments. All field experiments were conducted from 18 to 31 May at the 'Dumplings', on the eastern shore of Conanicut Island, Rhode Island, USA. Water depth was 3 to 6 m and temperature was 10°C. After a preliminary survey, SCUBA divers located lobsters in shelters and cleared any algae which might interrupt viewing of the lobster and/or its den. Lobsters were 45 to 67 mm CL, and of both sexes. Either the MiniRover or an underwater video camera was moved to the site and placed 1.5 m from the shelter. A 16 × 7.5 × 7.5 cm perforated transparent plastic box (the 'bait box') weighted with 2 kg of lead and filled with crushed fresh blue mussels was placed upstream 1 m from the den. A line marked every 20 cm was placed between the 'bait box' and the

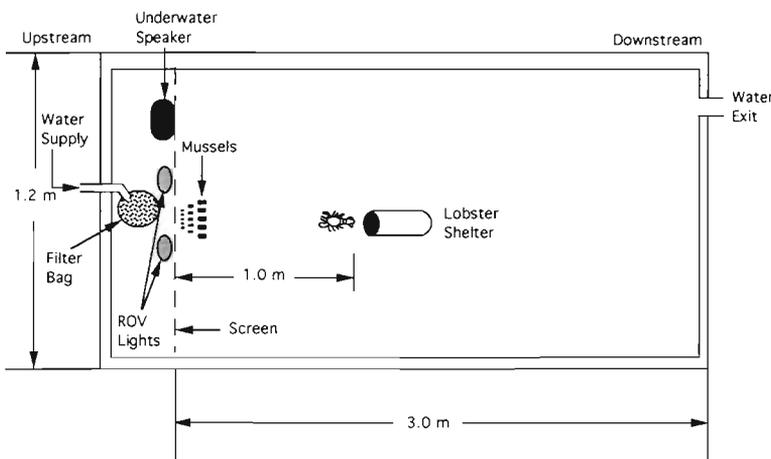


Fig. 1. Schematic diagram of the experimental tank used for the study of the effects of elements of the ROV

den and several additional crushed mussels were placed between the box and the den. Only sessions with a weak current present (small fish visible hovering in the water column) and no large (>20 cm total length, TL) potential fish predator present (tautog *Tautoga onitis* or cunner *Tautogolabrus adspersus*) were included in the final analysis. Each session lasted 1.5 h. At the end of each session divers retrieved the 'bait box' and attempted to catch the lobster, measure the carapace length, and determine sex.

Lobster behavior was observed in 3 ways. The control observations were made with a Sanyo VDC 4100 underwater video camera with 54.8 mm, f/1.8 E Rainbow lens mounted on a frame where the lens of the camera was at the same height from the bottom as the ROV video cameras. The treatment series was done with an operational ROV: lights on (Fig. 2), vertical thruster operating at 50% power and still camera (with electronic flash) firing every 15 min or whenever the lobster emerged from its den. The second control was the ROV with headlight, thrusters and flash off. An observer aboard the vessel observed the underwater activities through a video monitor. All sessions were recorded on a VCR. Video analysis was done in the laboratory using the same equipment as above. The

following activities were measured: number of times lobsters took mussels into den, number of times appendages (claws or antennae) were visible, number of times lobsters fully emerged from den (the whole body was visible), time (min) to first detection of the mussels and to first emergence. In the case of the fully operational ROV the number of lobster responses (stop walking, retreat to den or tail flip) was also counted in relation to the number of still camera and flash firings. Statistical analysis of the number of times lobsters responded was done using the Kruskal-Wallis test (Sokal & Rohlf 1981). Statistical analysis of time to first response was done by using the Wilcoxon test of equality over strata (survival analysis; Breslow 1970).

