EFFECTS OF EXPOSURE AND CONFINEMENT ON SPINY LOBSTERS, *PANULIRUS ARGUS*, USED AS ATTRACTANTS IN THE FLORIDA TRAP FISHERY

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ABSTRACT

Traps in the south Florida spiny lobster fishery are baited with live sublegal-sized lobsters (shorts), many of which are exposed for considerable periods aboard vessels before being placed in traps and returned to the sea. Average mortality rate of lobsters exposed ½, 1, 2, and 4 hours in controlled field tests was 26.3% after 4 weeks of confinement. About 42% of observed mortality occurred within 1 week after exposure, indicating exposure to be a primary cause of death. Neither air temperature during exposure nor periodic dampening with seawater had significant effects on mortality rate. Mortality among confined lobsters increased markedly in the Atlantic oceanside but not in Florida Bay during the fourth week of confinement following exposure, probably because more natural food organisms entering traps from nearby seagrass beds delayed starvation at the latter site. Mortality caused by baiting traps with shorts may produce economic losses in dockside landings estimated to range from $1.5 to $9.0 million annually.

The fishery for spiny lobster, *Panulirus argus*, in south Florida utilizes a method of baiting traps that is apparently unique among fisheries worldwide. Sublegal [<76 mm carapace length (CL)] lobsters, locally called "shorts", are confined in traps as living attractants for legal-sized lobsters. Shorts have been demonstrated to be effective attractants of other lobsters (Yang and Obert 1978; Lyons and Kennedy 1981; Kennedy 1982). Some use of shorts as bait in the Florida fishery occurred as early as the 1950's (Cope 1959), but use increased appreciably after 1965 when the minimum legal size was reduced from 1 lb (about 79-80 mm CL) to 3 in (76 mm) CL, and the fishery expanded from Atlantic oceanside reefs and flats into Florida Bay where availability of shorts is considerably greater (Lyons et al. 1981). The practice was widespread but illegal during early years of its use (Wolfferts 1974) and only received legal sanction in 1977. Today, bonded fishermen are allowed to possess as many as 200 shorts aboard a vessel for use as bait. Shorts are customarily kept in wooden boxes on deck until replaced in traps, and exposure times vary from several minutes to 1 h or more. As many as 1 million shorts may be confined in traps as bait during peak portions of the harvest season (Lyons and Kennedy 1981).

During 1979, the Florida Department of Natural Resources initiated a study in which baiting practices in the fishery were mimicked under controlled conditions to determine whether starvation occurred among lobsters confined in traps for long periods. So much mortality occurred among tested lobsters during the first 2 wk of confinement that the study was redirected toward causes of that mortality. Exposure was strongly implicated by preliminary results (Lyons and Kennedy 1981). Spokesmen for the fishing industry suggested that observed mortality was caused by other factors related to experimental design, prompting expansion of the program to test those factors.

This report presents results and conclusions from that expanded program. The relationship between exposure and mortality is examined, including influences of season and location. Mortality rates of lobsters held dry or periodically dampened prior to placement in traps are also compared. Results from this study are used in a model which estimates the relative importance of baiting mortality to economics of the fishery.

METHODS

Mortality rates of spiny lobsters used to bait traps were measured in Florida Bay 3 km north of Vaca Key and in the Atlantic Ocean 6 km south of Vaca Key. The Florida Bay site was located in shallow water (~3 m) with a muddy sand substrate overlain by seagrass beds. The ocean site was located in

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deeper water (~8 m) just inside the reef tract; the bottom consisted of a mosaic of scattered seagrasses, small patch reefs, and open areas of coarse sand. Salinities at both sites ranged from 34‰ to 36‰ and water temperature ranged seasonally from 17° to 29°C.

