An Evaluation of the Impact of Fishing Practices on the Spiny Lobster, *Panulirus argus*, Fishery in South Florida

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ABSTRACT

The spiny lobster, *Panulirus argus*, is intensively exploited in south Florida with over 650,000 traps used in the fishery generating landings of about six million pounds per year. Efficiency of traps depends significantly on bait type, but sublegal lobsters (shorts) are the most efficient in attracting legal lobsters. This practice may create growth overfishing if handling mortality is high; consequently, adoption of trap escape gaps has been proposed. The high catching efficiency of traps using shorts may, however, offset yield gains derived from increased short survivorship when using escape gaps. In this study we present quantitative analyses based on ratio yield-per-recruit levels of the fishery using shorts and other baits. The results show that ratios at levels of fishing mortality rates which generate maximum yield-per-recruit and at 90% of maximum yield-per-recruit are all higher in the fishery mode using shorts as bait than those that might be generated by the fishery operating with escape gaps and using cowhide as attractant. This conclusion has a significant bearing on management actions planned for the fishery.

INTRODUCTION

The spiny lobster (*Panulirus argus*) fishery is the second most economically important fishery in the State of Florida, being surpassed only by shrimp in commercial value (Harper, 1991). As such, management actions imposed on this fishery should be planned on strong technical and scientific evidence that management will enhance overall output from the fishery. Spiny lobster landings have fluctuated between 4.5 and 7.9 million pounds during the period 1975-1990, with total value to the fishery varying between $8.5 and $18.7 million. During this period, landings have reached maximum, although variable, levels; whereas the number of traps used in the fishery reached a record of 675,000 traps in 1984 (GMSAFMC, 1986)(Figure 1).

Recruitment appears to be driven by spawning in foreign regions and to a lesser extent by spawning of local populations (Menzies and Kerrigan, 1980; Lyons, 1981). The fishery has a closed fishing season during the months of April to July to protect spiny lobsters during peak spawning months; however, the effective length of the commercial fishing season is less than six months