RESULTS

Laboratory experiments

Fully operational MiniRover

During control periods (MiniRover absent) lobsters consumed mussels while none of the same lobsters ate any mussels during the test periods when the ROV was

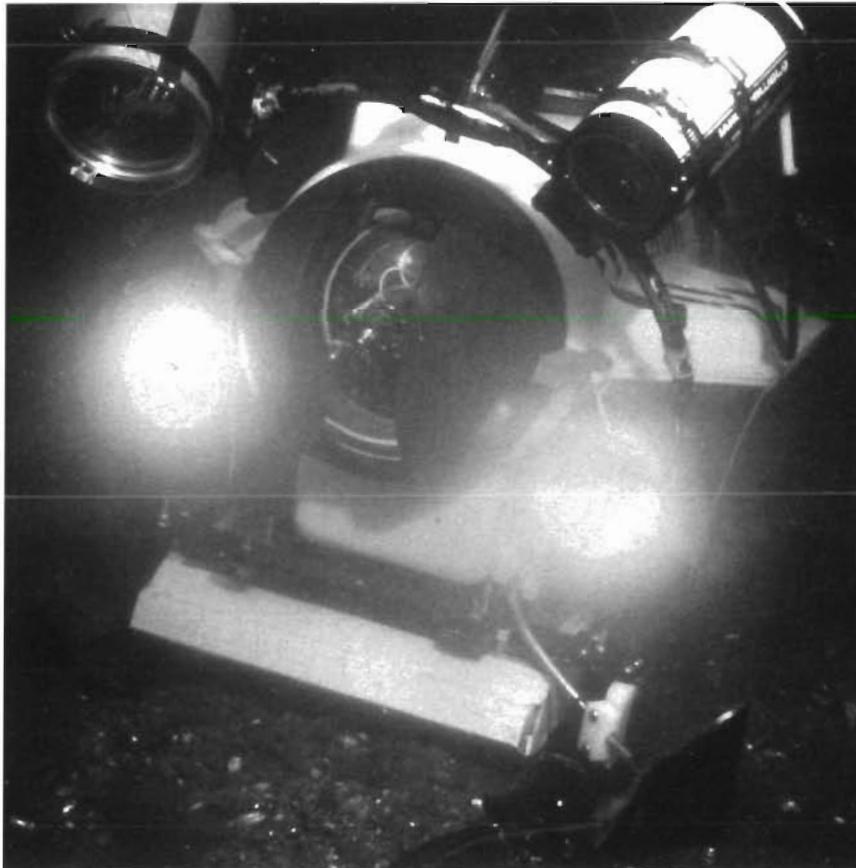


Fig. 2. An operational ROV underwater in the field, taken from the point of the lobster den (1.5 m downstream from the ROV) (photo D. Sipperly)

Table 1 *Homarus americanus*. Number of mussels eaten or moved by juvenile lobsters in the presence of an operational ROV (test) and during control periods in the laboratory. Number of mussels by size class (large, medium, small) in brackets. The same lobsters were used for the control and test experiments

Lobster	No. of mussels eaten		No. of mussels moved	
	Control	Test	Control	Test
1	3 (0, 1, 2)	0	15	0
2	4 (0, 2, 2)	0	15	0
3	0	0	0	0
4	3 (1, 0, 2)	0	15	1
5	0	0	0	0
6	5 (1, 2, 2)	0	15	0
7	2 (0, 1, 1)	0	15	0
Total	17 (2, 6, 9)	0	75	1
Range	0–5	0	0–15	0–1
Average	2.4	0	10.7	0.1

present (Table 1). The lobsters moved more mussels during the control period than while the ROV was operating (Table 1).

Lobsters spent significantly more time in shelter in the presence of a fully operational ROV than during the control periods. There was no significant difference in time out of shelter during control periods when compared to test periods although there was a tendency to spend more time out of shelter during the control periods (Fig. 3). When lobsters did emerge while the ROV was operating, they retreated to their shelter in response to the camera and electronic flash or hid under the ROV where they were shaded from the lights and the electronic flashes of the ROV.

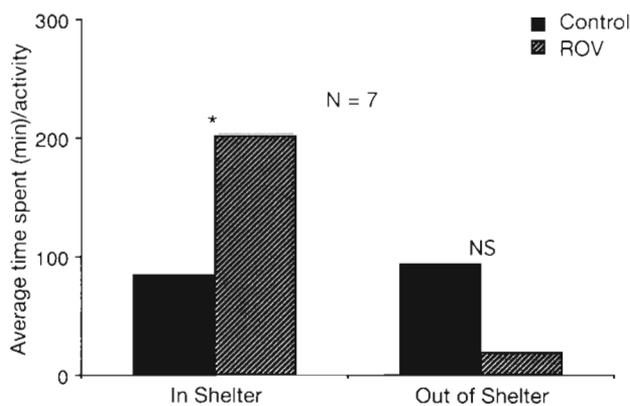


Fig. 3. *Homarus americanus*. Time spent by lobsters in and out of shelters in the presence of an operational ROV and during control periods in the laboratory. The same individuals were used for each of the 2 treatments. Statistical significance for the comparison between the 2 columns was determined using Mann-Whitney *U*-test (* $p < 0.05$); NS: not significant

