Catch Rates of Spiny Lobsters (*Panulirus argus*) in Traps Equipped with Escape Gaps and Potential Benefits to the South Florida Fishery

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ABSTRACT

Catch rates of legal-sized spiny lobsters in traps equipped with escape gaps of 2, 2-1/16 and 2-1/8 inch heights were 21, 32 and 37% less than that obtained in standard traps baited with cowhide and 41, 50 and 53% less than that of standard traps containing 3 live lobster attractants. Sublegal catch rates were 66, 88 and 94% less than that of standard traps with cowhide and 75, 90 and 95% less than that of traps with attractants. Failure of recruitment by growth to replace harvested legal-sized lobsters is due in part to fishery-induced impacts on the sublegal stock. Escape gaps will reduce those fishery-induced impacts and increase legal-sized recruitment 49-62%.

INTRODUCTION

During 1984-85, the Florida Department of Natural Resources (FDNR) conducted experiments on escape gaps to identify for management an appropriate gap size that would retain most legal-sized [> 76 mm carapace length (CL)] spiny lobsters, *Panulirus argus*, in traps while allowing most sublegal (< 76 mm CL) lobsters to escape. Escape gaps reduce catch of sublegal spiny lobsters in traps, and a 1 mm difference in gap height can affect significantly the size of lobsters retained (Brown and Caputi, 1986).

Mortality and growth retardation of sublegal spiny lobsters caused by exposure, handling and confinement is a serious problem in spiny lobster trap fisheries (Brown and Caputi, 1983; Hunt *et al.*, 1986). Damage inflicted on the sublegal stock has been estimated to result in economic losses worth millions of dollars annually in south Florida (Hunt *et al.*, 1986). In the Western Australia rock lobster (*Panulirus cygnus*) fishery, escape gaps in traps have reduced such losses substantially (Brown and Caputi, 1985, 1986). Escape gaps also are used to reduce impacts to sublegal *Panulirus interruptus* in California (Odemar *et al.*, 1975).

Field tests of escape gaps were conducted concurrently with another experiment testing catch rates of various lobster baits (Heatwole *et al.*, 1987).

Weekly catch rate data acquired during each experiment, conducted during both the closed and open harvest season, provided information on relative reduction of the available stock by the fishery.

Results of both investigations are reported herein. Problems with present fishery management practices and projected yield increases obtainable with escape gaps are discussed.

METHODS

Escape gaps were made of 3/16 x 1 inch (5 x 25 mm) aluminum strips welded to form a rectangle. All gaps were 20 inches (508 mm) long. Gaps were made in four width categories: 2 (51 mm), 2-1/16 (52.5 mm), 2-1/8 (54 mm) and 2-1/4 inches (57 mm). English rather than metric units were selected for dimensions because English units are used exclusively in Florida marine fishery regulations. Escape gaps were placed near bottoms of traps at ends opposite buoy lines (Figure 1). Gaps were tested during winter (October 1984-January 1985) and summer (June-August 1985).

During winter, six trap lines each containing standard traps and traps equipped with escape gaps of three different widths (2, 2-1/8, 2-1/4 inches) were deployed in late October and early November 1984. Each line contained 48 or 52 traps with the exception of one line which had 36 traps. All traps were baited with cowhide and deployed in groups of 4 traps, *i.e.*, a standard trap followed by

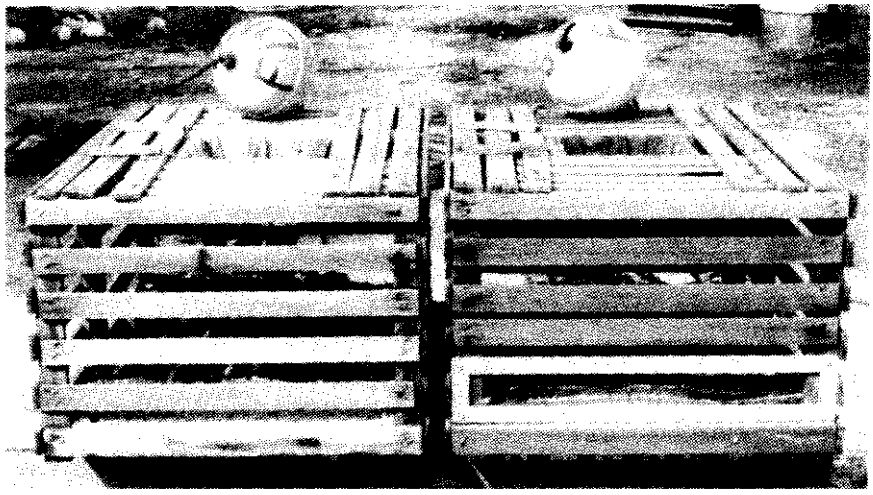

Figure 1. Standard wood slat spiny lobster trap (left) and same with escape gap (right).

traps with 2, 2-1/8 and 2-1/4 inch gaps, in each trap line. Three trap lines were established in 3-4 m depths in Florida Bay on the north side of Vaca Key and Seven Mile Bridge in the vicinity of Bethel Bank, Red Bay Bank and Moser Channel. Three others were established in the nearshore Atlantic Ocean on the south side of Vaca Key; these were designated "inside Hawk Channel" (10 m), oceanside Seven Mile Bridge (10 m), and Washerwoman Shoal (12 m). Traps were pulled on a weekly schedule, weather permitting. However, soak periods ranged from 3-18 days centered around a 7-day soak. All lobsters were measured (CL) and their sex determined. Bycatch was noted for each trap. Sampling continued through early January 1985.