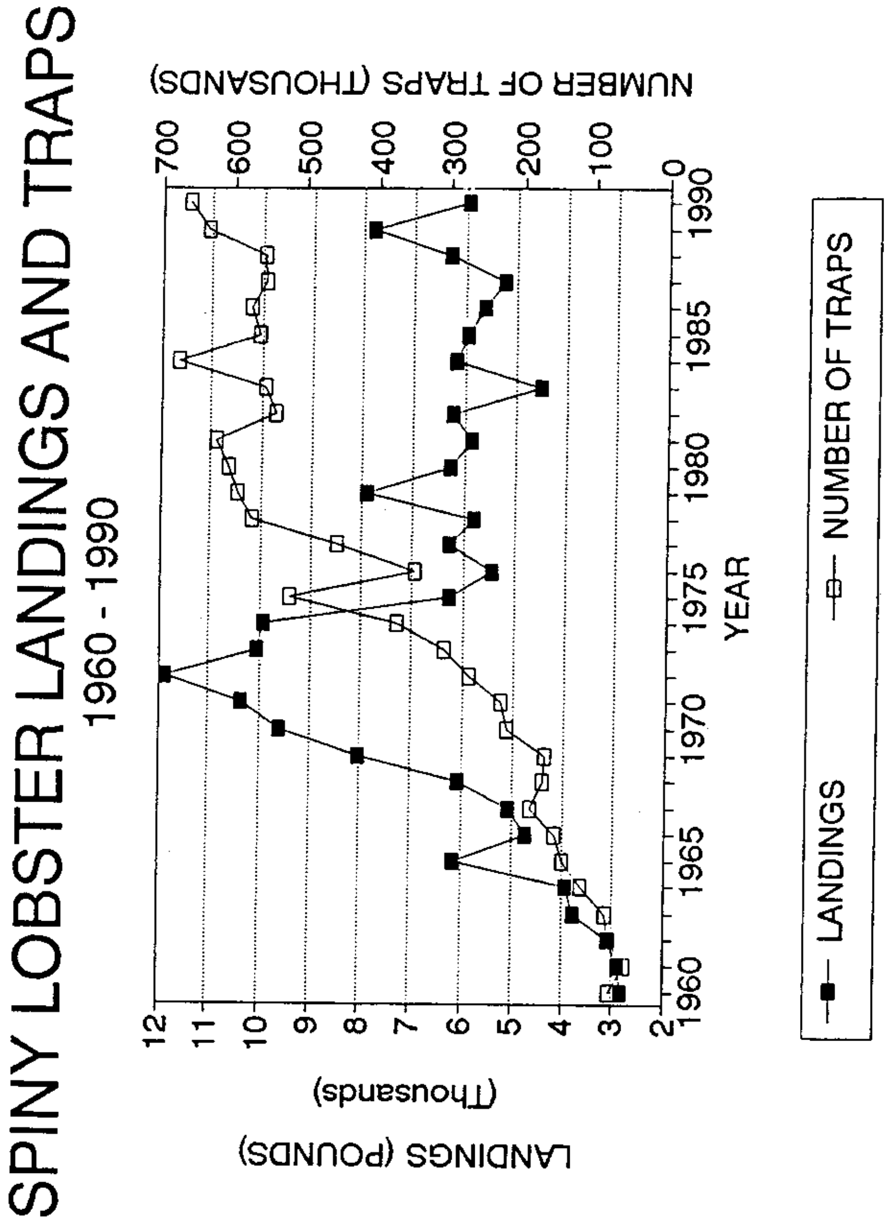

Figure 1. Annual landings (lbs) and number of traps deployed in the spiny lobster fishery in south Florida.

since over 90% of the landings are taken before the end of January (Powers and Bannerot, 1984; Harper, 1991). A shorter effective fishing season is the result of highly efficient gear used in the fishery and high fishing intensity applied on the stock. These conditions appear to be common to many fisheries in south Florida, and instrumental to the existence of multiple species fisheries because shorter effective seasons allow lobster fishermen to participate in several other important seasonal fisheries, such as stone crab and mackerel. In this way an efficient integration of multiple fishery resources available in the region is accomplished.

To avoid growth overfishing a minimum size of 76.2 mm carapace length (CL) has been imposed on the fishery although effectiveness of this management measure may be curtailed by mortality of sublegal lobsters (shorts) used in the fishery as attractants (bait). Sublegal lobster mortality is thought to create significant losses of future yield to the fishery (Hunt *et al.*, 1986; Powers and Bannerot, 1984; Powers and Thompson, 1986). In order to reduce mortality of sublegal lobsters, live wells were imposed on the fishery to increase survivorship of shorts kept on board by reducing their exposure to air. Also, adoption of escape gaps which will ensure escapement of under-sized lobsters, has been proposed for the fishery; however, this proposed measure is opposed by lobster fishermen who argue that fishing efficiency of traps will be significantly lowered. Short mortality and trap efficiency may have compounded effects on future yields which are not well understood. The purpose of this study has been to closely simulate the impact of the use of shorts as attractants in the Florida lobster fishery by modelling the fishing process and by incorporating the most likely sources of lobster mortality into a yield-per-recruit model specifically developed for the Florida lobster trap fishery.

MATERIALS AND METHODS

The effect of a change in yield due to savings generated by a decrease in short mortality as a consequence of introducing escape gaps was determined by quantifying ratios of yield-per-recruit with escape gaps to yield-per-recruit without escape gaps under several levels of fishing and short handling mortalities and relative capture efficiencies according to the use of shorts and other baits. A range of annual effective fishing mortality rates were applied in the analyses and modified by monthly mortality multipliers such that seasonal fishing mortality rates could reflect the seasonal character of commercial fishing operations. An age-structured population simulator, where life history of lobsters was divided into one-month classes over which growth, natural and handling mortalities, and selective harvests by the fishery occurred, was developed and implemented in Microsoft FORTRAN. A brief description of the components of the model and their rationale are presented below.