Elements of the MiniRover

In this experiment, we tested the hypothesis that activity during the control was greater than in any of the 3 treatments (lights, sound, or lights and sound together). Lobsters spent significantly more time walking during the control than when the lights or the lights and sound of the ROV were presented. When the sound was presented alone, the time spent walking tended to be less than the control, but the difference was not statistically significant (Fig. 4). There was no difference between any of the treatments and the control in the amount of time spent in shelter, but the time lobsters spent in shelter in the treatments tended to be longer than in the control (Fig. 4). The lobsters spent significantly more time foraging on the patch of mussels in the control condition than in any of the treatment conditions (Fig. 5). When both lights and sound were presented together, lobsters consumed significantly fewer mussels than when the stimuli were absent (Fig. 6), but there was no significant difference in mussels consumed between either the lights alone or the sound alone treatment and the control, although again the tendency was to decrease feeding when elements of the ROV were presented. More mussels were moved from their original position during control treatments than during any of the 3 test treatments (Fig. 6). The lobsters did not move any mussels at all, except for those they consumed, when the ROV lights and sound were presented simultaneously. In the control treatments, the 7 lobsters dug a total of 2 alternative shelters, while in each of the lights or sound treatments, they dug 4 alternative shelters. In the lights and sound treatment, lobsters dug only 1 alternative shelter. All

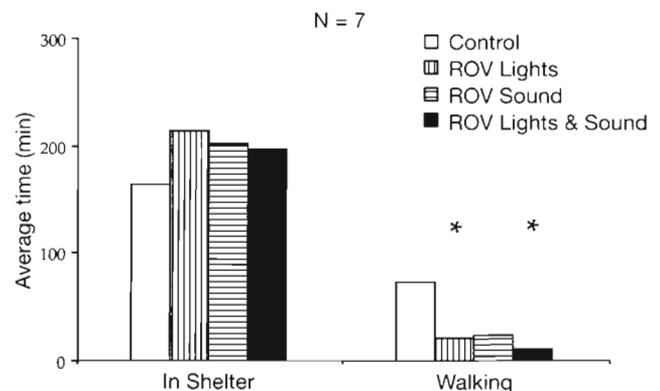


Fig. 4. *Homarus americanus*. Average time spent by lobsters in shelter or walking in laboratory experiments during control or in the presence of ROV elements. The same individuals were used for each of the 4 treatments. Each treatment was compared to the control using the Wilcoxon signed rank test. Significant differences are indicated by an asterisk above the relevant treatment ($p < 0.05$)

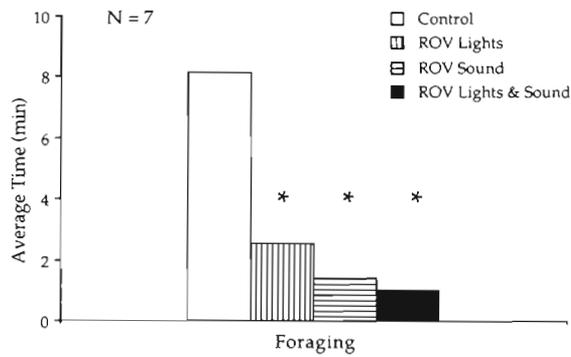


Fig. 5. *Homarus americanus*. Average time spent in laboratory experiments by lobsters foraging during control periods and in the presence of ROV elements. The same individuals were used for each of the 4 experiments. Each treatment was compared to the control using the Wilcoxon signed rank test. (*p < 0.05)

but 1 of the alternative shelters dug during the experimental treatments were further away from the stimulus than the clay tile shelter.

Analysis of the sound produced by this particular Benthos MiniRover Mk II revealed broad-band noise with peak amplitudes at high (> 3000 Hz) and low (< 1000 Hz) frequencies. The sound recorded and played back during this set of experiments had peak frequencies at 150 to 450, 600 to 2000 and 3600 to 4800 Hz.