During summer, five lines of 52 traps comprising 13 standard traps and 13 each equipped with escape gaps of three widths (2, 2-1/16, 2-1/8 inches) were established in late May 1985. All traps were baited with cowhide and deployed in groups of four traps. Sequences of trap type within each group was determined randomly. Two trap lines were deployed near oceanside reefs south of Key Vaca (Deep Reef, 25-30 m; Shallow Reef, 6-10 m), one line was deployed near Seven Mile Bridge in the vicinity of Bethel Bank (4 m), one line was deployed at Bamboo bank in the shallow (2-3 m) area of Florida Bay northeast of Key Vaca, and one line was deployed in outer Florida Bay near Harbor Key Light (4-5 m). Traps were pulled weekly and catch was measured and recorded as during winter. Sampling continued through 31 August 1985.

To assess weekly catch rates, average numbers of legal and sublegal lobsters per trap pull were determined for each week of July and August 1985. The nine weeks (1-9) included three weeks (1-3) of the closed season when fishery traps were not deployed, the week (4) of the five-day soak period during which traps could be deployed but not pulled, the first week (5) of the harvest season (when sublegal lobsters first could be distributed among traps as attractants), and the following four weeks (6-9) of the harvest season.

Catch data were obtained from seven stations which included the five summer stations of the escape gap study plus an oceanside station in Hawk Channel (6-8 depths) and a bayside station at Bullfrog Bank (2-6 m depths) where bait testing experiments were conducted (Heatwole *et al.*, 1987). Trends were examined for catch obtained in standard traps deployed empty (2 stations), standard traps baited with cowhide (7 stations), standard traps containing three sublegal attractants (2 stations), and traps equipped with 2-inch escape gaps (5 stations). Weekly catch rates were determined by dividing numbers of lobsters caught by numbers of traps pulled.

RESULTS

More sublegal than legal lobsters were captured during winter, whereas more legal than sublegal lobsters were captured during summer (Table 1). Differences in overall catch rates and in legal and sublegal catch composition

Table 1. Catch rates of spiny lobsters, *Panulirus argus*, at each location during winter (October 1984-January 1985) and summer (June-August 1985). Data pooled from all samples and trap types each season.

Location	Lobster Size	Trap Pulls	Number of Lobsters	Catch/Trap
		Winter		
Bethel Bank	Sublegal		144	0.32 ± 0.06
	Legal	454	50	0.11 ± 0.02
Red Bay Bank	Sublegal		56	0.16 ± 0.04
	Legal	362	33	0.09 ± 0.02
Moser Channel	Sublegal		90	0.30 ± 0.08
	Legal	298	22	0.07 ± 0.02
Inside Hawk Channel	Sublegal		45	0.10 ± 0.02
	Legal	466	40	0.09 ± 0.02
Oceanside 7 Mile Bridge	Sublegal		61	0.17 ± 0.05
	Legal	353	40	0.09 ± 0.02
Washerwoman Shoal	Sublegal		48	0.20 ± 0.05
	Legal	242	85	0.35 ± 0.09
Total	Sublegal		444	0.20 ± 0.02
	Legal	2175	260	0.12 ± 0.01
		Summer		
Deep Reef	Sublegal		172	0.33 ± 0.03
	Legal	515	998	1.94 ± 0.13
Inside Shallow Reef	Sublegal		123	0.24 ± 0.04
	Legal	503	378	0.75 ± 0.09
Bethel Bank	Sublegal		211	0.38 ± 0.05
	Legal	555	327	0.60 ± 0.06
Bamboo Bank	Sublegal		168	0.30 ± 0.04
	Legal	563	177	0.31 ± 0.04
Harbor Key Light	Sublegal		255	0.49 ± 0.06
	Legal	516	565	1.09 ± 0.10
Total	Sublegal		929	0.35 ± 0.02
	Legal	2652	2445	0.92 ± 0.04

resulted in part from the expectable population size structures of the different stations sampled during the two periods. It was expected that summer reef stations and the Harbor Key Light station would produce larger lobsters than would all winter stations, which previous work had shown to support predominantly sublegal lobsters. However, results from Bethel Bank, the one station common to both sampling periods, also indicate a much greater incidence of legal lobsters during summer than during winter. That difference is attributed to the expected increase in legal lobsters due to growth during the closed harvest season.

Number of trap pulls (effort) was nearly equal for each trap type within each seasonal sampling regime (Table 2). However, extremely poor legal-sized catches obtained in traps equipped with 2-1/4 inch gaps during winter dictated that this gap size be discontinued. Gaps of 2-1/16 inch height were substituted for the 2-1/4 inch gaps during summer. Catch rates were adjusted for variable soak periods to reflect catch from a constant 7-day soak period.

Escape gaps dramatically reduced capture of sublegal lobsters (Table 2). During winter, standard trap catches averaged 0.61 sublegal lobsters/trap pull, whereas catch rates of traps with escape gaps of 2, 2-1/8 and 2-1/4 inches were 80, 95 and 98% less. During summer, standard trap catches averaged 0.89 sublegal lobsters/pull, whereas catch rates of traps with escape gaps of 2, 2-1/16 and 2-1/8 inches were 66, 88 and 94% less. A posteriori comparisons of means (GT2-method; Sokal and Rohlf, 1981) revealed significant differences between catch rates among several trap types (gap sizes) during each season.

Catches of legal-sized lobsters also varied by trap type during each season (Table 2). During winter, standard trap catches averaged 0.19 legal lobsters/pull, whereas catch rates of traps with escape gaps of 2, 2-1/8 and 2-1/4 inches were 32, 47 and 89% less. During summer, catches of standard traps averaged 1.14 legal lobsters/pull, whereas catch rates of traps with escape gaps of 2, 2-16/ and 2-18 inches were 21, 32 and 37% less. Catches of legal lobsters in standard traps and in traps with 2-inch gaps were not significantly different during either season. Catches of legal lobsters in traps with escape gaps of 2-1/16 and 2-1/8 inches were similar to those in traps with 2-inch gaps but differed significantly from those of standard traps.

