CONNECTICUT SEA GRANT

Factors Affecting Catch of American Lobster, *Homarus americanus* in Baited Traps

by

Peter J. Auster

NOAA's National Undersea Research; Program
The University of Connecticut at Avery Point
Groton, CT 06340

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1.0 INTRODUCTION

The simplicity of fish and crustacean traps has contributed to the general impression that the trap is a relatively simple measure of fishing effort. This impression of simplicity is enhanced by comparing traps with the cited complexities of mobile fishing gear such as trawls and seines (Gulland, 1969; Munro, 1974; Rothschild and Suda, 1977; Carrothers, 1981; Foster et al., 1981). Intuitively, one accepts this dichotomy between mobile and fixed gear types, hence the significant complexities of fixed gear effort have often been neglected (IPHC, 1978).

The American lobster, Homarus americanus, is the target of the most valuable fishery on the eastern coast of Northern America (Smolowitz, 1978). Nearly 98% of the 1980 landings of 16700 metric tons of lobsters, worth 75 million dollars, were from the trap fishery (Fogarty et al, 1982). A great deal is known about the life history of lobsters in the northwest Atlantic (see Cooper and Uzmann, 1980 for an extensive review) but, as in most fisheries, little is known of stock recruitment relationships. Yield assessment techniques are restricted to those analyses which utilize catch-per-unit effort (CPUE) as an index of abundance.

Validation of CPUE from traps as an index of abundance requires an understanding of the dynamics of the capture process and how different variables influence the magnitude of the landed catch. Catch in fixed gear has been known to increase towards an asymptote (saturation) with increasing soak time (Gulland, 1955; Munro, 1974; Bennett and Brown, 1979). Skud (1979) found that catch/pot/day (C/P/D) in the New England offshore lobster pot fishery was substantially higher in the summer and early autumn than in other seasons. Catch per trap haul was found to be an unreliable measure of CPUE unless standardized for length of soak or unless estimates of ingress and egress were included. Catch-per-trap-haul-set-over-day (CTHSOD), which is catch-per-trap when hauled divided by set-over time in days (SOD) summed over all traps, has been widely accepted as a CPUE index in crustacean trap fisheries (Thomas, 1973; Caddy, 1977; Skud, 1979).

Changes in CPUE are better understood when variables such as temperature (McLeese and Wilder, 1958), gear selectivity (Krouse and Thomas, 1974; High, 1976; High and Worlund, 1979; Pecci et al., 1978), ability to sense and follow bait trails (McLeese, 1973), intraspecific and interspecific interactions in and around traps (Miller, 1980; Richards et al., 1982), effects of molt state on activity (Stewart, 1972; Morgan, 1974), and current speed (Howard, 1980; Howard and Nunny, 1983), are taken into account.

Although the volume of literature on the American lobster is large, the dynamics of the capture process and factors affecting catch are poorly known, leaving much of the variability associated with catch data unexplained.

In order to explain patterns in catch and to determine how selected variables affect CPUE, this study will (1) quantify daily ingress and

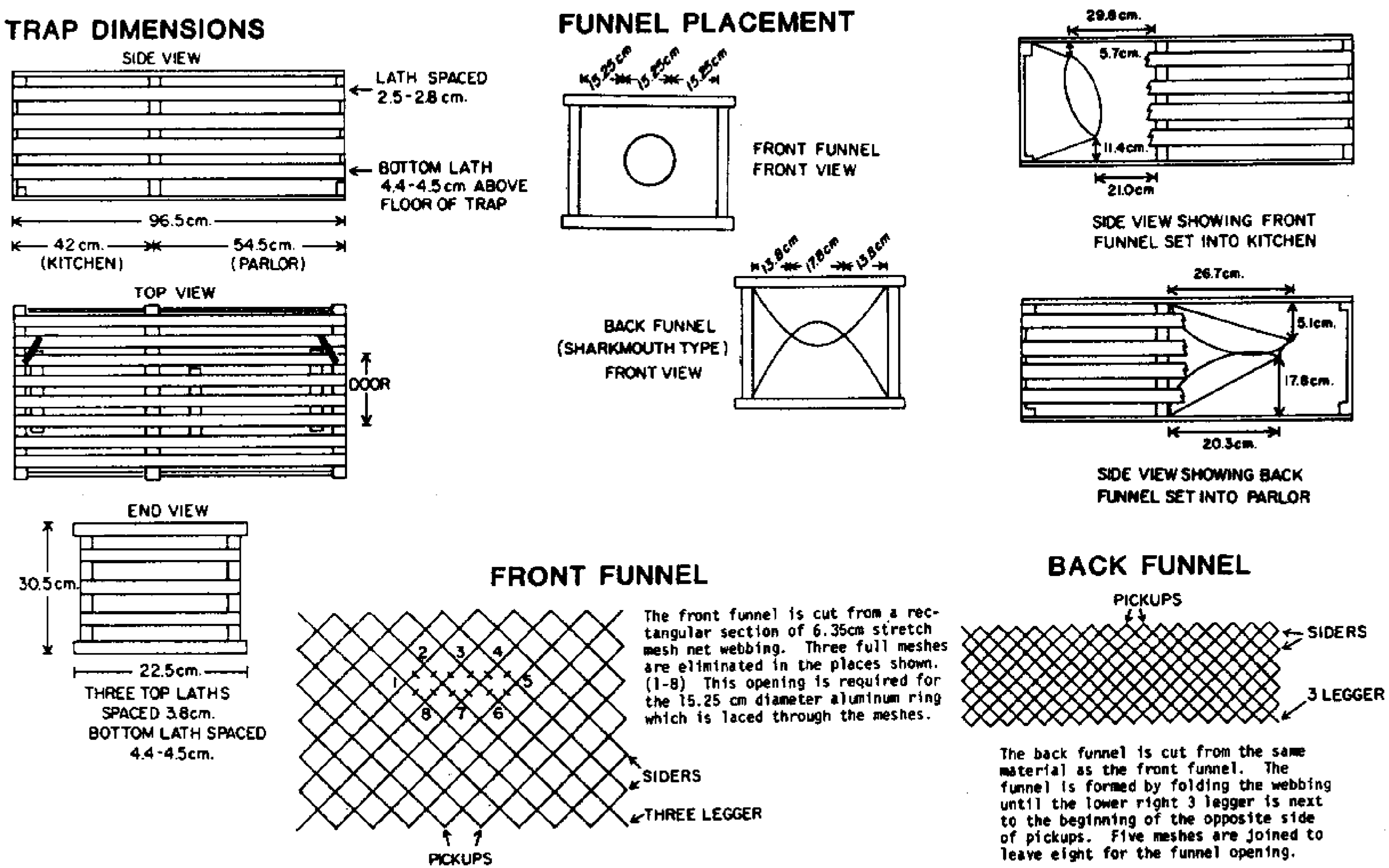


Fig. 1. An example of the trap type used in the field portion of this study. The trap design diagram shows mesh size, lath spacing and funnel configuration.

escapement of lobsters from traps, (2) test the hypothesis that non-target catch affects the catch of lobster, (3) test the hypothesis that lobsters have preferred positions in the traps, (4) describe the intraspecific and interspecific behavioral interactions of target and non-target species during capture and while in the trap, and (5) test the hypothesis that current speed affects catchability.