Growth

Published growth rates of spiny lobster in Florida are highly variable due to differences in statistical sampling designs, as well as apparently true biological variability. Few growth functions are published in the scientific literature and some are conflicting due to theoretical and statistical problems. For these reasons, in this study length-at-age was estimated for a range of possible scenarios with parameters obtained from several possible growth stanzas. Von Bertalanffy growth equations were obtained from the literature or developed from data either in the literature or provided by the Florida Department of Natural Resources (R. Muller and J. Hunt, personal communication) and they are presented in Figure 2. Growth equations for male spiny lobster by Lozano *et al.* (1991), and an equation we fitted to FDNR sexes-combined data were chosen for the analyses. We believe the range of size at age generated by these maximum and minimum growth equations will include the most likely growth pattern of *P. argus* in south Florida. The resulting growth equations are given as:

$$L_t = 257.0\ (1\text{-}e^{-0.2044(t)})\ \text{(Lozano } et\ al.\text{, 1991, Males)}$$

$$L_t = 118.0\ (1\text{-}e^{-0.5712(t)})\ \text{(FDNR Data, Sexes Combined)}$$

where L_t is carapace length at age t.

Published accounts (Little, 1972; Davis and Dodrill, 1980) of age-at-first capture suggest that spiny lobster reach legal size (76.2 mm CL) at 15 to 20 months after puerulus settlement. We used 21 and 23 months as age of first capture derived from the growth equations in the yield calculations. Carapace lengths (mm) at age estimated from the growth equations were transformed to grams at age (Wt) by means of a sexes combined length-weight relationship for spiny lobster published in the South Florida Spiny Lobster Fishery Management Plan (FMP) (GMSAFMC, 1982) and given as:

$$W_t = 0.00422\ L_t^{2.64091}$$

Asymptotic weights (W) were estimated at 1,250.2 g and 9,766.3 g based on values of L = 118.0 and 257.0 mm (CL) from the limiting growth equations. The estimated weights are considered reasonable given that large spiny lobsters caught off the Florida Keys with weights from 2,000 g and exceeding 5,036.5 g have been reported by fishermen and that asymptotic weight estimated from the Lozano *et al.* (1991) equation may represent animal with unreasonably old ages.