The effect of exposure was examined at both sites. Lobsters were held in shaded boxes for ½, 1, 2, and 4 h and then placed in traps. Entrances were sealed, and no lobsters were added after treatments were established. Each treatment utilized 5 standard wooden slat lobster traps; each trap contained 3 lobsters (total 15 lobsters/treatment) for each exposure period. Control treatments (minimum exposure) also consisted of 5 traps each containing 3 lobsters, but these lobsters remained in traps in which they were originally captured and were exposed only for the time required to clean, seal, and return a trap to the water. Intent was to place sublegal lobsters in all traps, but use of some larger lobsters was necessary to conduct experiments. Traps in oceanside experiments were reinforced with wire mesh sides to reduce damage by loggerhead turtles, *Caretta caretta*; traps in Florida Bay were not reinforced with wire sides.

In Florida Bay, all lobsters exposed ≥1 h were dampened every ½ h by pouring a bucket of seawater into the porous holding box, whereas equal numbers of lobsters exposed ≥1 h in oceanside tests were always treated with and without seawater dampening every ½ h to test the effect of dampening. Control and ½-h treatments were the same in dampened (wet) and undampened (dry) tests because their total exposure periods were less than or equal to the period between dampenings.

After initiation, all experiments were sampled at 1-wk intervals for 4 wk by pulling each trap and counting remaining live lobsters. The mortality estimate is a combination of missing lobsters and those observed to be dead. Several lines of evidence indicate that missing lobsters died and did not escape. Only lobsters too large to fit between trap slats were used in experiments, and trap entrances were boarded shut to seal the ordinary avenue of departure. Additionally, observations made during frequent dives at traps where lobsters died during other experiments indicated that carcasses could be broken up sufficiently by scavengers within 24 h after death to wash through slats when traps were pulled.

All original data, taken as number of living lobsters remaining in a trap each week, were converted to weekly mortality rates calculated as the number of lobsters that died during that week divided by the initial density during that week. This method provided the only independent, noncumulative estimate of mortality. All other methods biased the data by either increasing the weight given to deaths later in the experiment or altering mortality estimates because of trap losses. Although this method provided unbiased estimates of mortality, data still were not normally distributed, so all testing of treatment means used nonparametric Wilcoxon Two Sample Tests (Sokal and Rohlf 1969) to determine where the differences of significance occurred. Standard notations are used to designate signi-

TABLE 1.—Average weekly spiny lobster mortality (%) for each location, exposure period, and wet or dry treatment. N = number of traps; $\bar{x}$ = mean; SE = standard error; W = wet; D = dry.

Treatment		Initial	Week after initial exposure: Week 1			Week 2			Week 3			Week 4			Cumulative mortality
		N	N	$\bar{x}$	SE	N	$\bar{x}$	SE	N	$\bar{x}$	SE	N	$\bar{x}$	SE	%
Florida Bay															
Control		15	15	0.0	0.0	15	0.0	0.0	15	2.2	2.2	15	0.0	0.0	2.2
½ h		20	20	8.3	5.3	19	3.5	3.5	18	0.0	0.0	17	0.0	0.0	11.8
1 h	W	20	17	7.8	3.5	17	3.9	3.9	16	6.2	3.4	16	6.2	6.2	24.1
2 h	W	20	18	14.8	5.5	18	1.8	1.8	18	1.8	1.8	18	3.7	2.5	22.1
4 h	W	20	20	15.0	5.6	19	5.3	2.9	19	5.3	2.9	18	0.0	0.0	25.6
Atlantic Reef															
Control		29	28	4.8	2.8	23	1.4	1.4	23	0.0	0.0	27	7.4	3.2	13.6
½ h		29	29	8.0	3.6	24	1.4	1.4	23	4.3	4.3	27	12.3	4.8	26.0
1 h	W	29	29	16.1	4.8	24	9.7	3.7	19	7.0	4.1	24	12.5	5.2	45.3
	D	29	29	11.5	3.8	24	9.7	5.1	22	4.5	2.5	27	11.1	5.3	36.8
2 h	W	29	29	13.8	5.1	17	3.9	2.7	15	4.4	3.0	20	5.0	2.7	27.1
	D	29	29	16.1	5.4	23	5.8	2.7	22	4.5	2.5	24	5.6	3.3	32.0
4 h	W	29	29	12.6	3.8	23	4.3	3.2	19	8.8	6.2	22	6.1	2.8	31.8
	D	29	29	11.5	4.1	21	7.9	4.5	18	1.8	1.8	23	1.4	1.4	22.6

ficance at probability levels of 0.05, 0.01, and 0.001.