Field experiments

The majority of the lobsters observed in the field fed on mussels during the ROV control periods (ROVC) and during the sessions observed by the underwater

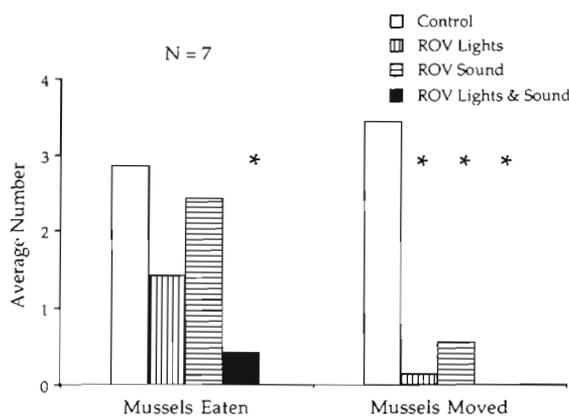


Fig. 6. *Homarus americanus* feeding on *Mytilus edulis*. Average number of mussels eaten or moved in laboratory experiments by lobsters during control periods and in the presence of ROV elements. The same individuals were used for each of the 4 treatments. Each treatment was compared to the control using the Wilcoxon signed rank test (*above the relevant treatment; p < 0.05)

TV camera (TVC), while only 2 out of 8 fed in the presence of the operated ROV (Fig. 7a). The time to first detection and to first emergence (full body out of the natural den) was significantly less during the control periods (ROVC and TVC) than while the MiniRover was fully operational (Fig. 7b). The number of live

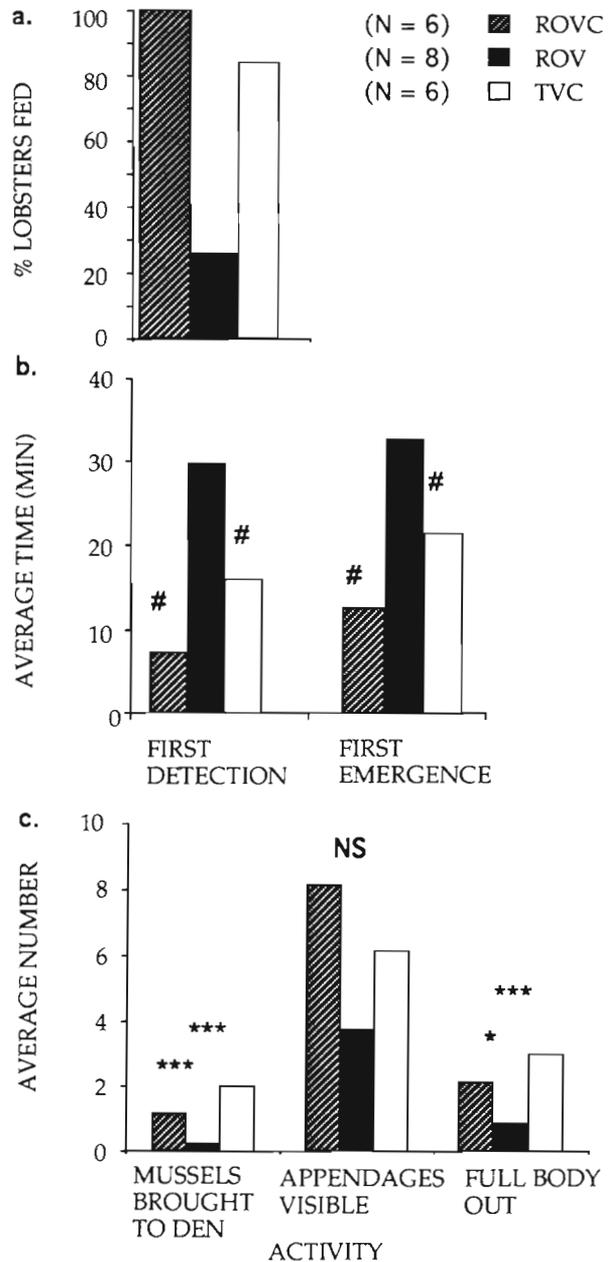


Fig. 7. *Homarus americanus*. Responses of field lobsters in the presence of an operational ROV with lights, flash, and thruster on and during control periods using ROV with lights and thrusters off (ROVC) or underwater TV camera with no lights (TVC). Statistical significance was determined (b) for time to first response by Wilcoxon test of equality over strata (#: p < 0.05) and (c) for number of responses by Kruskal-Wallis test (*p < 0.05; ***p < 0.005)