2.0 MATERIALS, METHODS AND STUDY AREA

2.1 Field Study - Ingress and Escapement, Effects of Non-Target Catch, Position Preference in Traps, Behavior. Sixteen wood lath single funnel traps (Fig. 1) were set in four trap trawls off Masons Point, Fishers Island Sound (Figs. 2 & 3). Traps were set on flat fine to coarse sand bottom with rock and boulder habitat approximately 20 m shoreward. Traps were set end to end and staked to

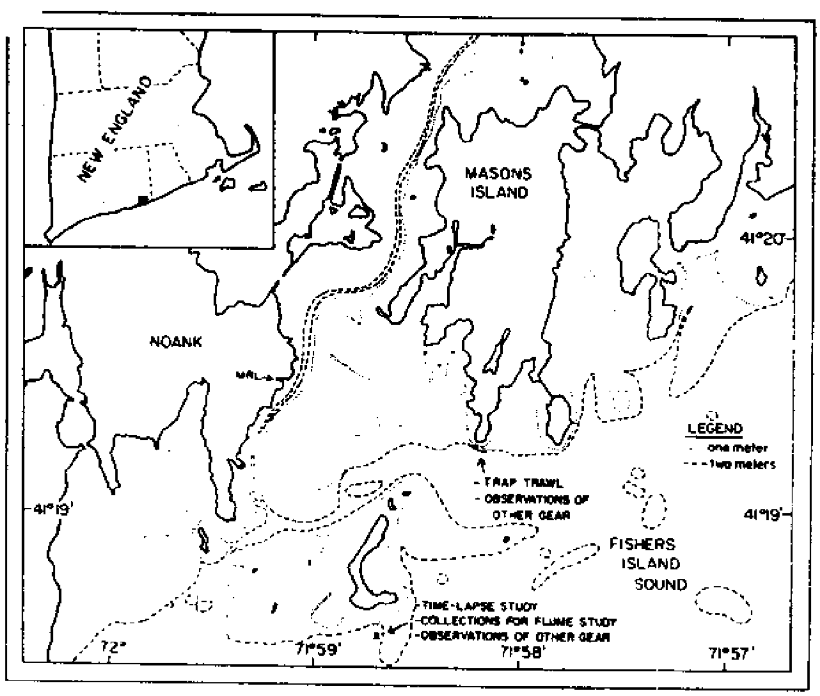


Fig. 2. Locations of the study sites.

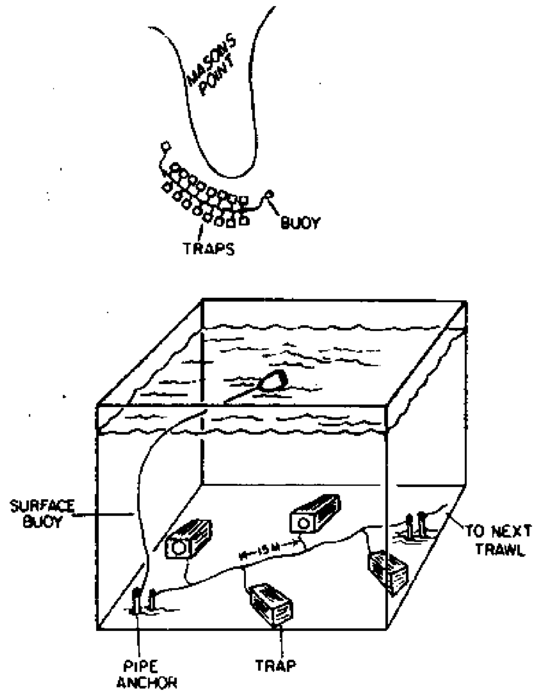


Fig. 3. The trap trawl site in detail. Traps were set with the funnel entrances perpendicular to the current direction.

the bottom to minimize disturbance and loss. Buoys were set at the ends of the sixteen-trap sequence and staked to the bottom to aid in relocation by divers and to avoid trap disturbance.

Traps were spaced at 5 m intervals along the trawl with funnel entrances perpendicular to the current. This was done to avoid effects of current direction on the catch of individual traps (Miller, 1980), since lobsters orient to the direction of bait odor (McLeese, 1973). Each trap was numbered for identification.

Traps were baited at the beginning of each set with 250 ml of Trident Mark 12 bait in perforated bait cans and placed above the kitchen funnel entrance. A set consisted of seven SOD. Trap sets were conducted from 10 September to 8 December, 1982.

Fig. 4. A lobster tagged with the tie-rap leg tag. The tag is attached to the upper portion of the rear left walking leg so it does not interfere with movement.

Catch sampling was conducted daily during a set using SCUBA. Lobsters in each trap were measured for carapace length (tangential length between the rear of the right eye socket and posterior edge of carapace) and carapace width (tangential distance between widest portion of carapace), sexed, examined for handedness (left or right crusher claw), condition (missing or damaged body parts), and molt stage (external criteria sensu Aiken, 1980). Each lobster was tagged with a numbered tie-rap on the fourth left walking leg (Fig. 4) and tail punched for identification. Daily condition of each lobster was noted. Position of lobsters in traps was enumerated during a careful approach to each trap throughout sets two to six.

Non-target catch was enumerated by species, size and number. Crustacean by-catch was measured, but fish length was only estimated due to handling constraints underwater. Behavior of target and non-target catch was observed and photographed in and around traps used for this study as well as for commercial traps.

At the end of a set, all sublegal lobsters (< 81 mm CL) were released and legal lobsters removed from the study site as in an actual fishing situation. Traps were cleared of macroalgae, shaken clean of sediment and rebaited at the beginning of the next set.

Mean C/P/D, which is total catch per day during a set, divided by the number of traps in the set, then divided by SOD, was computed for each SOD. A least squares linear regression was computed to determine the pattern of catch.

To describe the patterns of ingress and escapement with time, the individual trap data was summed by day and set and the cumulative percent ingress and escapement for each SOD was computed. Data were then transformed to arcsine values to decrease heterogeneity in the variance, and a mean was computed for each day of soak time. A multiple regression model was constructed to discern patterns of ingress and escapement with time.

Escapement of lobsters greater than 100% retention carapace length was computed separately. Each trap was measured (in water) and a 100% retention carapace length for lobster determined from data presented in Nulk (1978). Legal lobsters were considered those individuals with a carapace length greater than or equal to the 100% retention length for each trap. Only those animals in molt stages C4 to D1 were used in this analysis. Data was analyzed in the same manner as total ingress and escapement. To determine the effect of non-target catch on the catch of lobsters and vice versa, each daily trap record was enumerated for the presence of target and/or non-target catch by species. A 2 x 7 table was compiled and chi-square test of independence computed.

Daily position of each lobster was enumerated for individuals which occupied the parlor in the absence of non-target catch in order to determine if a preferred position existed within traps (too few individuals were observed in the kitchen to subject to statistical analysis). Lobster positions were grouped into four general areas (under funnel, sides along funnel, sides opposite funnel, and center) and four densities (one to four individuals). A 4 x 4 table was constructed and tested (chi-square) for homogeneity of distribution.

2.2 Effects of Current Speed on Behavior and Catch

2.21 Flume Study. The behavior of lobster at specific current speeds was determined in a calibrated flume (see Freadman, 1979 for details). The flume chamber (45- x 20- cm) was divided into nine equal segments, three in an upstream-downstream direction and three segments across. The upstream segment had a lee area formed by a brick and the downstream segment provided a shelter (Fig. 5). Five lobsters of 54.7 mm to 59.6 mm CL were used as experimental animals. Larger animals were not used due to the small size of the subject chamber. The experimental animals were collected at Ram Island Reef, Fishers Island Sound and transported to the National Marine Fisheries Service, Northeast Fisheries Center, Milford Laboratory.

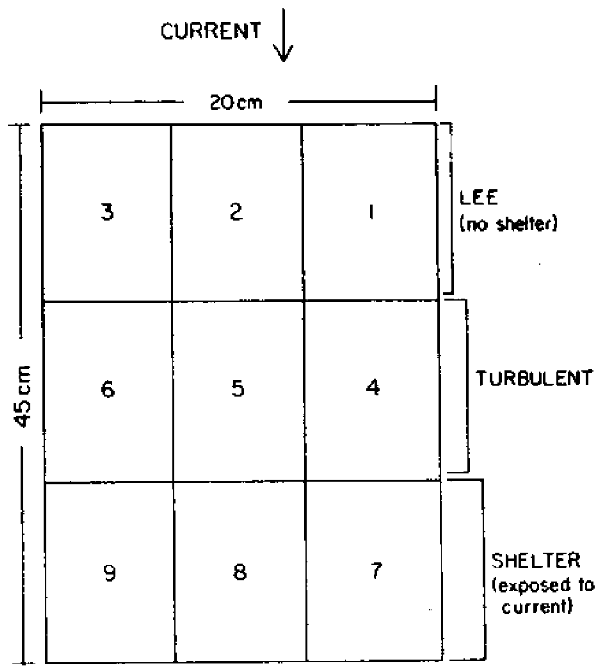


Fig. 5. Sections of the flume chamber. The shelter portion is exposed to current while the lee section provides no shelter.