Weighted cumulative average mortality values were obtained by multiplying the relative effort (%) in each treatment (e.g., site, exposure period ≥½ h) by the cumulative mortality for that treatment and then summing those values.

RESULTS

The mortality experiment was conducted four times between January and September 1980 in Florida Bay and six times between May 1981 and June 1982 near Atlantic reefs. Wet vs. dry tests were conducted with each oceanside replicate. The unweighted average cumulative mortality calculated from Table 1 for all lobsters exposed ½, 1, 2, and 4 h, both sites combined, was 26.3% at the end of 4 wk. Average weighted cumulative mortality in Florida Bay was 20.8%, and that near Atlantic reefs was 31.9%. When weighted for relative effort at each site, the overall mortality rate increased to 28.5%.

No tests were established at oceanside stations during December, January, or February, so effects of air and water temperatures on mortality during exposure were tested only in Florida Bay. Of four tests conducted there, two were established during cool months (January, February; air 15.2°-21.0°C, water 17.0°-17.5°C during initiation), and two were established during warm months (May, September; air 27.6°-33.5°C, water 29.3°-29.5°C). Mean weekly mortality rates of lobsters during these tests (winter $\bar{x}$ = 4.4%; summer $\bar{x}$ = 4.6%) were not significantly different.

Average mortality rates obtained in wet vs. dry treatments (Table 1, Fig. 1) were not significantly different for any exposure or subsequent confinement period. Furthermore, neither wet nor dry treatments consistently caused greater mortality.

Because all Florida Bay lobsters were dampened when exposed ≥1 h, comparisons of bay vs. ocean mortality rates were made using wet treatments only. All five treatments (Control, ½, 1, 2, and 4 h) were combined and overall mean weekly mortality rates were compared. The average weekly mortality rate of lobsters in bay tests ($\bar{x}$ = 4.5%) differed significantly (Z = 2.51, $P < 0.05$) from that of lobsters tested in the ocean ($\bar{x}$ = 7.6%).