Examination of catch by 5 mm CL size class (Figure 2) provides insight into results presented in Table 2. Very few lobsters <50 mm CL were captured during either season, and 90% of all sublegal lobsters <70 mm CL were captured in standard traps (573 of 638 lobsters, both seasons combined). Thus, it is evident that any escape gap of height >2 inches (51 mm) effectively reduced capture of lobsters<70 mm CL. In the largest sublegal size class (71-75 mm CL), traps with 2-inch gaps caught 61.7% as many lobsters (61.5%, winter; 61.8%, summer) as did standard traps, whereas traps with 2-1/16 inch gaps caught 24.2% as many (summer) and traps with 2-1/8 inch gaps caught 12.2% as

Table 2. Comparisons of sublegal and legal lobster catch in standard traps and traps with escape gaps during winter (October 1984-January 1985) and summer (June-August 1985). Catch rates adjusted to constant 7-day soak period. Catch/trap = mean + 1 SE. Statistical tests made using ANOVA on log transformed data. ANOVA significant for sublegal and legal lobsters. Vertical lines indicate results of GT2 comparisons.

Trap Type	Trap Pulls	Number of Lobsters	Catch/Trap	%<S
		Winter		
		Sublegal		
Standard (S)	546	332	0.61 ± 0.07	
2" Gap	552	67	0.12 ± 0.03	80
2-1/8" Gap	543	17	0.03 ± 0.01	95
2-1/4" Gap	534	2	0.01 ± 0.00	98
Total	2175	418		
		Legal		
Standard (S)	546	102	0.19 ± 0.03	
2" Gap	552	70	0.13 ± 0.02	32
2-1/8" Gap	543	52	0.10 ± 0.02	47
2-1/4" Gap	534	9	0.02 ± 0.01	89
Total	2175	223		
		Summer		
		Sublegal		
Standard (S)	658	588	0.89 ± 0.07	
2" Gap	664	198	0.30 ± 0.03	66
2-1/16" Gap	658	71	0.11 ± 0.02	88
2-1/8" Gap	672	37	0.05 ± 0.01	94
Total	2652	894		
		Legal		
Standard (S)	658	748	1.14 ± 0.09	
2" Gap	664	596	0.90 ± 0.08	21
2-1/16" Gap	658	504	0.77 ± 0.07	32
2-1/8" Gap	672	482	0.72 ± 0.07	37
Total	2652	2330		

many (18.7%, winter; 10.2% summer). Thus, 2-inch gaps reduced catches of 71-72 mm CL lobsters only 38%, whereas 2-1/16 and 2-1/8 inch gaps reduced catches of those sublegal lobsters 76 and 88%, respectively.

Escape gap selectivity on catches of legal lobsters was also evident (Table 2). Traps with 2-inch gaps caught 21% fewer legal lobsters during summer and 32% fewer during winter than did standard traps. Traps with 2-1/8 inch gaps caught 37% fewer legal lobsters during summer and 47% fewer during winter. Summer catches obtained using 2-1/16 inch gaps resembled those of 2-1/8 inch gaps, *i.e.*, 32% less than those from standard traps. Expectedly, greatest catches of legal lobsters were in the 76-80 mm CL size class, the smallest legal size

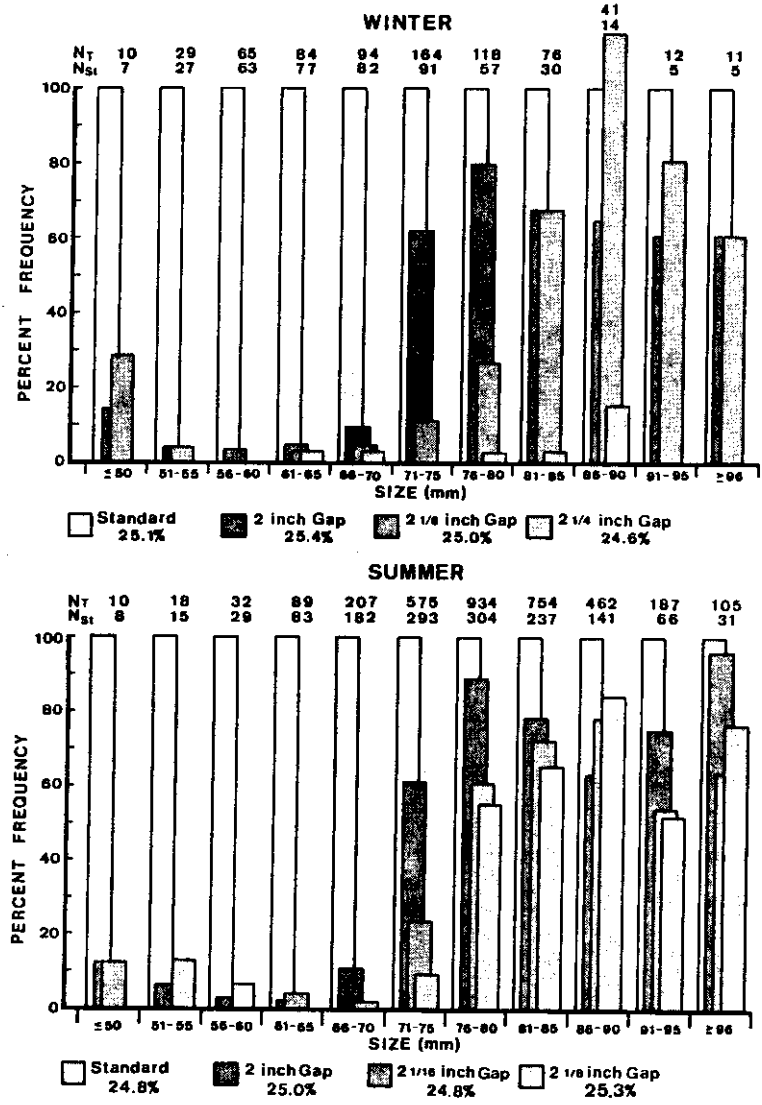

Figure 2. Relative catch per 5 mm CL lobster size class by traps with escape gaps (2, 2-1/8, 2-1/4 inches, winter 1984—85; 2, 2-1/16, 2-1/8 inches, summer 1985) as percentage of catch obtained from standard (no gap) traps (Nst). Nt = total lobsters per 5 mm CL size class obtained by all trap types. Relative effort (% pulls/trap type) indicated in code below figures.