Lobsters were kept in ambient running seawater for one week prior to the start of the experiment. Seawater was kept at 45 ^{o}F($\pm$ 2 ^{o}C) in the flume and changed for each animal. Each lobster was allowed to become acclimated to the chamber for sixty minutes. Position in the chamber was noted every fifteen seconds for fifteen minutes at each current velocity, yielding a total of 60 observations for each of the five current velocity regimes (0, 22, 30, 37, 46 cm/sec). Changes in current velocity were made over five minutes. The next set of observations was started at the end of this period. Behavior and posture of each animal during the experiment was noted when appropriate. No animal was used twice.

Position data was pooled for all lobsters at each current velocity for each of nine positions. The upstream-downstream segments were pooled (i.e. positions 1, 2, 3; 4, 5, 6; and 7, 8, 9) into a 3 x 5 table and tested (chi-square) for homogeneity of distribution to determine whether lobsters will react to changes in current velocity and seek alternate (low current velocity) shelter. The effects of changing current velocity on general mobility was determined by the lobsters' ability to make lateral movements. Side to side segments were pooled (i.e. positions 1, 4, 7; 2, 5, 8; and 3, 6, 9) into a 3 x 5 table and tested in the same manner.

Behavior and postural observations were summarized for each current speed.

2.22 Time-Lapse Study. The effect of changing tidal current velocities on foraging behavior, and hence catchability, was determined with a time-lapse camera and strobe system attached to an electromagnetic current meter array (see Bohlen, 1980, for details), deployed at Ram Island Reef, Fishers Island Sound (Fig. 2) on 10 August 1983 at 1055 hours, EST. A bait of fresh frozen winter flounder, *Pseudopleuronectes americanus*, was attached to a ground-level stake beneath the camera. Area of view was approximately 0.5 m^2. The camera photographed the bait and associated fauna at the rate of one frame per minute over the course of the fifty hour deployment. Current speed and direction was recorded every fifteen seconds at 0.5 meters above the substrate. Each time-lapse frame was enumerated for species and abundance and correlated with current velocity.

2.23 Connecticut Trap Fishery Logbook Analysis. Connecticut lobster fishermen are required to submit trip logs for the Department of Environmental Protection statistical reporting system. Log entries include the number of traps hauled, SOD, catch in pounds, and area of capture for each day fished (Smith, 1977, 1980).

Logbook records were used as a data base to test the hypothesis that catch is negatively correlated with increasing mean current velocity. CPUE would be higher for lunar quarter phases than for new or full moon phases which have higher tidal current velocities. Fishermen's belief that catch is greater on nights around a new moon than during any other lunar phase was also tested.

A time frame within the data base was needed to test the above hypotheses minimizing bias created by wide temperature fluctuations, inshore-offshore migration or increasing molt frequency. A review of CPUE data in Smith (1977) and raw catch data from the 1982 lobster fishery revealed the April and early May period fit these criteria. Records from statistical area 2 (Fig. 6) provided the most complete data set. Records were edited for traps set and hauled within a time period of ± 3 days around each lunar quarter (United States Naval Observatory, 1980).

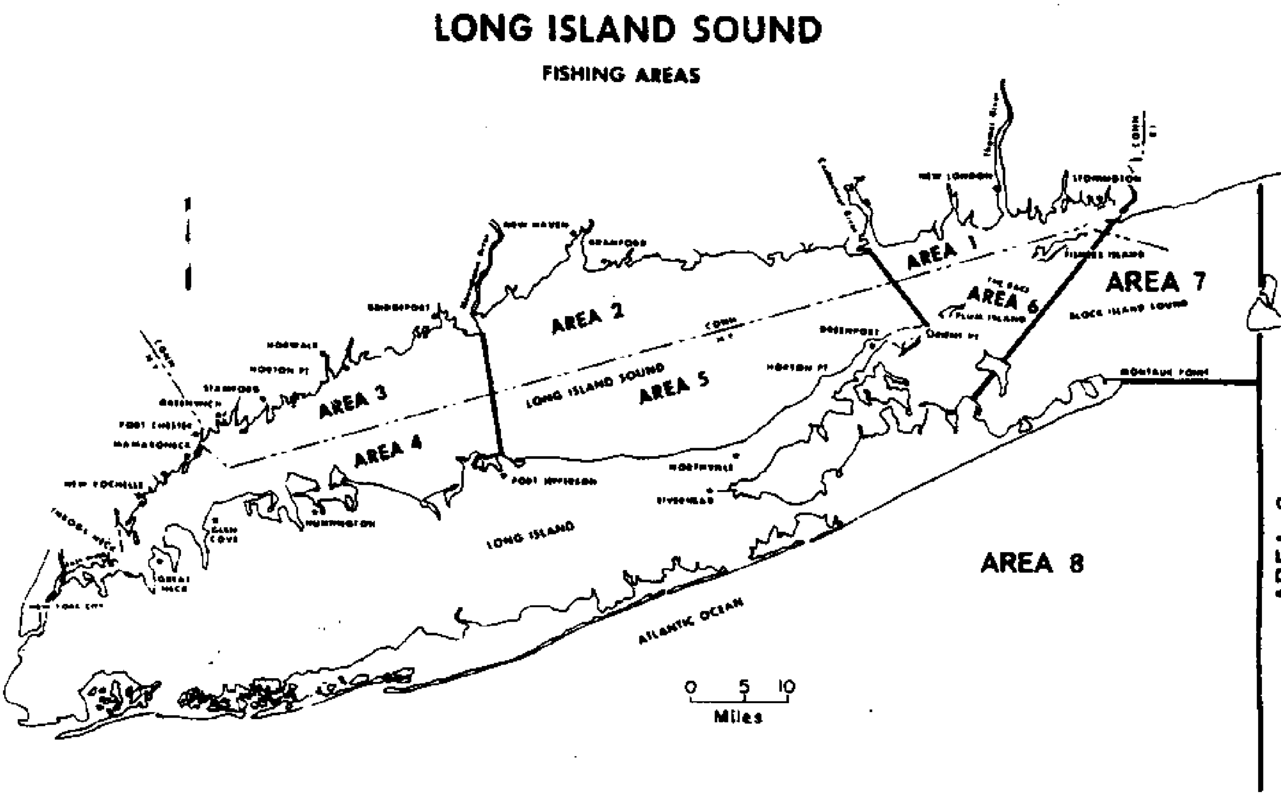


Fig. 6. Management areas of the Connecticut Department of Environmental Protection lobster fishery reporting system.

Individual records were grouped by SOD for each lunar quarter. For each record, the number of traps fished was multiplied by the number of SOD yielding trap haul set over days (THSOD) and summed for each SOD group. Catch was also summed for each SOD group. Total catch was divided by total THSOD for each SOD group within each lunar quarter, yielding catch per THSOD (CTHSOD) as a CPUE indicator for each level of fishing effort within each lunar quarter. A two-way analysis of variance was computed to determine effects of SOD and lunar quarter on CTHSOD.

3.0 RESULTS

3.1 Field Study. Six sets of the 16 traps were monitored and enumerated (Table 1). SOD varied for each set due to logistic limitations such as weather. Application of data for set 6 is limited due to excessive drift macroalgae fouling of individual traps. A total of 485 trap SODs were monitored during the course of this phase of the study.

3.11 Ingress and Escapement. Mean C/P/D for each SOD is shown in Table 2 and plotted in Fig. 7. A negative correlation of increasing SOD with catch is apparent. This data also shows a significant decline in catch after the first SOD and begins to level off at a low rate of catch after the fourth SOD.

Cumulative percentages of numbers of all lobsters ingressed by SOD from pooled data for all sets is presented in Table 3. These data

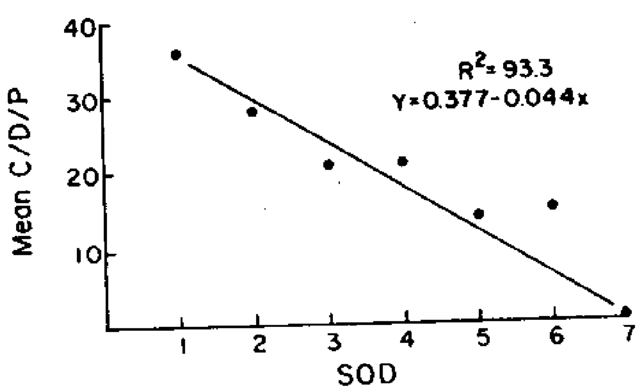


Fig. 7. Catch per pot per day (numbers) versus SOD of lobsters.