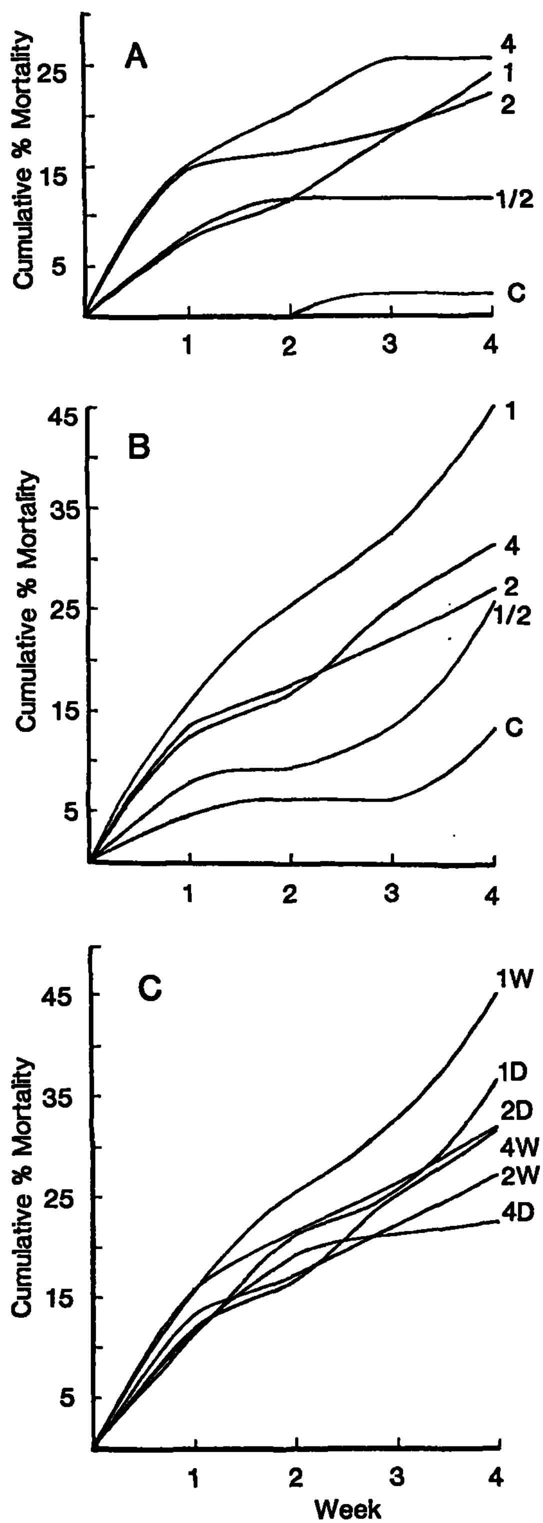

FIGURE 1.—Cumulative mortality rates (%) for exposure tests: A. Florida Bay, wet only; B. Atlantic reefs, wet only; C. Wet (W) vs. dry (D), Atlantic reefs only. C = controls; exposure periods = ½, 1, 2, and 4 h.

Comparisons of each exposure period within a treatment with every other exposure period within that treatment are shown in Table 2. In the bay, mortality rates experienced by controls were significantly different than those of lobsters exposed 1, 2, or 4 h. Additionally, lobsters exposed ½ h suffered a significantly lower mortality rate than did those exposed 4 h. However, some of these differences were not significant among lobsters exposed at the Atlantic reef site. Among dampened lobsters tested there, only the mortality rate of those exposed 1 h differed significantly from that of controls and from that of lobsters exposed ½ h. Among undampened lobsters tested at the ocean site, mean mortality rates of controls differed significantly only from those exposed 1 or 2 h. Differences between controls and 1 h exposures were significant in every treatment, but mean mortality rates never differed significantly among lobsters exposed 1, 2, or 4 h.

The mean mortality rate of all tested lobsters during the first week following exposure was 11.2%, which represents about 42% of all mortality; 54% of all mortality in Florida Bay and 38% of all which took place near Atlantic reefs occurred during the first week (Table 1, Fig. 1). High mean weekly mortality rates which occurred during week 1 decreased to much lower levels during week 2 (4.7%) and week 3 (3.9%) in both bay and ocean (Fig. 2). Comparisons of mean mortality rates incurred during week 1 with those of weeks 2 and 3 revealed significant differences in every instance (Table 3). During week 4, the overall rate increased to 6.1% (Fig. 2), but this combined value masked highly divergent changes in rates of mortality at bay and ocean sites.

TABLE 2.—Results of Wilcoxon Two Sample Tests (*Z* values) from comparisons of mean weekly mortality rates from different exposure periods for various treatments at Florida Bay (Bay) and Atlantic Reef (Ocean) locations. C = controls; exposure = hours.

Tests	Exposure	C	½	1	2	4
Bay wet	C	—				
	½	1.14	—			
	1	2.48*	1.62	—		
	2	2.52*	1.68	0.02	—	
	4	2.93**	2.17*	0.51	0.49	—
Ocean wet	C	—				
	½	1.10	—			
	1	3.07**	2.02*	—		
	2	1.87	0.81	1.17	—	
	4	1.93	0.85	1.16	0.03	—
Ocean dry	C	—				
	½	1.10	—			
	1	2.20*	1.12	—		
	2	2.12*	1.03	0.10	—	
	4	1.17	0.08	1.01	0.92	—

* = $P < 0.05$; ** = $P < 0.01$; *** = $P < 0.001$.

Bayside mortality rates actually decreased slightly, whereas oceanside rates increased dramatically. Statistical comparisons between mean mortality rates during weeks 1 and 4 demonstrate significant differences in the bay but not in the ocean (Table 3). Graphic depictions of cumulative weekly mortality rates (Fig. 1) reveal a decrease in slope after week 1 at both bay and ocean sites. These decreases indicate reduced rates of mortality which persist through the end of the experiment in the bay and through week 3 in the ocean. However, the slope increases sharply during week 4 in most oceanside tests, indicating an additional period of high mortality there.