mussels brought to den as well as the number of times the full body of the lobster was visible outside the den were significantly greater during control periods than while the MiniRover was fully operational (Fig. 7c). Although there was a tendency for appendages (claws and/or antennae) to be visible in the den opening more often during controls than during operational ROV periods, this difference was not significant. When actually foraging (full body out of den) and bringing food back to the den, lobsters showed significantly higher activity during control compared to operational ROV sessions (Fig. 7c). The number of times emerging lobsters responded to the activation of the still camera and the electronic flash by retreating to the den (via backward walking), by ceasing to advance ('freezing'), or by tail flips are presented in Table 2. Lobsters responded to most of the firings but in at least 1 case (where the lobster initially responded by a tail flip back to its den and emerged again), the lobster showed a tendency of reduced responses with the increasing number of flashes.

Table 2. *Homarus americanus*. Number of responses of individual field lobsters emerging from their den towards bait (blue mussels) to flashes by the electronic flash of the ROV's still camera. -: lobsters did not emerge even partially; *including 1 tail flip

Lobster no.	No. of flashes	No. of responses
1	3	3
2	2	0
3	6	5
4	-	-
5	1	1
6	-	-
7	2	2
8	45	23*

DISCUSSION

Both laboratory-held and field lobsters showed reduction in feeding activities in the presence of an ROV with lights on and with thrusters running at 50% capacity when compared to control periods. In laboratory experiments the fully operational ROV not only completely prevented feeding of food-deprived lobsters but considerably reduced foraging activities as evident from the low number of mussels moved. The presence of an operational ROV significantly increased the time laboratory lobsters remained in shelter (at the expense of foraging). The average time spent out of shelter, although shorter than during the control, was not significantly different. This can, in part, be explained by the fact that not all the lobster activities

during the control sessions could be recorded. For example, when lobsters were walking along the walls of the tank towards the food patch, it was occasionally difficult to detect them on the recorded video tapes, in the background of the shaded area. Portions of these activities, therefore, were not added to the time spent out of shelter. On the other hand, when lobsters in the test sessions occasionally sought alternative shelters along the wall of the tank away from the operational ROV and remained motionless (which did not occur during the control) this was recorded as activity 'out of shelter' for the test lobsters.

It is interesting to note that the majority of mussels consumed by lobsters during control sessions in the laboratory were of small and medium size, perhaps because they were easier for lobsters to carry to the shelter.

The physical presence of the ROV does not seem to have much effect on feeding behavior since field lobsters showed relatively high feeding activity in the presence of an ROV with lights and thrusters off, similar to their behavior in the presence of a much smaller lightless underwater video camera. The fully operational ROV, however, not only considerably reduced the percentage of lobsters feeding, but also significantly increased the time to first detection and first emergence from den. Although it was impossible to deprive field lobsters of food in the framework of the experimental design of the present study, field lobsters are highly food motivated at this time of the year (spring) after the decreased level of feeding activity during the winter. They responded to the smell of food located upstream of their shelters by first extending their antennae, claws, and walking legs out of their den. Clawed lobsters of the genus *Homarus* were found to have chemical receptors located on their claws, walking legs, mouth parts, and the antennules (first antennae) (Shelton & Laverack 1970).

The rapid, brief and brilliant illumination from the electronic flash of the ROV still camera, possibly accompanied by electrical and acoustic outputs, seemed to be the most effective factor in reducing feeding behavior of lobsters in the laboratory and in the field. It caused cessation of movement toward the food source, hiding behavior or retreating to shelter, and even an escape response (tail flip). Cromarty et al. (1991) showed that hard-shelled juvenile lobsters produced forceful escape swimming in response to a threatening stimulus. However, at least 1 field lobster, after responding to many flashes, ignored this stimulus and proceeded towards the food patch and fed. In view of this observation, one should not reject the possibility of habituation of a highly motivated animal even to such a strong disturbance after repeated stimulations.