Table 1. Chronology of each set of 16 traps during the field portion of this study.

Set Number	Dates Inclusive (1982)	Remarks
1	10 Sept. - 17 Sept.	7 SOD
2	28 Sept. - 5 Oct.	7 SOD
3	10 Oct. - 16 Oct.	6 SOD
4	20 Oct. - 25 Oct.	5 SOD
5	17 Nov. - 22 Nov.	5 SOD
6	2 Dec. - 8 Dec.	Various SOD per trap due to macro-algal fouling.

Table 2. Mean catch-per-pot-per-day (C/P/D) in numbers of lobsters for sets 1 to 5.

SOD	Mean C/P/D per set	Mean C/P/D	Standard Deviation
1	.06	.36	.22
	.19		
	.50		
	.50		
	.56		
2	.25	.28	.10
	.19		
	.44		
	.31		
	.19		
3	.25	.21	.03
	.19		
	.19		
	.19		
	.25		
4	.19	.21	.13
	.13		
	.13		
	.44		
	.19		
5	.19	.14	.03
	.13		
	.13		
	.13		
	.13		
6	.19	.15	.08
	.19		
	.06		
7	.06	.06	0.0
	.06		

Table 3. Patterns of ingress of all lobsters into traps by set-over-day (sets one to five).

SOD	Percent Cummulative Ingress	Arcsine Percent Cummulative Ingress	Mean Arcsine Percent Ingress (S.D.)
1	1.00	90.00	90.00
	1.00	90.00	(0)
	1.00	90.00	
	1.00	90.00	
	1.00	90.00	
2	.80	63.43	43.95
	.50	45.00	(12.35)
	.47	43.28	
	.38	38.06	
	.25	30.00	
3	.44	41.55	31.36
	.33	35.06	(7.05)
	.17	24.35	
	.19	25.84	
	.25	30.00	
4	.25	30.00	26.06
	.18	25.10	(5.74)
	.10	18.43	
	.30	33.21	
	.16	23.58	
5	.20	26.57	20.34
	.15	22.79	(4.24)
	.09	17.46	
	.08	16.43	
	.10	18.43	
6	.17	24.35	20.58
	.19	25.84	(7.86)
	.04	11.54	
7	.05	12.92	13.55
	.06	14.18	(0.89)

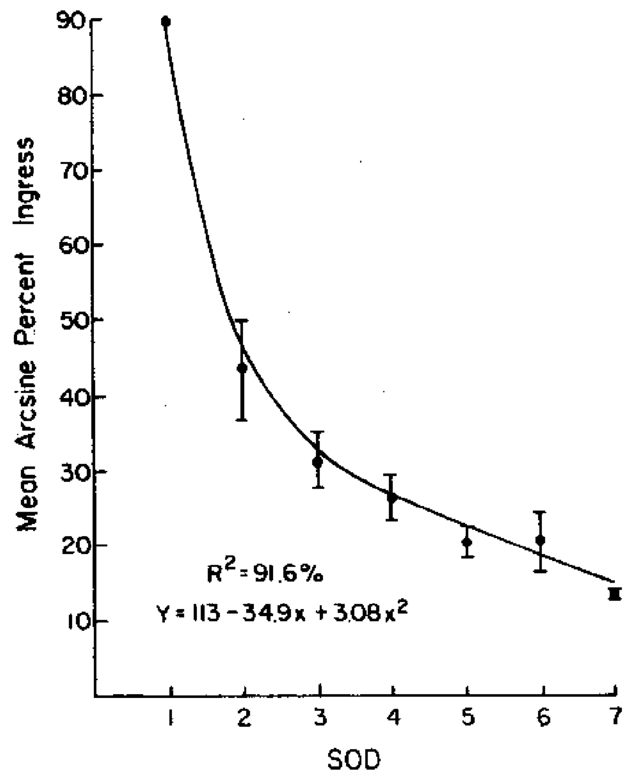


Fig. 8. Cumulative percent ingress versus SOD for all lobsters.

show the pattern of ingress as saturation increases. Ingress drops steeply after the first SOD (Fig. 8).

Cumulative escapement of all lobsters from pooled data for all sets is presented in Table 4. The data fit a second order regression with positive slope (Fig. 9). Escapement increases after the first SOD and reaches an asymptote after the fourth SOD. Data partitioned to include only lobsters of greater than 100% retention CL also demonstrates this pattern (Table 5 and Fig. 10).

Three instances of "funnel feeding" behavior were observed at commercially fished double side entry wood lath traps. Individual lobsters sat on the kitchen funnel and fed on bait in a mesh bait bag (flounder

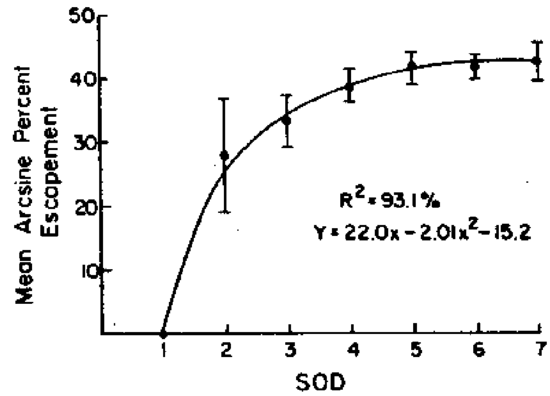


Fig. 9. Cumulative percent escapement versus SOD of all lobsters.

Table 4. Patterns of escapement of all lobsters from all traps by set-over-day (sets 1 to 5).

SOD	Percent Cummulative Escapement	Arcsine Percent Cummulative Escapement	Mean Arcsine Percent Escapement (S.D.)
1	0	0	0 (0)
2	.20	26.56	28.14 (8.10)
	.33	35.06	
	.07	15.34	
	.23	28.66	
	.33	35.06	
3	.22	27.97	33.97 (6.98)
	.33	35.06	
	.22	27.97	
	.31	33.83	
	.50	45.00	
4	.42	40.39	39.02 (5.31)
	.27	31.31	
	.35	36.27	
	.48	43.85	
	.47	43.28	
5	.53	46.72	42.44 (5.31)
	.38	38.06	
	.36	36.87	
	.44	41.55	
	.57	49.02	
6	.50	45.00	42.30 (3.72)
	.38	38.06	
	.48	43.85	
7	.53	46.72	43.27 (4.88)
	.41	39.82	

Table 5. Escapement of lobsters greater than or equal to 100% retention CL from all traps by set-over-day (sets 1 to 5; all intermolt condition).

SOD	Percent Cummulative Escapement	Arcsine Percent Cummulative Escapement	Mean Arcsine Percent Escapement (S.D.)
1	0	0	0 (0)
2	.50	45.00	25.01
	.00	0.00	(23.20)
	.00	0.00	
	.50	45.00	
	.33	35.06	
3	.20	26.56	26.70
	.00	0.00	(19.40)
	.11	19.37	
	.33	35.06	
	.63	52.53	
4	.33	35.06	32.81
	.00	0.00	(19.70)
	.30	33.21	
	.50	45.00	
	.60	50.77	
5	.57	49.02	41.72
	.33	35.06	(7.01)
	.36	36.87	
	.38	38.06	
	.58	49.60	
6	.62	51.94	47.11
	.66	54.33	(10.50)
	.33	35.06	
7	.56	48.45	51.39
	.66	54.33	(4.16)

frames in all instances). Pieces of the bait were torn off by the seizer chela and brought to the mandibles. The lobster had at least the rear two or three walking legs on the funnel meshes and only the first or second pair of walking legs over the ring. After feeding, the individuals backed out of the funnel and left the area of the trap. In all cases, there were one to several lobsters in the trap parlor and one in the kitchen feeding on the bait. In one case, Jonah crabs, Cancer borealis, were on the bait bag and on the outside top of the trap feeding on the bait (Fig 11).