(Figure 2). Catches of 76-80 mm CL lobsters by traps with 2-inch gaps resembled those by standard traps, whereas catches obtained using larger escape gaps were considerably less. Catches of larger (> 80 mm CL) lobsters obtained using gaps of 2, 2-1/16 and 2-1/8 inches usually were similar within CL size classes.

Relative catch rates of legal and sublegal lobsters by bait and gear type were examined by comparing total catches from the summer escape gap experiment with those of standard traps with three attractants deployed concurrently in the bait-testing experiment. Effort data were equalized by converting all values to catch per 1000 trap pulls and then converting those values to catch relative to catch of 1000 legal lobsters in standard traps with attractants (Table 3). For example, effort that produced 1000 legal lobsters in a standard trap with

Table 3. Catch (N) of legal and sublegal spiny lobsters, *Panulirus argus*, in standard traps baited with cowhide and traps with escape gaps, relative to catch in standard traps with 3 attractants.

	Trap Type									
	Standard				Escape Gaps					
Lobster	3 Attractants(A)		Cowhide		2"		2-1/16"		2-1/8"	
Size	N	%<A	N	%<A	N	%<A	N	%<A	N	%<A
Legal	1000	0	743	25.7	589	41.1	503	49.7	465	53.5
Sublegal	774	0	595	23.1	195	74.8	75	90.3	35	95.5

attractants also produced 774 sublegal lobsters, whereas equal effort in standard traps baited with cowhide produced only 743 legal and 595 sublegal lobsters. Legal catch was greater than sublegal catch because most data were obtained during the closed season, when legal-sized lobsters are predominant. Equal effort by traps with escape gaps caught 41-53% fewer legal lobsters than did standard traps with attractants, but traps with escape gaps also caught 75-95% fewer sublegal lobsters than did traps with attractants.

Because of concern expressed by fishermen regarding catch of stone crabs *Menippe Mercenaria* in lobster traps, bycatch data were analyzed for each trap type (Table 4). Escape gaps effectively allowed most stone crabs to exit traps.

Average catch rates changed markedly between weeks 1-4 and weeks 6-9 for each trap and bait type, decreasing 73.8-87.6% for legal lobsters and 62.5-86.8% for sublegal lobsters (Table 5). Although magnitudes of catch differed in response to deployment location, bait attractiveness, and the ability of traps to retain lobsters, weekly catch rate trends were similar for all trap and bait types (Figure 3). Consequently, results obtained using all four trap and/or bait types were pooled to depict overall average weekly catch rates (Figure 4).

Table 4. Catch rates of stone crabs, *Menippe mercenaria*, from standard and escape gap traps during June-August 1985. Catch/trap = mean ± 1 SE. Data pooled from all locations.

Trap Type	Trap Pulls	Number of Stone Crabs	Catch/Trap
Standard	658	37	0.056 ± 0.011
2" Gap	664	8	0.012 ± 0.004
2-1/16" Gap	658	5	0.008 ± 0.003
2-1/8" Gap	672	7	0.010 ± 0.004

Table 5. Decrease in spiny lobster catch per trap pull between July closed season (weeks 1-4) and August open season (weeks 6-9) obtained using four trap and/or bait types in the Florida Keys, 1985.

Trap/Bait Type	Mean Catch Rate				Percent Decrease	
	Weeks 1-4		Weeks 6-9			
	Legal	Sublegal	Legal	Sublegal	Legal	Sublegal
Standard, No Bait	0.60	0.49	0.13	0.10	78.3	79.6
Standard, Cowhide	1.30	1.04	0.34	0.39	73.8	62.5
Standard, 3 Attractants	1.86	1.21	0.23	0.16	87.6	86.8
Modified, 2" Gap	1.19	0.37	0.29	0.11	75.6	70.3
Total, All Traps	1.24	0.78	0.28	0.24	77.4	69.2

DISCUSSION

Catch rates of legal-sized *Panulirus argus* were somewhat less in traps with 2-inch escape gaps and considerably less in traps with 2-1/16 and 2-1/8 inch gaps than in standard traps. This was due partially to loss of legal lobsters through gaps, especially among larger gap sizes. However, the phenomenon of self-baiting also was a major contributor to greater catch of legal-sized lobsters in standard traps. Self-baiting occurs when lobsters enter previously empty traps and are retained. Spiny lobsters in traps are more effective attractants than are any conventional baits, including the cowhide used to bait traps in the escape gap study (Heatwole *et al.*, 1987). Traps with escape gaps are less likely to become self-baited at shallow bay locations where most lobsters are small and