The ROV elements experiments indicated that even in the absence of the flash some ROV outputs such as the noise produced by the thruster and/or the lights by themselves can affect feeding behavior in the lobster. Although lobster behavior was highly variable, perhaps because of internal reasons, several significant differences were detected. Actual time spent foraging on the food patch was significantly shorter during presentation of the ROV elements than during control periods. The number of mussels moved during such reduced foraging periods was, therefore, significantly lower than those moved during control periods. Although the average number of mussels eaten during the presentation of ROV lights or ROV sound was smaller than during the control, this difference was not significant. This can be explained by the fact that food-deprived lobsters could bring a mussel to their shelter and consume it even after a very short period of foraging. Closer lights seem to disturb, at least partially, feeding activities of juvenile *Homarus americanus* which forage mainly nocturnally and during crepuscular times (Stewart 1972, Cooper & Uzmann 1980, Ennis 1983). In addition, Lawton (1987) suggests that intra-specific competition and hunger level may also affect foraging time. The noise of the ROV, and especially that of the vertical thruster used to keep the ROV on the bottom and stationary, can also affect behavior. The high-frequency components of the noise should not affect the lobsters which may not be able to perceive them (Offutt 1970). The low-frequency components of the noise (> 200 Hz), however, may well affect the behavior of *H. americanus* since the lobsters produce low frequency (100 to 300 Hz) sounds (Fish 1966) and also respond to sound of similarly low frequency (Offutt 1970). Also the manufacturer of the MiniRover used in this study (Benthos, Inc., Falmouth, MA, USA) measured a peak of >20 dB above the average self-noise of the system under 300 Hz (Benthos unpubl. data).

The results of the ROV elements experiments point out that the simultaneous presentation of lights and sound is more effective in reducing feeding behavior than each stimulus presented separately. Walking lasted a significantly shorter time in the presence of the ROV lights than during the control periods. The lights seem to be more effective in reducing walking activity than the sound since the average time spent walking in the presence of ROV lights was significantly shorter than during the control whether it was present with sound or not. Although there was less walking during the presentation of ROV sound than during the control, this difference was not significant. However, the number of mussels eaten during the simultaneous presentation of ROV lights and sound was much lower and significantly different from the control, while for each

stimulus presented separately, it was not significantly different from the control. This may indicate a summation of stimuli. Also, of the mussels that were not eaten during the simultaneous presentation of ROV lights and sound, none were moved, whereas some were moved when each of the ROV elements was presented separately. The lobsters are apparently able to integrate the 2 different stimuli of 2 different sensory modalities into a stronger stimulus in higher centers of their nervous system.

The average time spent in a shelter during control periods is not significantly different than sheltering time during stimuli presentation despite the significant difference in foraging time. This seeming discrepancy can be explained partially by the individual variability of the behavior of lobsters but also by the fact that during stimulus presentation, lobsters were occasionally out of their original artificial shelter digging alternative dens. These were constructed mainly downstream away from the stimulus source (even all the way near the downstream wall of the experimental tank; see Fig. 1) where the intensity of the stimuli decreased with the distance from the source.

Myrberg (1973), reviewing the use of underwater television (UTV) for the study of the behavior of marine animals *in situ*, pointed out some of the advantages and disadvantages of what was then a relatively new technique. Among the advantages he mentioned were the ability to overcome depth and time restrictions associated with the use of SCUBA diving, the capability for precise temporal records of specific events and actions via direct monitoring, and elimination of disturbances, particularly those caused by exhaled bubbles, caused by a diver on site. Among the disadvantages of the UTV was the necessity of a more portable system so that the behavioral phenomena could be investigated with relative ease at different locations. He pointed out that UTVs were relatively inflexible compared to a diver-observer who could carry out numerous on-site duties with little preparation. Also, the resolution and speed of mechanical movement of the UTV could not replace the experienced eye of SCUBA-equipped scientists and their ability to move rapidly in many directions. The maneuverability of the ROV, its sophisticated cameras, manipulator and other devices, have overcome some of these problems. Yet, they have also reintroduced some of the problems associated with SCUBA operations, such as noise and the relatively rapid approaches and departures from the study site. Difficulties inherent in 2-dimensional viewing via UTVs are similar in ROVs (e.g. loss of depth perception, size estimation). In the future, it might be useful to conduct a comparative study of the relative utility of SCUBA versus ROV technology for shallow-water observation of the behavior of marine animals.