Ingress experiments to determine when a lobster is actually within a trap, show that the point of no return (i.e. unable to back out) was after the third pair of walking legs was over the funnel ring (ten trials of lobsters placed directly on the funnel entrance). If the chelae were on a suspended bait bag in front of the entrance funnel,

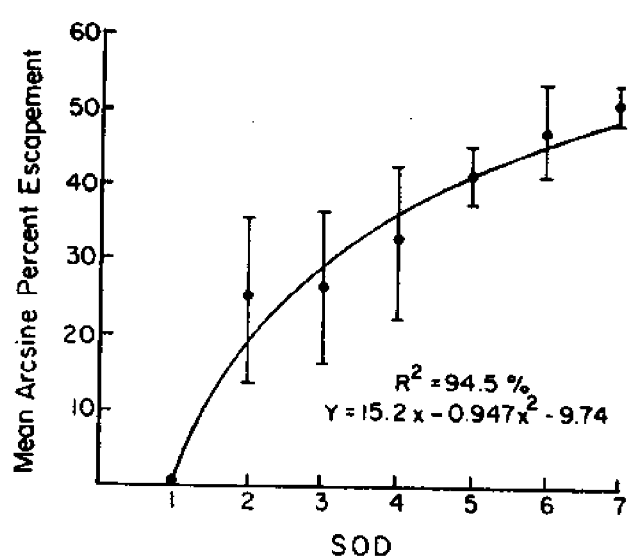


Fig. 10. Cumulative percent escapement versus SOD of ≥ 100% retention length lobsters.

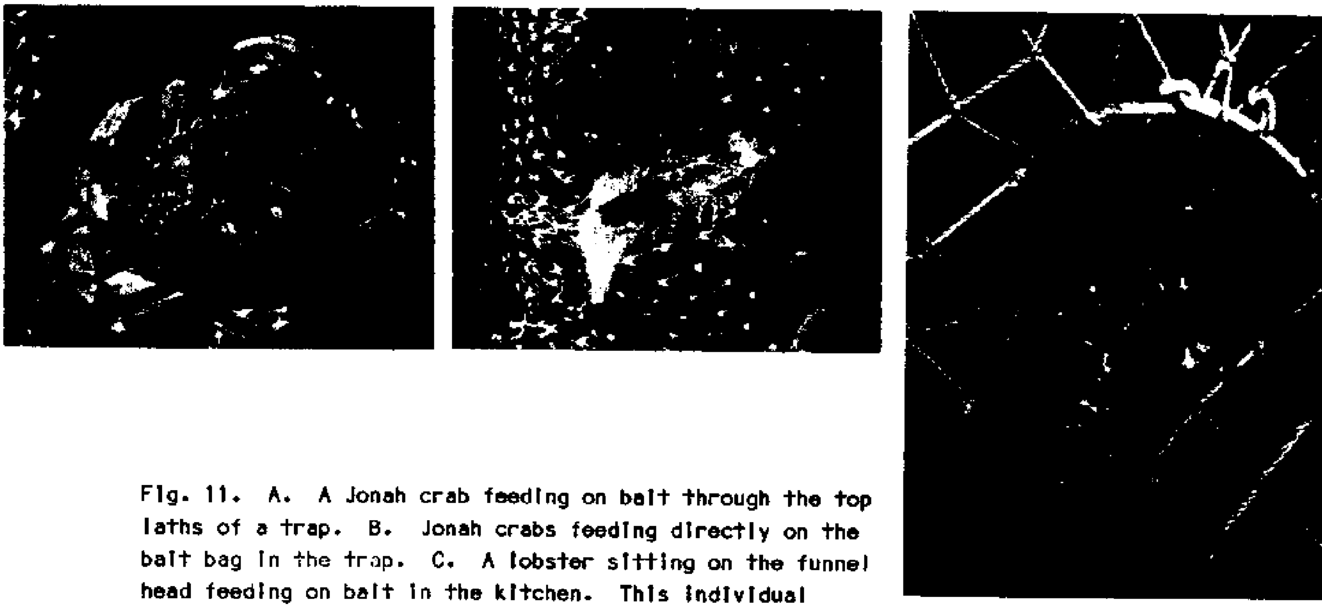


Fig. 11. A. A Jonah crab feeding on bait through the top laths of a trap. B. Jonah crabs feeding directly on the bait bag in the trap. C. A lobster sitting on the funnel head feeding on bait in the kitchen. This individual backed out of the funnel after feeding ceased.

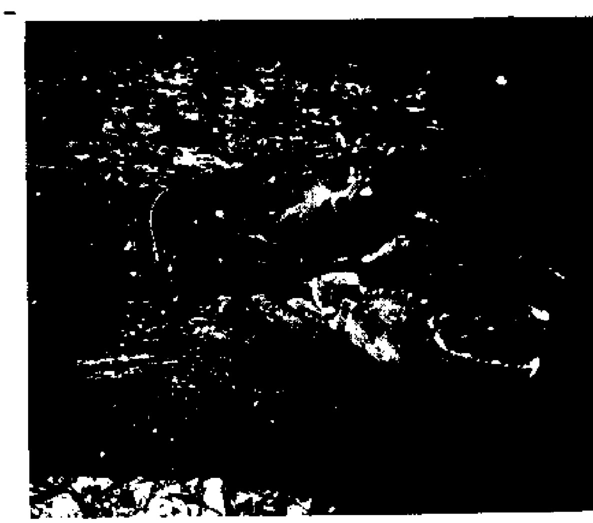
the point of no return was either after the third or fourth pair of walking legs was over the ring (five trials).

Ingress to single front entry and double side entry traps was observed on several occasions. Individuals walked through the kitchen funnel in either the anterior or posterior forward position (Fig. 12). No specific cue was observed which would account for the variability of ingress posture.

On four occasions, the behavioral escapement sequence of sublegal lobsters through the trap laths was observed. An upright or sideways posture was used which apparently depended upon carapace width and depth. Small sublegal lobsters with sufficiently small carapace depth were able to simply walk out of traps in an upright posture. Two individuals which exhibited this behavior walked out of the parlor, chelae first, through the laths. The lobsters then worked the walking legs through, one leg on each side at a time, until the entire body was free. Individuals too large to fit through the laths in an upright posture but with a carapace width capable of fitting through the laths went through in a side-ways posture (Fig. 13). Once chelae and walking legs were put through on one side, a sideways posture was assumed and the walking legs allowed the individual to "shimmy" through the laths freeing the rest of the body.

Fig. 12. A lobster entering a trap in the posterior forward position.

Fig. 13. The sequence of escapement through the laths of a trap. In A, the walking legs are passed through the laths. The individual turns sideways and shimmies through the space (B). Carapace width is the critical dimension for escapement.



Escape from the kitchen was not only observed for sublegal lobsters through the trap laths, but also for legal-size individuals through the funnel. The chelae were placed one over the other into the funnel ring and pressed down, lifting the body up (Fig 14). The forward walking legs grasped the funnel webbing and the lobster worked one leg, then the next, over the ring to the outside and lifted itself out onto the funnel. Eighteen percent of the ingressed lobsters which were greater than 100% retention CL and were observed in the kitchen, escaped during this study.

Escapement behavior of other crustacean bycatch was similar to lobsters. Jonah crabs exited traps through the bottom, side or top laths in a normal sideways locomotion and were limited by carapace depth.

Fig. 14. An individual escaping the kitchen through the funnel. The chelae are used to lift the individual up so the walking legs can pass through the funnel webs. The individual then works its way over the ring and out of the trap.

Fig. 15. Escapement of crustacean bycatch was limited by carapace depth. This Jonah crab is escaping through the top laths of one of the study traps.

Small Jonah crabs moved freely in and out of traps and on and over the bait bag through the top laths.

Spider crabs, Libinia emarginata, exited traps from all areas in the same manner as Jonah crabs, again limited by carapace depth (Fig. 15). Fish generally stayed in the middle of the parlor. There were no observations of sea raven, Hemitripterus americanus, escapement but tautog, Tautoga onitis, routinely moved in and out of traps through the lath in a sideways swimming motion.

3.12 Effects of Non-Target Catch. Spider crabs were the most abundant non-target catch species. The second most numerous species was the sea raven, followed by Jonah crabs. The position of spider crabs within each trap was generally on the sides and top laths of the parlor, while lobsters normally occupied the bottom level. Non-target fish catch generally occupied the bottom level or all levels of the parlor. Generally, lobsters were not present when fish were in the catch.