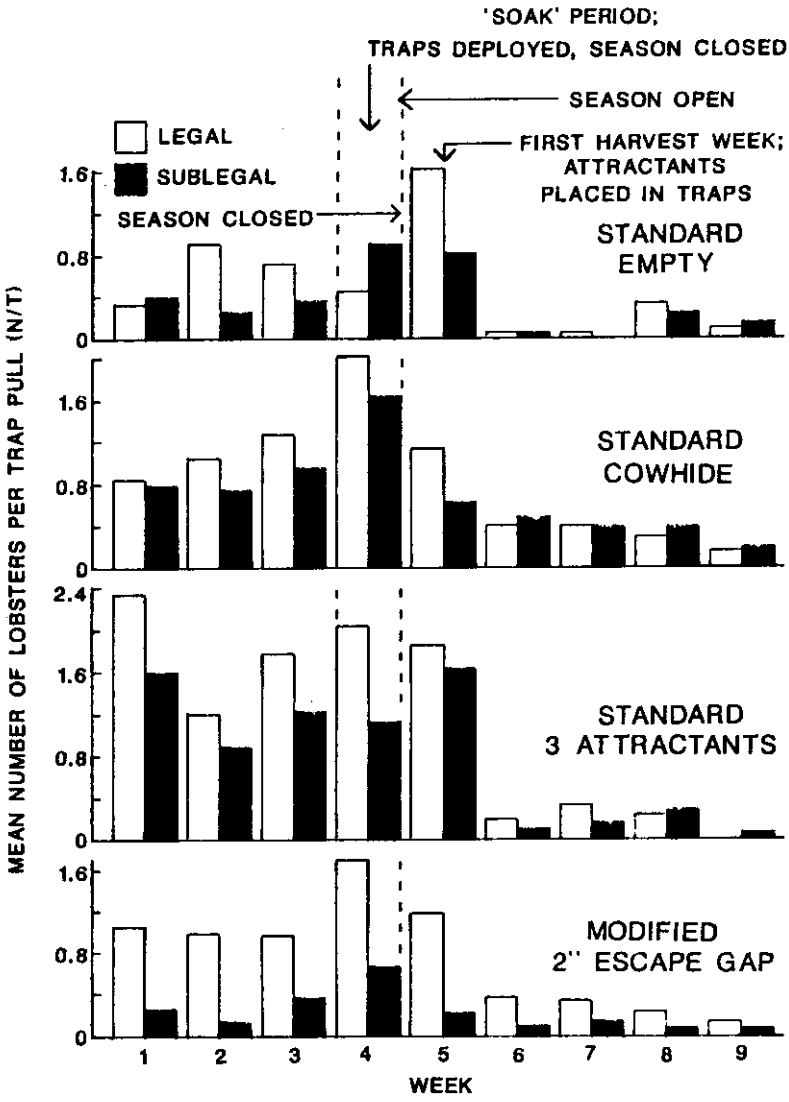

Figure 3. Average weekly catch per trap of legal and sublegal spiny lobsters obtained in standard traps deployed empty, baited with cowhide, or deployed with 3 attractants, and in traps with 2-inch escape gaps, 1 June - 30 August 1985. See also Table 5.

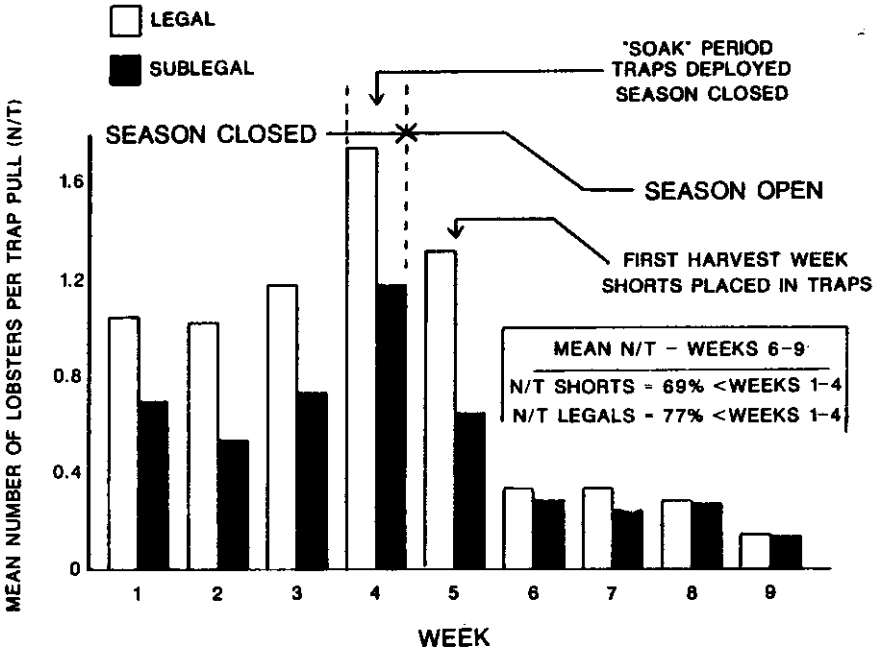

Figure 4. Average weekly catch per trap of legal and sublegal spiny lobsters, 1 June—30 August 1985; data combined from Figure 3.

can escape, but self-baiting of traps with escape gaps may be as likely to occur as self-baiting of standard traps in areas where large lobsters are more abundant.

All gaps effectively released lobsters <70 mm CL (Figure 2). However, nearly 62% of all 71-75 mm CL lobsters were retained by 2-inch gaps, whereas very few of those lobsters were retained by larger gaps. In this study and elsewhere in the Florida Keys fishery (Lyons *et al.*, 1981), the modal size class of all lobsters caught in standard traps has been 71-75 mm CL. Use of escape gaps > 2-1/16 inches in the fishery would protect nearly all lobsters in this and smaller size classes, thereby increasing modal size to just above legal size (76-80 mm CL). Increased abundance of legal lobsters by growth of sublegal lobsters should more than offset the presently lower catch rates of traps with escape gaps. Increased abundance also would enhance self-baiting properties of traps, further increasing catch rates.

During 1985, average weekly catch per trap of legal-sized lobsters decreased 77% and that of sublegal lobsters decreased 69% between the last four

weeks of the closed season and weeks 2-5 of the open season (Table 5). In each case, the decrease became evident during the first week of the harvest season and was fully effected by the second week (Figure 4). The only reasonable explanation for those decreased catch rates is that the fishery removed large numbers of both legal and sublegal lobsters from the population. The immediate great reduction in availability of legal-sized lobsters by the fishery is supported by landings data. Nearly half (average 45.3%; range 43.5-47.2%) of the annual harvest during each season since 1980-81 was landed during August and September, *i.e.*, the first two harvest months (Thompson and Powers, 1987). During the same years, an average 62.7% of total harvest was landed by the end of October, 78.7% was landed by the end of November, and 86.8% was landed by the end of December. These data indicate that catch rates far exceed the rate of replenishment by growth (recruitment) of sublegal lobsters into the legal fishery.