DISCUSSION

Exposure unquestionably causes mortality among *Panulirus argus* used to bait traps. Increasing ex-

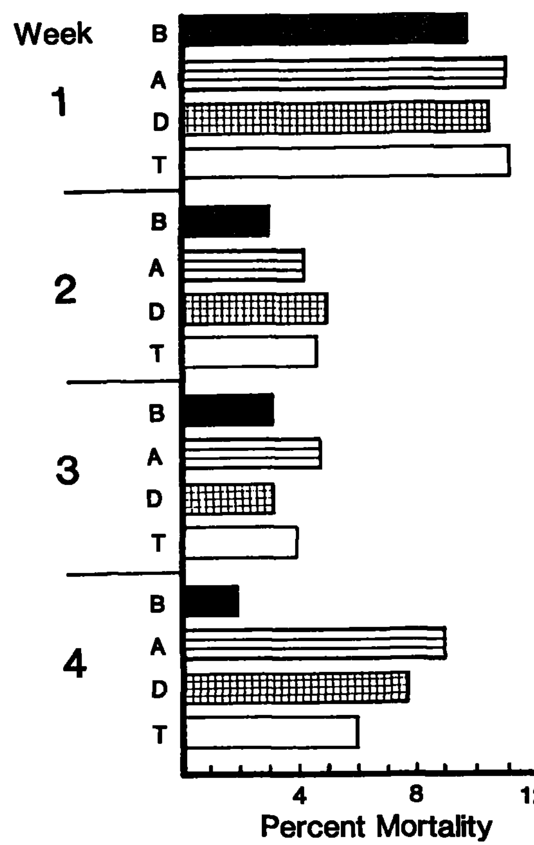

FIGURE 2.—Average weekly mortality rates (%) per treatment type during weeks 1-4, all exposures combined. A = oceanside (Atlantic Ocean) wet; B = bay (Florida Bay) wet; D = oceanside dry; T = all treatments combined.

posure periods up to 1 h resulted in corresponding increases in mortality. Similar mortality has been observed in the Western Australia spiny lobster (*Panulirus cygnus*) fishery (Brown and Caputi 1983; Brown et al. in press). In that fishery, undersize lobsters are not used as bait but are often retained aboard vessels for varying periods during the sorting process. To test effects of that practice, Australian lobsters were tagged, held aboard vessels for 0, ¼, ½, 1, and 2 h, and then released. Recapture rates were markedly lower in exposed groups than in controls. As in our experiments, results from exposure times >1 h were similar to those of 1 h exposures.

The greatest rate of mortality to *Panulirus argus* in our tests occurred during the first week following exposure (Fig. 2). Although physiological causes of mortality have not been determined, several factors may be involved. Dehydration due to desiccation may affect survival, but lobsters dampened at ½ h intervals died at rates similar to those left unattended. One effect of exposure is to dry gills (Anonymous 1980), which may result in respiratory problems. Dehydration and gill damage may cause mortality directly, but more likely are contributory factors to physiological stress caused by buildup of toxic compounds in the blood. Handling stress has been demonstrated to cause temporary acidic conditions in the blood of European lobsters, *Homarus vulgaris* (McMahon et al. 1978). After reimmersion in seawater, lobsters should rehydrate fairly quickly, but effects of physiological stress are likely to linger.

Contrary to prior expectations, mortality rates of dampened lobsters did not differ significantly from those left unattended (dry). Dampening also failed to enhance survival of the northern lobster, *Homarus americanus* (McLeese 1965). McLeese suggested

TABLE 3.—Results of Wilcoxon Two Sample Tests (Z values) from comparisons of mean weekly (1-4) mortality rates for various treatments at Florida Bay (Bay) and Atlantic Reef (Ocean) locations.

Tests	Week	1	2	3	4
Bay wet	1	—			
	2	2.86**	—		
	3	2.40*	0.55	—	
	4	3.58***	0.94	1.48	—
Ocean wet	1	—			
	2	2.72**	—		
	3	3.04**	0.59	—	
	4	0.66	2.08*	2.50*	—
Ocean dry	1	—			
	2	2.40*	—		
	3	3.33***	1.02	—	
	4	1.31	1.14	2.13*	—

* = $P \leq 0.05$; ** = $P \leq 0.01$; *** = $P \leq 0.001$.

that a relationship existed between metabolic rate and mortality. An increase in metabolic rate and concurrent more rapid depletion of reserves may have offset advantages of increasing moisture by dampening during our experiments as well.