Analysis of the occurence of lobster and non-target species in individual traps revealed a significant negative effect of the catch of one type on the other. Chi-square analysis of the presence or absence of both lobster and non-target catch in a 2 x 7 table (Table 6) indicate a significant negative correlation ($p < 0.01$).

Table 6. Non-target catch effects on the catch of lobsters in baited wood lath traps (chi-square test of independence). Numbers in each cell are observed frequency, expected frequency and contribution to total chi-square. Non-target species are: SC, spider crab (Libinia emarginata); T. tautog (Tautoga onitis); SR, sea raven (Hemitripterus americanus); JC, Jonah crab (Cancer borealis); BC, blue crab (Callinectes sapidus); and HC, hermit crab (Pagurus pollicaris).

		Non-target Species							
		SC	T	SR	JC	BC	HC	No non-target species	Totals
Lobster	Present	25 48.5 11.40	0 5.2 5.25	3 13.1 7.80	4 10.9 4.39	2 1.3 0.36	0 1.3 1.31	178 131.6 16.38	212
	Absent	86 62.5 8.85	12 6.8 4.07	27 16.9 6.06	21 14.1 3.41	1 1.7 0.28	3 1.7 1.02	123 169.4 12.72	273
	Totals	111	12	30	25	3	3	301	485

$\chi^2 = 83.31$; 6 d.f.; $p < 0.01$

3.13 Position Preference in Traps. Analysis of daily logged positions of lobsters (Table 7) in the parlor (under head, sides by head, sides opposite head, center) at densities of 1, 2, 3, and 4 lobsters indicate a preferred position under the parlor head (X^2 test, $p < 0.005$). Single individuals generally took positions directly under the parlor head. Individuals generally took positions at the trap sides by the head at densities of 2 lobsters per trap. Positions opposite the head and in the center were occupied by some individuals at higher densities. Generally the less-preferred positions were occupied by smaller size class or body-damaged individuals.

One individual was cannibalized in the parlor during the course of this study and only one instance of nonfatal, physically damaging aggression in the form of two autotomized chelae was observed. The aggressor was of a larger size class than the individual damaged or killed.

Table 7. The distribution of positions of lobsters in the trap parlor at four densities. The 4 x 4 table is tested for homogeneity of distribution. Numbers in each cell indicate observed frequency, expected frequency and contribution to total chi-square value.

		Under Funnel	Corner By Funnel	Corner Opposite Funnel	Sides	Total
Density of Lobster	1	75 50.6 12.70	10 33.6 16.55	11 9.7 0.18	2 5.1 1.90	99
	2	10 28.6 12.13	40 19.0 23.25	5 5.5 0.04	1 2.9 1.24	56
	3	2 7.7 4.19	8 5.1 1.67	0 1.5 1.47	5 0.8 23.00	15
	4	1 2.0 0.53	1 1.4 0.09	1 0.4 0.95	1 0.2 3.04	4
Totals		89	59	17	9	174

$\chi^2 = 102.93$; 9 d.f.; $p < 0.005$

Position preferences of the non-target catch species in traps was difficult to enumerate since their behavior was highly variable during observation periods. Positions through an observation period were maintained by some animals while others would move about within the trap. In general, however, all non-target catch species showed no apparent position preference within the trap parlor. No individual displaced any lobster from preferred positions but simply utilized available unoccupied areas in the parlor.

Several lobsters were observed burrowed under traps or sheltered under blades of kelp fouled on traps. No interactions of these individuals with catch in the trap was seen, and no apparent effect on position of catch in the trap was discerned.

3.2 Effects of Current Velocity on Behavior and Catch

3.21 Flume Study. The analysis of the effects of current on position (Table 8) indicated that lobsters will seek a refuge from current at some critical velocity (X^2 test, $p < 0.005$). Lateral movements, hence maneuverability, were also significantly restricted at increasing current velocities (X^2 test, $p < 0.005$) (Table 9).

Lobsters exhibited general specific postures at low and high current velocities (Table 10). At zero and low current velocities, indivi-

Table 8. The changes in position of lobsters in a flume at increasing current velocities (Chi-square test of independence).

Current Velocity (cm/s)	Position in Flume: Current Lee	Turbulent	Exposed Shelter	Total
0	25 68.4 27.54	40 35.6 0.54	175 136.0 11.18	240
22	20 68.4 34.25	37 35.6 0.06	183 136.0 16.24	240
30	42 68.4 10.19	57 35.6 12.86	141 136.0 0.18	240
37	63 68.4 0.43	24 35.6 3.78	153 136.0 2.13	240
46	192 68.4 223.35	20 35.6 6.84	28 136.0 85.76	240
Total	342	178	680	1200

$\chi^2 = 435.33$; 8 d.f.; $p < 0.005$

Table 9. The effect of changes in current velocity on the lateral movement of lobsters in a flume (Chi-square test of Independence).

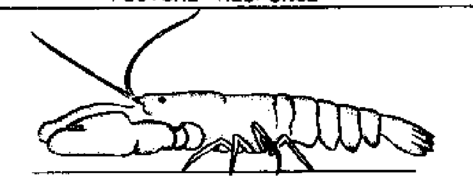
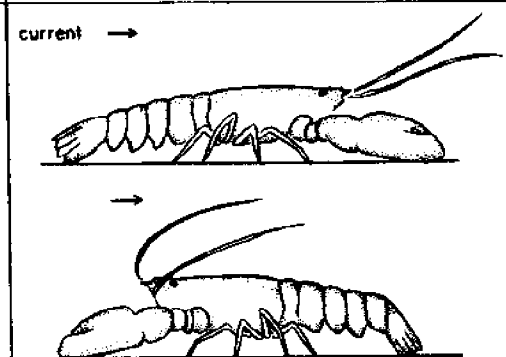
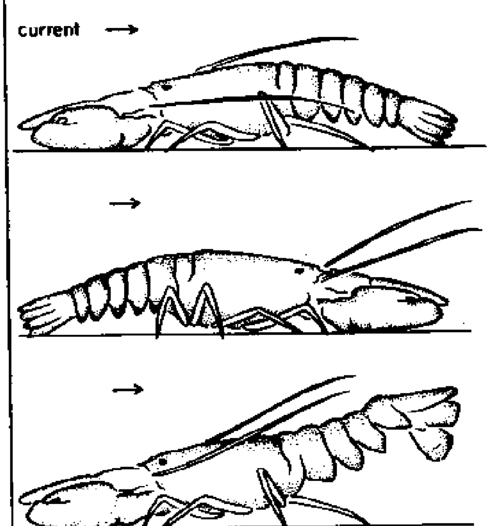
Current Velocity (cm/s)	Position in Flume: Side	Center	Side	Total
0	38 14.4 38.68	168 211.0 8.76	34 14.6 25.78	240
22	26 14.4 9.34	187 211.0 2.73	27 14.6 10.53	240
30	5 14.4 6.14	226 211.0 1.07	9 14.6 2.15	240
37	2 14.4 10.68	237 211.0 3.20	1 14.6 12.67	240
46	1 14.4 12.47	237 211.0 3.20	2 14.6 10.87	240
Total	72	1055	73	1200

$\chi^2 = 158.27$; 8 d.f.; $p < 0.005$

duals were generally unlimited in their mobility, and postures were erect (off the substrate). The carapace and tail segments were elevated from the substrate by the walking legs, chelae were raised and forward, and antennae positions were variable and probing in all directions. Mobility was restricted and postures of individuals were generally low and close to the substrate at higher current velocities. The carapace and tail segments were depressed to the substrate, chelae were also drawn close to the body and held down to the substrate and antennae were forced into the downstream position. Occasionally, individuals facing into the current would exhibit an elevated tail posture with body and chelae depressed to the substrate. In all high current postures, walking legs were braced against the substrate in

TABLE 10

LOBSTER POSTURE IN RELATION TO CURRENT VELOCITY

CURRENT VELOCITY	POSTURE RESPONSE	NOTES ON BEHAVIOR
0 to less than 15 cm/sec.		–Erect, off-bottom posture –Chelae forward, off bottom –Tail off bottom –Telson fanned and horizontal or vertical –Antennae posture variable over potential range
Slight current 22 cm/sec.		–Erect, off bottom posture –Chelae and tail not as high off substrate –More hydrodynamically stable posture –Antennae movements influenced by current
Fast current 46 cm/sec.		–Body down to substrate –Walking legs braced –Chelae down to substrate –Tail down to substrate (occasionally up when antennae pointed upstream) –Antennae swept in direction of flow

the chamber with movements utilizing slow and short distance steps of one leg at a time.