The failure of recruitment to replace legal lobsters as the harvest season progresses must be related to the considerable impacts of fishery practices on the sublegal stock. Sublegal lobsters were removed from the middle Keys fishery population at a rate only slightly less than that of legal lobsters during August 1985 and were removed from the lower Keys fishery population at the same rate as were legal lobsters during the 1975-76 season (Yang and Obert, 1978). The distribution of experimental trapping stations in both studies encompassed much of the areas fished by their respective lobster fleets and included parts of the juvenile nursery for the Florida Keys fishery. Similar fishing effort occurs throughout the nursery except in Everglades National Park. Consequently, it is probable that reductions in sublegal lobster abundance were experienced throughout much of the area that provides recruitment of Florida's legal stock.

Sublegal lobsters caught by the fishery are either confined as attractants in fishery traps or landed illegally. There is no valid measure of the magnitude of illegal landings. However, fishermen customarily place three (or more) attractants in each trap, and 536 thousand traps were deployed to land the 1985-86 catch (Thompson and Powers, 1987). Thus, more than 1.6 million sublegal lobsters were needed to satisfy initial fishery requirements if three attractants were placed in each trap at the beginning of the season. The number of sublegal lobsters confined in traps is a rough approximation because the number of traps deployed is an inexact estimate, and fishermen may confine fewer or more attractants depending upon sublegal lobster availability. Some fishermen use legal-sized lobsters as attractants if sublegal lobsters are scarce. As the season progresses, sublegal lobsters continually are added to traps to increase or replace those that escaped or died. Virtually no sublegal lobsters are released deliberately until the end of the season.

Sublegal lobsters confined in traps by the fishery are subject to exposure, injury, and starvation which may result in trauma, growth retardation, or death.

Trauma from exposure and handling induces physiological damage manifested as aberrant defensive and escape behavior (Vermeer, 1987). Injury (usually appendage loss) reduces growth rate as much as 40% (Davis, 1981), and confinement reduces growth rate as much as 27% (Kennedy, 1982). Reduced growth of sublegal lobsters is a prevalent phenomenon in the Florida Keys fishery population (Hunt and Lyons, 1986). In recent studies of fishery-induced mortality, an average 28.5% of all lobsters died after being exposed aboard vessels for 1/2-4 hr and then confined 3/trap for 4 wk; 18.5% died from effects of exposure and 10% died from starvation and other causes (Hunt *et al.*, 1986). Rate of mortality among lobsters confined 5/trap was 52% greater than that of lobsters confined 3/trap (Lyons and Kennedy, 1981). Kennedy (1982) estimated that an average 48.2% of all lobsters confined in traps for 1-12 week died. Powers and Bannerot (1984), using modeling techniques, estimated that if overall sublegal lobster mortality due to handling, exposure and confinement is 40%, fishery yield will be reduced 20-50%.

Information on gap selectivity, spiny lobster population size, growth and fishery-induced impacts on the sublegal stock allow a simple prediction of benefits to be gained by use of escape gaps. The following discussion uses summer gap selectivity values because they reflect a more robust lobster population such as that which should exist if fishery-induced mortality were reduced.

Sufficient information exists to formulate an approximation of the magnitude of the Florida Keys spiny lobster fishery population. Average annual landings reported during the most recent six-year period (1980-81 through 1985-86 seasons) were 5,174,380 lbs (Thompson and Powers, 1987). Unreported commercial catch is probably not more than 10% of reported catch (F.S. Kennedy, Jr., FDNR Fishery Statistics Section, personal communication), so average total commercial catch is probably about 5.7 million lbs (3,138 metric tons). If the average individual weight of landed lobsters is 1 lb, then about 5.7 million legal lobsters are captured annually in fishery traps.

More sublegal than legal lobsters are caught during a harvest season. Only 37% of the lobsters caught during the 1975-76 open season in the lower Keys (Warner *et al.*, 1977) and 39% of those caught during the 1978-79 open season in the middle and upper Keys (Lyons *et al.*, 1981) were of legal size. In both studies, stations were distributed from the shallow bay to the offshore reef and were representative of the entire fishery area. Traps in the 1975-76 study used confined attractants, as does the ongoing fishery, whereas traps in the 1978-79 study used cowhide baits, but no advantage toward capture of legal versus sublegal lobsters is conferred by either bait (Heatwole *et al.*, 1987). Both data sets indicate that slightly more than three sublegal lobsters were captured for every two legal lobsters landed. That 3:2 ratio also should have occurred in fishery traps. If so, 8.55 million sublegal lobsters were captured during fishery

operations that landed 5.7 million legal lobsters. Some sublegal lobsters were landed illegally. However, because there is no valid estimate for the magnitude of illegal landings, the following discussion presumes that all of the 8.55 million sublegal lobsters were placed in traps as attractants during the course of the harvest season.

Of the 8.55 million lobster attractants, 2.44 million (28.5%) died within four weeks and 4.12 million (48.2%) died before they could escape or were released at the end of the season. Sublegal lobsters that are captured in traps should attain legal size in an average 15 wk (Lyons, 1986) and annual natural mortality is 34.8% (Olsen and Koblic, 1975; Davis, 1981), so 10% may die of natural causes during the 15-wk period. Thus, 3.71 million of the 4.12 million sublegal lobsters that died would have grown to legal size, increasing the potential legal harvest by 65%. That 65% loss is totally fishery-induced. The 65% loss in potential legal recruitment assumes that no more than three attractants were confined in traps. If more than three attractants were confined, attractant mortality was higher.