Exposure was probably the principal cause of mortality among bait lobsters during our tests in Florida Bay. However, a small but distinctly greater level of mortality among all lobsters, including controls during weeks 1-3 and a marked increase in mortality during week 4 at the ocean site, suggest that other factors in addition to exposure were responsible for mortalities there (Figs. 1, 2). When average mortality rates of controls (Table 1) are subtracted from overall average mortality rates of exposed lobsters, resultant values (18.6%, Florida Bay; 18.3%, Atlantic reefs) are nearly equal and probably represent the rates of mortality actually ascribable to exposure at each site. Thus, effects of exposure were similar regardless of where traps were placed.

Mortality due to other effects related to confinement evidently do vary depending upon locations where traps are placed, especially if confinement periods are lengthy. Increased mortality rates such as those we observed during week 4 at the Atlantic reef site may result from starvation. Lyons and Kennedy (1981) presented evidence of weight loss and starvation among lobsters confined at densities of 3 and 5/trap in Florida Bay for 8 wk. Rate of weight loss increased during week 4 among lobsters at densities of 5 but did not increase rapidly until week 6 among lobsters confined at densities of 3. Those tests were conducted in the same portion of Florida Bay where present exposure tests were conducted, an area characterized by muddy sand overlain by seagrass beds. A disparity in available food organisms between this area and that where oceanside tests were conducted may explain differences in mortality during week 4.

Seagrass beds in Florida Bay are lush and heavily covered with epibionts (J. H. Hunt, pers. obs.). These epibionts serve as food for larger organisms which in turn are appropriate food for *Panulirus argus*. Snails in the genera such as *Modulus*, *Turbo*, *Astraea*, and *Cerithium* and crabs in the genera *Mithrax* and *Pitho* are abundant in these grass beds and are frequently seen within or clinging to sides of lobster traps. All of these also occur commonly in stomach contents of *P. argus* in south Florida (W. G. Lyons, pers. obs.). At the ocean site, grass beds are sparse and patchily distributed, and fewer organisms enter traps from the surrounding sand. It seems reasonable to suppose that the weight loss observed to occur among lobsters confined near lush grass beds (Lyons and Kennedy 1981) might occur at accelerated rates in the relatively more sparse ocean environment. If food is sufficiently scarce, accelerated weight loss may lead to starvation and increased mortality within the observed 4-wk period.

Traps in these experiments had their entrances boarded over to prevent escape, whereas lobsters that escape from traps used in the fishery are likely to recover from effects of starvation. Escape rates, though, are quite low, ranging from 0.8 to 1.8%/d (Yang and Obert 1978; Davis and Dodrill 1980; Lyons and Kennedy 1981).

We offer no explanation for our observation that highest mortality rates are associated with 1-h exposures nor for the persistent background mortality among oceanside controls. Nevertheless, neither seem to be artifacts of experimental design and, instead, probably represent other yet-to-be understood physiological reactions to stress caused by exposure, handling, or confinement. If so, they represent other effects of baiting with shorts and are justly included among estimates of total fishery-induced mortality.

Economic Effects of Mortality

Baiting traps with shorts results in significant economic loss to the fishery. Although use of shorts is an effective means of attracting other lobsters without requiring out-of-pocket expenses for bait, each bait lobster that dies is one that potentially will not enter fishery landings. In addition, repair of broken legs, antennae, and other injuries caused by handling may retard growth by as much as 40% (Davis 1981), increasing the time required for a lobster to attain legal size and extending the time during which it may be used as bait. An injured lobster that escapes from a trap where it was placed will direct energy toward repair, not growth, thereby reducing the probability that it will attain legal size during its next molt. If the lobster does not attain legal size, it is again vulnerable to capture and to use as bait. Confinement itself also results in reduced lobster growth rate (Kennedy 1982), which doubtlessly extends the period during which a lobster may be vulnerable to use as bait.