3.22 Time-Lapse Study. Inspection of 2000 frames from the time lapse/current meter deployment revealed no lobsters or crabs were present around the bait during the functional period of the camera system. The bait was consumed from the bag after fifty hours when the system was recovered.

Figs. 16 and 17 show the current speed and direction respectively at Ram Island Reef during the deployment. Note the variability in the current speed and direction over several fifteen-minute intervals. Current speeds recorded in this area were in the range of speeds used in the flume study.

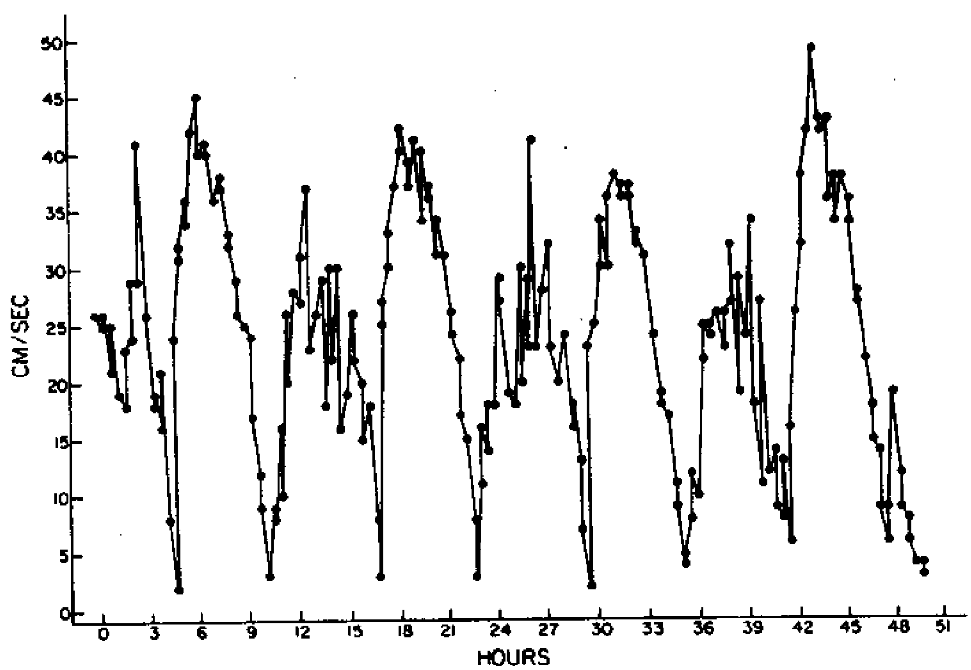


Fig. 16. Current speed (cm/s) versus time at Ram Island Reef during the current meter/time lapse camera deployment.

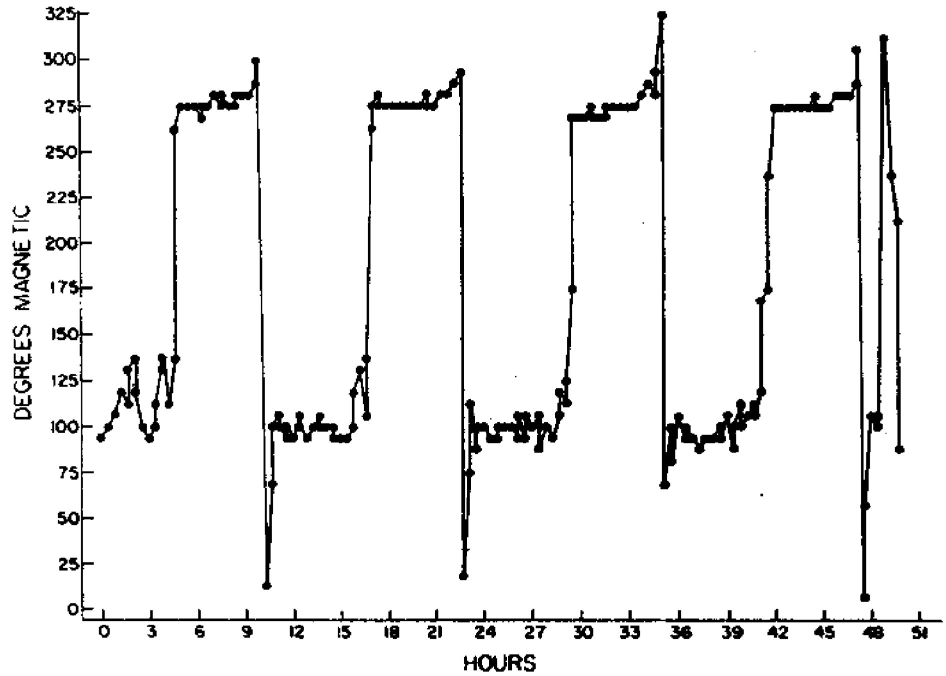


Fig. 17. Current direction versus time at Ram Island Reef during the current meter/time lapse camera deployment.

3.23 Connecticut Trap Fishery Logbook Analysis. The two-way analysis of variance (Table 11) revealed there was no significant difference in CTHSOD between lunar quarters ($F = 0.786$, $p > 0.250$). A significant effect of SOD on CTHSOD was discerned ($F = 8.882$, $p < 0.005$) and t-tests revealed CTHSOD on the first SOD was significantly different from the rest of the SODs ($p < 0.05$).

4.0 DISCUSSION

The pattern of C/P/D is consistent with the pattern discerned by Skud (1979) in the offshore lobster trap fishery. This pattern provides a validation for this data set for a more refined analysis of ingress and escapement dynamics.

Table 11. Two-way analysis of variance of Connecticut trap fishery CTHSOD by SOD versus lunar quarter.

Due to	DF	SS	MS=SS/DF	F
SOD	4	258386	64597	8.882 sig.p<0.005
Lunar Quarter	4	22853	5713	NS
Error	16	116373	7273	
Total	24	397612		

Trap ingress and escapement patterns of lobsters reach asymptotic levels within the same time frame. This pattern is predicted from catch models in fixed gear fisheries (Gulland, 1955; Munro, 1974; Bennett and Brown, 1979), where gear reaches levels of saturation after time t, and escapement also increases to a level where ingress maintains catch at saturation levels. After a time t + x, escapement exceeds ingress and total catch falls below saturation levels. Therefore, while saturation effects are apparent in landed catch, the occurrence of individuals in the trap at any specific time is dynamic. Escapement is not totally random but exhibits a predictable pattern. Probability of escape increases with time as more attempts at escape are made. Asymptotic patterns in cumulative escapement have been documented in several trap fisheries (Munro, 1974; High, 1976; High and Worlund, 1979). These patterns are further complicated by size class retention characteristics of the gear (Templeman, 1939; Wilder, 1945; Fogarty and Borden, 1980), where one would expect a correlation in number of escape attempts, before successful escape, with increasing size class.

Funnel feeding at the trap head, if a common occurrence, may be a factor limiting the catchability of specific size classes of lobster. The critical distance for capture, from the observational data, is from the rear of the carapace to the tips of the extended chelae. The distance from the edge of the funnel ring to the bait should be greater than the distance between the posterior edge of the carapace and the tip of the extended chelae for the size class lobster desired to ingress with 100% efficiency. For an economic and productive fishing strategy, the optimum funnel ring to bait distance would depend on the size class lobsters present in the fishing area, which has been found to be generally limited by available habitat (Stewart, 1972). Funnel feeding also prevents other individuals from entering the trap.

Lobsters may not enter traps only for food (when an anterior forward position would be appropriate) but also for shelter (where either posture would seem equally appropriate depending upon circumstances). This would explain reported cases of ghost traps with no bait having large catches of lobster. For example, Smolowitz (1978) cited an instance of recovering a trawl of 18 ghost traps from which 24 lobsters (156.5 pounds) were landed after the trawl had been untended from 17 March to 26 May, 1968.