Not all sublegal lobsters are caught in fishery traps prior to attaining legal size. If 48.2% of the estimated 8.55 million attractants die from fishery-induced causes, 4.33 million sublegal lobsters will remain. Using the 15 wk growth and 10% natural mortality parameters, only 3.99 million of these sublegal lobsters will survive to legal size. Those lobsters represent only 70% of the average annual harvest. At least 30% of the legal recruits evidently evade prior impact by the fishery, either by not entering traps or by residing in sanctuaries. Many of the latter probably grow to legal size in Everglades National Park and the Biscayne Bay-Card Sound Spiny Lobster Sanctuary, where trapping is prohibited.

The fishery has advocated use of live wells to hold attractants aboard vessels prior to placement in traps, in the belief that live wells will eliminate mortality from exposure. If exposure causes an 18.5% short-term mortality rate, elimination of exposure might reduce short-term mortality to 10%. However, even if the exposure-induced mortality rate is subtracted from the long-term mortality rate (48.2%), a 29.7% mortality rate remains. That estimate is overly simplistic because it assumes that none of the attractants that previously died of exposure (*i.e.*, 18.5%) will instead die of other causes to which attractants succumb. If those "survivors" die at the same rate as the other attractants, then the final mortality rate will be the original 29.7% plus 29.7% of the survivors, for a total of 35.2%. Any increase in harvest due to live wells will accrue from the 13% lower mortality rate engendered by their use. Given the 35.2% fishery-induced mortality and the growth and natural mortality rates used previously, 4.99 million lobsters will survive to recruit to the legal stock, increasing present landings by 17%. Mandatory use of live wells in the fishery

began with the 1987-88 season, so average annual commercial landings during future seasons should increase to 6.7 million lbs.

It is doubtful that live wells actually will produce the magnitude of gain in legal landings here described. The estimate of 17.5% increase assumes the following:

1. No more than 3 attractants are placed in each trap.
2. No other lobsters enter the traps.
3. Live wells completely eliminate mortality due to exposure and handling.
4. Survivors suffer no other adverse effects.
5. No illegal harvest occurs.

None of these assumptions can be fully met by live wells.

1. There is no way to control the number of attractants placed in traps. Fishermen prefer 3 to 5 attractants/trap and will use more if they catch them.
2. Any other lobster, legal or sublegal, that enters a trap containing attractants will compete for food and accelerate the mortality rate of the attractants (Lyons and Kennedy, 1981).
3. Some trauma and mortality may occur because of live wells; lobsters chased in a tank for 5 min showed physiological symptoms similar to those which caused nervous system impairment in lobsters exposed 2 hr (G.K. Vermeer, FDNR, personal communication).
4. Confinement reduces molt increments and increases intermolt periods (Kennedy, 1982). Growth rate slows considerably, so survivors require longer to attain legal size. Instead, they remain vulnerable to recapture and another period of confinement, increasing the likelihood of mortality.
5. Live wells will not reduce the excessive trapping effort that encourages illegal harvest.

Two management options are available to seriously reduce the great loss in potential yield presently experienced in the south Florida lobster fishery. One option requires a reduction from the presently deployed six hundred thousand traps to no more than two hundred thousand [Gulf of Mexico and South Atlantic Fishery Management Councils (GMSAFMC), 1987]. Such a reduction would require a maximum limit of about 300 traps per fisherman for the 600-700 "serious" permit holders in the fishery. At present, Florida limits traps to 2000/permit in state waters, but there is no limit on numbers of traps deployed in federal waters. It is unlikely that a significant reduction in trap numbers will be accomplished soon.

Escape gaps constitute management's best option to improve spiny lobster harvest. Losses in potential yield engendered by damage to the sublegal stock can be reduced or virtually eliminated, depending on gap size employed, without having to reduce the excessive effort presently expended in the fishery. Average annual fishery landings involve two components, lobsters that attain legal size

before encountering fishery traps and lobsters that survive capture while sublegal. The former, unaffected component provides 30% of legal recruitment, and the latter, affected component provides the other 70% (Table 6). The unaffected component consists of about 1.71 million legal lobsters which, when sublegal, numbered about 1.9 million. Assuming continued recruitment contributions by the unaffected component, increased recruitment to legal lobster stocks will depend on measures taken by management to improve survival of the 8.55 million sublegal lobsters which comprise the affected component. Traps with 2, 2-1/16 and 2-1/8 inch escape gaps caught 75, 90 and 95% fewer sublegal lobsters than did standard traps with attractants. If those escape rates were afforded to the 8.55 million sublegal lobsters presently captured by the fishery, the availability of legal-sized lobsters to be caught should increase 49-62% (Table 6).

Catch rates of legal lobsters will be reduced, at least initially, if escape gaps are used. However, catch rates of traps without attractants should soon improve because more legal lobsters will be available to be caught, and any lobster caught in a trap initiates the self-baiting phenomenon. Even if catch rates do not recover to the present rate, effort expended in the fishery is three times that necessary to harvest the entire legal stock (GMSAFMC, 1987). Consequently, catch rates would have to decline by more than two-thirds of the present rate before total landings would decline. No escape gap produced a catch rate that low. Lower catch rates simply mean that harvest would be distributed throughout more of the season, reversing the trend of shorter effective harvest seasons in recent years (Powers, 1985).

Table 6. Predicted increases in legal recruits by reduction of presently affected component of sublegal spiny lobster stock through use of live wells or escape gaps.