The hidden costs of baiting with shorts needs to be considered in future management efforts. The following model, based only upon observed mortality rates, estimates that cost:

$$Y = A \times B \times C \times D$$

where Y = seasonal mortality of shorts used as bait;
A = number of traps in the fishery;
B = average number of shorts per trap;
C = season length (in months);
D = average monthly mortality rate.

Because the actual allocation of fishery traps among Florida Bay and Atlantic sites is unknown but believed to be relatively equal, we selected the unweighted average cumulative 4-wk mortality rate to estimate monthly mortality throughout the fishery. By using a range of values for other variables, several estimates of the average number of shorts that die seasonally because of fishery baiting practices may be obtained (Table 4). Thus, if each trap in the fishery is baited with only 1 short/mo and all fishermen leave the fishery after only 4 mo, more than 600,000 sublegal lobsters may die as a result of their use as bait. If all traps are deployed for the full 8 mo and each trap uses 3 shorts as bait, more than 3.6 million shorts may die as a result of that use. Both examples probably represent extreme cases, and actual fishery-induced mortality probably lies somewhere between these estimates.

The problem is really more complex. Some lobsters that die because they were used as bait would probably fall victim to other causes, but natural mortality among lobsters of sizes appropriate for use as bait (65-75 mm CL) may be low, particularly since incidence of their principal predators, large serranids, has been greatly reduced in the fishery area. Furthermore, not all traps are baited with shorts because shorts are not readily available in some peripheral areas of the fishery. Both of these factors suggest that the model may overestimate fishery-induced mortality. However, values used in the model for numbers of shorts per trap are probably low. Fishermen prefer to use 3-5 shorts/trap (Gulf of Mex-

TABLE 4.—Estimates of the economic effect of baiting with shorts in the south Florida spiny lobster fishery.

Average monthly mortality rate[1]	No. of traps in fishery[2]	Season length[3]	No. of shorts/trap[4]	Seasonal mortality of shorts as bait
0.263	573,000	4	1	602,796
0.263	573,000	4	3	1,808,338
0.263	573,000	6	1	904,194
0.263	573,000	6	3	2,712,582
0.263	573,000	8	1	1,205,592
0.263	573,000	8	3	3,616,776

[1]Unweighted average cumulative 4-wk mortality rate from this study.
[2]Number of traps in 1981 (E. J. Little, Jr., Southwest Fisheries Center Resource Statistics Office, National Marine Fisheries Service, NOAA, P.O. Box 269, Key West, FL 33041, pers. commun. November 1982).
[3]The season is 26 July-31 March, 8+ mo; some fishermen begin removing their traps after November, and many have left the fishery by the end of January, causing a considerable reduction in the number of traps fished during February and March.
[4]Conservative estimates; fishermen try to put as many shorts as available into traps.

ico and South Atlantic Fishery Management Councils 1982), and it seems probable from fishermen's comments that virtually no shorts are intentionally released. Similarly, the model only allows one input of bait per month, whereas in reality additional shorts are continually introduced, typically at 1-2 wk intervals, to replace others lost because of death or escape. These factors suggest that the model may underestimate fishery-induced mortality.

Regardless of which values are applied, the model indicates that resultant losses to the fishery are considerable. Since a lobster weighs slightly <1 lb at legal size, fishery-induced mortality may cause losses ranging from 0.6 to 3.6 million lb. At recent ex-vessel prices of $2.50 per pound, this represents a potential loss to the fishery of $1.5-$9.0 million annually. In 1981, total reported commercial lobster harvest was 5.9 million lb valued at $14.5 million[3], so the hidden cost of baiting with shorts is considerable.

This loss may be viewed as a necessary cost, albeit large, of doing business in the fishery or as a problem that may be alleviated by alternative management strategies. If the latter course is deemed necessary, use of other baits and installation of escape gaps that allow shorts to escape while retaining legal lobsters in traps (Bowen 1963) are potentially effective strategies to increase harvest of legal lobsters without adversely affecting the population.

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