The observed behavioral repertoire of escapement of lobsters through the trap laths was similar to that reported by Nulk (1978) for escapement of sublegal lobsters through escape vents in a laboratory experiment. The critical body dimension he discerned for escapement was carapace width. These data are consistent with his previous observations and indicate that carapace width is the critical dimension for escape in other trap designs.

Escapement through the trap head is a non-size selective factor since an individual which obviously entered the trap through it theoretically should be able to exit through it. In fact, since the escapement behavior requires the chelae to pull the body up, larger animals may have a higher probability of escapement using this tactic, since they can reach the funnel ring more easily than smaller ones. Crustacea are, however, noted for their ability to find a way out of a trap. For example, Miller (1979) noted C. productus could make 180^{o} turns on a funnel head to escape. Smaller lobsters may also be able to execute such a maneuver.

The negative effect of non-target catch on the catch of lobsters and vice versa found in this study may explain some of the high trap to trap variability in catch characteristics of the fishery. Richards et al. (1982) showed that while traps stocked with lobsters reduced the catch of Jonah crabs, rock crabs (C. irroratus), and lobsters, traps stocked with crabs had no significant effect on lobster catch.

The difference in effects of non-target catch may be due to gear type, the mixed species composition of the non-target catch in the present study, or differing behavioral interactions with the various non-target catch species. For example, in the present study, tautog and sea raven were a routine part of the non-target catch. These species are predators of lobsters (Cooper and Uzmann, 1980) and may provoke a negative reaction from lobsters around the trap. Other non-target catch such as Jonah crab are competitors. Jonah crabs have been noted to passively displace lobsters from burrows and vice versa (Lund et al., 1971; Stewart, 1972; Lund et al., 1973; Fogarty, 1975), so direct negative interactions in traps may not be readily apparent.

Observations of lobster position preference in this study are consistent with aquaria studies of dominance hierarchies in lobsters (Stein et al., 1975). Although linear hierarchies have not been observed, size, sex and molt state have been identified as factors influencing these types of hierarchical interactions.

Space limitations due to preferred positions in traps may, in part, limit catch and contribute to saturation effects. Position preference at four densities demonstrated that lobsters prefer a position under the head, out of direct light, with tactile contact points surrounding the animal. These criteria have been found to be important determining factors in the lobster's selection of natural shelter sites as well (Cobb, 1971).

Pecci et al. (1978) noted that Jonah crabs apparently dominated lobsters in obtaining preferred sites within traps. In contrast, Richards et al. (1982) showed that Jonah crabs and rock crabs moved to higher vertical positions in the traps in the presence of lobsters. The present study also demonstrates that lobsters dominate preferred sites in traps. Differences in the outcome of these studies may be due to various interspecific interactions related to size class, sex, prior agonistic experience (Scrivener, 1971; Atema and Cobb, 1980), or prior residence effects (O'Neill and Cobb, 1979), all of which have been shown to affect the outcome of agonistic encounters.

Saturation effects may not be due solely to within-trap interactions. Miller (1979, 1980) observed agonistic interactions in laboratory aquaria between rock crabs, C. productus and Hyas araneus approaching baited traps from downstream, and found they often left the trap area when catch was high. He suggesed that agonistic interactions of trapped animals with approaching animals created the saturation effect. No observations of lobsters engaged in this activity were made during this study although several animals were observed burrowed under traps, unaffected or at least not interacting with the catch in the traps. However, the increased density of animals burrowed around individual traps may deter other animals from approach.

Interactions of individuals resulting in injury in traps was lower in this study than the literature indicates. In a ghost trap study, Pecci et al. (1978) found 16 to 47 percent injured lobsters in traps monitored from 79 to 111 days. Smith (1977) determined 33% of lobsters landed in the Connecticut trap fishery in 1976 had some form of body injury. Saturation levels in different types of traps may create situations in which agonistic interactions increase, perhaps causing the observed incidence of damage in landings.

Lobsters have specific behavioral patterns for dealing with changes in current speed. Howard and Nunny (1983) and Maude and Williams (1983) described these patterns for Homarus gammarus and Cambarus spp.. There seems to be general decapod behavior patterns for dealing with current speeds in excess of some critical velocity in which movement is inhibited. Substrate type (for gripping the bottom) and relief (for reducing near bed current speeds) would be limiting factors.

The analysis of logbook data showed no effect of lunar stage, which reflects cyclic changes in current speed and lunar illumination, on CPUE. This pattern, however, may be an artifact of the distribution of the fishing gear. Nearbed current velocities vary both spatially and temporally. The form of the basin affects the spatial variation of the current and cyclic variations in tidal stage affect the temporal aspect of this regime. The distribution of lobster habitat, the actual current velocity experienced by individual lobsters, and the distribution of traps will result in variation in the catch. The behavioral data suggests lobster movements may be restricted in areal extent by variations in tidal current speed, but further study is required to understand how these patterns affect catch.

Catch patterns found in this study should hold over all seasons since other studies in the Gulf of Maine (Thomas, 1973) and offshore canyon fisheries (Skud, 1979) have shown landed catch patterns to be similar over all seasons. The magnitude of catch will of course change due to a variety of factors such as temperature (McLeese and Wilder, 1958) and molt state, which affect activity patterns and hence availability to the fishery (Stewart, 1972).

The data presented here do not explain why, during spring and fall "runs" (sensu Stewart, 1972) resulting from post molt activity, CTHSOD increases greatly. This pattern of runs is reflected in the catch data of the Connecticut trap fishery (Smith, 1977). Stewart (1972) found that lulls in activity and catch of lobsters in the Long Island Sound region resulted from greater than 30% of inshore lobsters exhibiting mass ecdysis in spring and fall, with resultant decreases in foraging activity. Summer decreases in catch rate in nearshore areas resulted from increases in water temperature and movement of lobsters to deeper, cooler water. Lobster "runs" resulted from simultaneous increases in post-molt foraging activity and availability to the fishery. This relatively simultaneous increase in post-molt foraging activity, great increases in catch, and apparent reduction of hierarchical interaction around traps, may result from reduced intraspecific agonistic responses due to molt state and shell condition (Atema and Cobb, 1980).

Caddy (1977) discusses the utility of correcting catch data in relation to the types of variables examined in this study for use in predictive fishery models and for assessment purposes. For example, when simply considering the effect of SOD, fishing mortality will be over-estimated if the decreasing probability of capture is not taken into account when calculating total fishing effort (Ricker, 1975).

The accumulation of sufficient immersion time data by experimental fishing in order to discern effects of variables which affect catch, is time-consuming. This is why most data used in previous studies were taken from commercial fishing logs. It is difficult to utilize commercial catch data as trap types are not standardized (i.e. number of funnels, trap material, funnel configuration), or fished in a standard manner (i.e. set in relation to current, bottom type, depth, bait type, trap spacing along trawl or on grounds), although in most cases this is the only data set available or practical for use in assessment and management schemes.

5.0 SUMMARY

1. Total C/P/D (both legal and sublegal) in this study is consistent with patterns discerned in previous studies which used surface hauled trap data.

2. The ingress and escapement of lobsters follows a negative and positive asymptotic function, represctively. These data fit models used to describe fixed gear fisheries in general and can be applied with more confidence to the lobster trap fishery.

3. Lobsters have preferred positions in the trap parlor which may limit preferred habitat space effecting saturation levels in this type of gear.

4. Non-target catch has a negative effect on the catch of lobster and vice versa.

5. A behavior termed "funnel feeding" is described. This reduces the catchability of individuals greater than a critical size and prevents

other individuals from entering the trap.

6. Individuals enter traps with either anterior or posterior ends of the body forward. This behavior infers lobsters enter traps not only to feed on the bait but also possibly for shelter, defense or other unapparent reasons.

7. Individual lobsters are limited in their escape through the laths by their carapace width, crabs by carapace depth, roundfish by widest diameter and laterally compressed fish by width.

8. Lobsters have a behavioral repetoire of postures and movements for dealing with changing current velocities.

9. Logbook records from the Connecticut trap fishery indicate no significant difference in CPUE between lunar quarters. This indicates catch is not affected by changing current velocity regimes associated with changes in lunar quarter or with changing lunar light intensity. However, this pattern may be due to stratified fishing gear distribution and may not reflect limits on the activity of individual lobsters.

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