	Standard Traps		Escape Gap Traps		
	Exposure	Live Wells	2"	2-1/16"	2-1/8"
Unaffected Component R1 (X 10^6)	1.71	1.71	1.71	1.71	1.71
Affected Component A (X 10^6)	8.55	8.55	8.55	8.55	8.55
Evade Capture %A	0	0	75	90	95
*Survive to Legal Recruits R2 (X 10^6)	0	0	5.77	6.93	7.31
Confined Attractants %A	100	100	25	10	5
**Survive to Legal Recruits R3 (X 10^6)	3.99	4.99	1.00	0.40	0.20
Total Legal Recruits R1 + R2 + R3 (X 10^6)	5.70	6.70	8.48	9.04	9.22
% Increase from Present Landings	0	17.5	48.8	58.6	61.8

*R2 = %A-10% natural mortality.
**R3 = (%A-48.2% fishery-induced mortality) - 10% natural mortality except for live wells, where R3 = (%A-35.2%)-10%.

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REFERENCES

Brown, R.S. and N. Caputi. 1983. Factors affecting the recapture of undersize western rock lobster *Panulirus cygnus* (George) returned by fishermen to the sea. *Fish. Res.* 2:103-128.

Brown, R.S. and N. Caputi. 1985. Factors affecting the growth of undersize western rock lobster, *Panulirus cygnus* George, returned by fishermen to the sea. *Fish. Bull. (U.S.)* **83**:567-574.

Brown, R.S. and N. Caputi. 1986. Conservation of recruitment of the western rock lobster *Panulirus cygnus* by improving survival and growth of undersize rock lobsters captured and returned by fishermen to the sea. Can. J. Fish. *Aquat. Sci.* **43**(11): 2236-2242.

Davis, G.E. 1981. Effects of injuries on spiny lobster, *Panulirus argus*, and implications for fishery management. *Fish. Bull. (U.S.)* **78**:979-984.

Gulf of Mexico and South Atlantic Fishery Management Councils. 1987. Amendment number 1 to spiny lobster fishery management plan for the Gulf of Mexico and South Atlantic. Gulf of Mexico Fishery Management Council, Tampa, FL. 92pp.

Heatwole, D.W., J.H. Hunt and F.S. Kennedy, Jr. 1987. Catch efficiencies of live lobster decoys and other attractants in the Florida spiny lobster fishery. Fla. Mar. Res. Publ. No. 44. 16pp.

Hunt, J.H. and W.G. Lyons. 1986. Factors affecting growth and maturation of spiny lobsters, Panulirus argus, in the Florida Keys. Can. J. Fish. Aquat. Sci. 43(11): 2243-2247.

Hunt, J.H., W.G. Lyons and F.S. Kennedy, Jr. 1986. Effects of exposure and confinement on spiny lobsters, *Panulirus argus*, used as attractants in the Florida trap fishery. *Fish. Bull (U.S.)* **84**:69-76.

Kennedy, F.S., Jr. 1982. Catch rates of lobster traps baited with shorts, with notes on effects of confinement. Pg. 20 in: W.G. Lyons, ed. Proc. workshop on Florida spiny lobster research and management. Fla. Dept. Nat. Resources, St. Petersburg.

Lyons, W.G. 1986. Problems and perspectives regarding recruitment of spiny lobsters, *Panulirus argus*, to the south Florida fishery. *Can. J. Fish. Aquat. Sci.* **43**:2099-2106.

Lyons, W.G., D.G. Barber, S.M. Foster, F.S. Kennedy, Jr. and G.R. Milano. 1981. The spiny lobster, *Panulirus argus*, in the middle and upper Florida Keys: population structure, seasonal dynamics and reproduction. Fla. Mar. Res. Publ. No. 38. 38 pp.

Lyons, W.G. and F.S. Kennedy, Jr. 1981. Effects of harvest techniques on sublegal spiny lobsters and on subsequent fishery yield. *Proc. Gulf Carib. Fish. Inst.* 33:290-300.

Odemar, M.W., R.R. Bell, C.W. Haugen, and R.A. Hardy. 1975. Report on California spiny lobster, *Panulirus interruptus* (Randall) research with recommendations for management. Calif. Fish Game Operations Res. Branch. 98 pp.

Olsen, D.A. and I.G. Koblic. 1975. Population dynamics, ecology and behavior of spiny lobsters, *Panulirus argus*, of St. John, U.S.V.I.: II. Growth and mortality. Pg. 17-21 in S.A. Earle and R.J. Lavenberg, eds. Results of the Tektite program: coral reef invertebrates and plants. Nat. Hist. Mus. Los Ang. Cty. Sci. Bull. 20 pp.

Powers, J.E. 1985. An update of spiny lobster assessment data. NMFS Southeast Fisheries Center, Miami Laboratory. Fishery Analysis Division, Contrib. No. MLI-85-28. 10 pp.

Powers, J.E. and S.P. Bannerot. 1984. Assessment of spiny lobster resources of the Gulf of Mexico and southeastern coasts of the United States. NMFS Stock Assessment Report to Joint Gulf of Mexico and South Atlantic Fishery Managment Council Meeting, June 1984. 26 pp.

Sokal, R.R. and F.J. Rohl. 1981. *Biometry, 2nd ed.* W.H. Freeman and Co., San Francisco. 859 pp.

Thompson, N.B. and J.E. Powers. 1987. Spiny lobster assessment update. NMFS Southeast Fisheries Center, Miami Laboratory. Coastal Resources Division, Contrib. No. CRD-86/87-30. 11 pp.

Vermeer, G.K. 1987. Effects of air exposure on desiccation rate, hemolymph chemistry, and escape behavior of the spiny lobster, *Panulirus argus*. *Fish. Bull. (U.S.)* 85:45-51.

Warner, R.E., C.L. Combs and D.R. Gregory, Jr. 1977. Biological studies of the spiny lobster, *Panulirus argus* (Decapoda: Palinuridae), in south Florida. *Proc. Gulf Carib: Fish. Inst.* 29:166-183.

Yang, M.C.K. and B. Obert. 1978. Selected statistical analyses of Key West spiny lobster data. Pp. 4-7 in: R.E. Warner, ed. Spiny lobster research review: Proc. Conf. Dec. 16, 1976, Key West Florida. Fla. Sea Grant Tech. Pap. No. 4.