The scope of the present study did not include all the possible effects of the ROV on the behavior of marine animals. The actual movement of the ROV (with tether) can affect some behavioral activities. Other elements such as the heat produced by the lights of the ROV and the movement of the manipulator may also have small or negligible effects. Despite these various difficulties, ROVs are presently one of the best ways to conduct *in situ* behavioral observations in the deep sea and for lengthy studies even in shallow water. In view of the findings of the present study, we recommended to approach and depart from the study site as slowly and quietly as possible, and to make the actual behavioral observations with the ROV in a stationary position. ROV ballast should be increased rather than using the vertical thrusters to keep the vehicle on the bottom. Light and noise levels should be kept minimal and still photography with the use of electronic flash should be taken, if necessary, only after quantitative data are obtained. Video frame capture devices, when used with a high-resolution camera, could eliminate the need for still photography. New innovations in ROV technology such as quieter brushless thrusters (Anonymous 1991), infrared illumination (Auster et al. 1990), and more sensitive video cameras may further improve the use of this tool for *in situ* behavioral observations in the marine environment.

Acknowledgements. This research was funded, in part, by grant number 92-12-008 from NOAA's National Undersea Research Center to the University of Rhode Island. The views expressed herein are those of the authors and do not necessarily reflect the views of NOAA or any of its subagencies. We thank Helga Sprunk from NOAA's National Undersea Research Center, the University of Connecticut at Avery Point for her cooperation. Thanks are due also to D. Sipperly, T. Brown, J. Kinney and H. Mayers for helping in the SCUBA diving operation, to H. Winn from the University of Rhode Island for lending the electro-acoustic instruments and to E. Yascil and C. Hanumara for statistical guidance. The helpful comments of an anonymous reviewer are gratefully acknowledged.

LITERATURE CITED

- Anonymous (1991). ROV design concepts for the 1990s. *Sea Technology*. August 1991: 57-59
- Atema, J. (1986). Review of sexual selection and chemical communication in the lobster, *Homarus americanus*. *Can. J. Fish. Aquat. Sci.* 43: 2283-2290
- Auster, P. J., Good, D. H., La Rosa, S. C., Cooper, R. A., Stewart, L. L. (1991). Microhabitat utilization by megafaunal assemblage at a low relief outer continental shelf site — Middle Atlantic Bight, USA. *J. Northw. Atl. Fish. Sci.* 11: 59-69
- Auster, P. J., Good, D. H., La Rosa, S. C., Sprunk, H. J. (1990). Observing animal behavior with ROVs: minimizing impacts with red light. In: *Proc. ROV 90. Marine Technology Society, Washington, DC*, p. 185-190
- Bergström, B. I., Larsson, J., Pettersson, J.-O. (1987). Use of a Remotely Operated Vehicle (ROV) to study marine phenomena: I. Pandalid shrimp densities. *Mar. Ecol. Prog. Ser.* 37: 97-101
- Breslow, F. (1970). A generalized Kruskal-Wallis test for comparing samples subject to unequal patterns of censoring. *Biometrika* 57: 579-594
- Cooper, R. A., Uzman, J. R. (1980). Ecology of juvenile and adult *Homarus americanus*. In: Cobb, J. S., Phillips, B. F. (eds.) *The biology and management of lobsters*, Vol. 2. Academic Press, New York, p. 97-142
- Croll, R. P. (1983). Gastropod chemoreception. *Biol. Rev.* 58: 293-319
- Cromarty, S. I., Cobb, J. S., Kass-Simon, G. (1991). Behavioral analysis of the escape response in the juvenile lobster *Homarus americanus* over the molt cycle. *J. exp. Biol.* 158: 565-581
- Ennis, G. P. (1983). Observations of the behavior and activity of lobsters (*Homarus americanus*) in nature. *Can. Tech. Rep. Fish. Aquat. Sci.* 1165: 1-26
- Fish, J. F. (1966). Sound production in the American lobster *Homarus americanus* H. Milne Edwards (Decapoda, Reptantia). *Crustaceana* 11: 8-9
- Greene, C. H., Wiebe, P. H., Miyamoto, R. T., Burczynski, J. (1991). Probing the fine structure of ocean sound-scattering layers with ROVERSE technology. *Limnol. Oceanogr.* 36: 193-204
- Hamner, W. M., Robison, B. H. (1992). *In situ* observations of giant appendicularians on Monterey Bay. *Deep Sea Res.* 39: 1299-1313
- Hardin, D. D., Graves, D., Imamura, E. (1992). Investigating seafloor disturbances with a small ROV. *Mar. tech. Soc. J.* 26(4): 40-45
- Kennish, M. J. (1989). *Practical handbook of marine science*. CRC Press, Boca Raton
- Lawton, P. (1987). Diel activity and foraging behavior of juvenile American lobsters *Homarus americanus*. *Can. J. Fish. Aquat. Sci.* 44: 1195-1205
- McKenzie, T. P. (1989). Foraging behavior of juvenile American lobsters, *Homarus americanus*, under predation risk. M.Sc. thesis, University of Rhode Island
- McLeese, D. W. (1973a). Orientation of lobsters (*Homarus americanus*) to odor. *J. Fish. Res. Bd Can.* 30: 838-840
- McLeese, D. W. (1973b). Olfactory responses of lobsters (*Homarus americanus*) to solutions from prey species and to seawater extracts and chemical fractions of fish muscle and effects of antennule ablation. *Mar. Behav. Physiol.* 2: 237-249
- Miller, R. J., Mann, K. H., Scarratt, D. J. (1971). Production potential of a seaweed-lobster community in eastern Canada. *J. Fish. Res. Bd Can.* 28: 1733-1738
- Myrberg, A. A. Jr (1973). Underwater television — a tool for the marine biologist. *Bull. mar. Sci.* 23(4): 824-836
- Offutt, G. C. (1970). Acoustic stimulus perception by the American lobster *Homarus americanus* (Decapoda). *Experientia* 26: 1276-1278
- Peckarsky, B. L. (1980). Predator-prey interaction between stoneflies and mayflies: behavioral observations. *Ecology* 61: 932-943
- Shelton, R. G. J., Laverack, M. S. (1970). Receptor hair structure and function in the lobster *Homarus gammarus* (L.). *J. exp. mar. Biol. Ecol.* 3: 303-309
- Sih, A., Moore, R. D. (1980). Interacting effects of predator and prey behavior in determining diet. In: Hughes, R. N. (ed.) *Behavioral mechanisms of food selection*. Springer-Verlag, London, p. 771-796

- Smith, G. A. (1989). NOAA's Caribbean ambassador of science and technology. In: Oceans' 89, Vol. 3. Institute of Electrical and Electronic Engineers, Piscataway, p. 810–815
- Sokal, R. R., Rohlf, F. J. (1981). Biometry, 2nd edn. W. H. Freeman, New York
- Spanier, E., Tom, M., Galil, B. S. (1991). Preliminary ROV study of the epibenthic megafauna at Akhziv Canyon, Mediterranean coast of Israel. In: Galel, B., Mart, Y. (eds.) Proc. 3rd Symposium on the Mediterranean Continental Shelf of Israel, Haifa, May 1991. Israel Oceanographic and Limnological Research, Haifa
- Spanier, E., Zimmer-Faust, R. K. (1988). Some physical properties of shelter that influence den preference in spiny lobsters. *J. exp. mar. Biol. Ecol.* 122: 137–149
- Sprunk, H. J., Auster, P. J., Stewart, L. L., LoValvo, D. A., Good, D. H. (1992). Modifications to low-cost remotely operated vehicles for scientific sampling. *Mar. tech. Soc. J.* 26(4): 54–58
- Squires, H. J. (1969). Lobster (*Homarus americanus*) fishery and ecology in Port au Port Bay, Newfoundland, 1960–65. *Proc. natn. Shellfish. Ass.* 60: 22–39
- Stewart, L. L. (1972). The seasonal movements, population dynamics and ecology of the lobster, *Homarus americanus*, off Ram Island, Connecticut. Ph.D. dissertation, University of Connecticut, Storrs
- Stone, G. S., Busch, W. S. (1991). Deep ocean science and facility needs. *Mar. tech. Soc. J.* 25(2): 14–21
- Weiss, H. M. (1970). The diet and feeding behavior of the lobster *Homarus americanus* in Long Island. Ph.D. thesis, University of Connecticut, Storrs
- Zimmer-Faust, R. K. (1989). The relationship between chemoreception and foraging behavior in crustaceans. *Limnol. Oceanogr.* 34: 1367–1374

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*Manuscript first received: April 1, 1993
Revised version accepted: November 4, 1993*