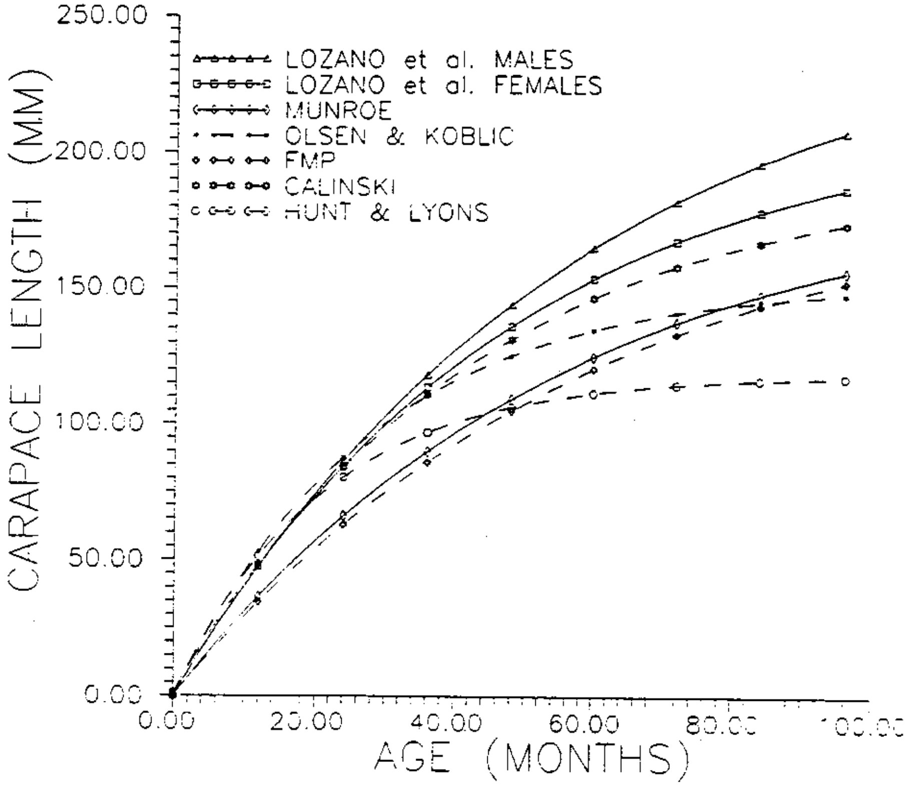

Figure 2. Growth curves given by various authors and fit from data of various authors for spiny lobsters.

Mortality

Natural Mortality. Few estimates exist of the natural mortality of adult *P. argus*. Yang and Obert (1978) estimated the total mortality rate (Z) for lobsters in the lower Florida Keys to be 1.68. Also, Warner *et al.* (1977) obtained an estimate of fishing mortality rate (F) of 1.32 for the same area and time; therefore, an approximate natural mortality rate (M) of 0.36 can be obtained from the difference between total mortality and fishing mortality given above. The value of M appears to fall on the lower range of natural mortality rates given in the FMP (0.4 to 0.6), and it is significantly lower than the value of 0.651 given by Olsen and Koblic (1975). We calculated natural mortality rates as a function of growth parameters and water temperature following Pauly's (1980) natural mortality equation. For the range of growth equations considered, M resulted in values ranging from 0.66 to 1.72 per year. The later of these two values is significantly higher than those used in all previous analyses (Powers and Bannerot, 1984; Powers and Thompson, 1986). Based on the available information we have chosen the range 0.40 to 0.60 as the most likely range that may include the true annual instantaneous natural mortality rate for spiny lobster in south Florida.

Fishing Mortality. There are no reliable estimates of fishing mortality rates inflicted on the Florida lobster stock; however, given the very high number of traps used in the fishery, it can be expected that fishing mortality rates should be higher than the natural mortality rate of the species. In fact, Warner *et al.* (1977) report a fishing mortality rate of 1.32 for the lower Florida Keys which is over three times as large as the lower natural mortality rate of 0.40 adopted in this study and over two times higher than the highest mortality rate of 0.60 adopted in this study. In the analysis a range of fishing mortality rates between 0 and 3 will be considered and evaluations will be made at instantaneous fishing mortality rates generating maximum yield-per-recruit (F_{max}) and at 90% of maximum yield-per-recruit ($F_{0.9}$).

Short Mortality. Hunt *et al.* (1986) investigated the use of shorts as attractants in the Florida trap fishery to determine the effects of air exposure time and confinement on short mortality. Their results indicate that mortality due to exposure is significant when exposure times are one, two and four hours and that confinement increases the chances of mortality due to starvation among lobsters in sealed traps operated in the Atlantic Ocean but not in the Gulf of Mexico (Florida Bay).

Mortality due to exposure prompted implementation of water filled "live-wells" on lobster vessels in the mid 1980s, and in the present fishery exposure time during traps services is extremely short (less than one minute). Mechanical stress during trap retrievals and short manipulations may still generate an unknown amount of mortality among shorts; however, the fact that mortality excluding starvation and predation of control shorts reported by Hunt *et al.* (1986) was lower than the lower natural mortality estimate adopted for the species is an indication that in those experiments mortality due to mechanical stress among control shorts was not significant.

Mortality due to starvation resulting from confinement is a function of the ability of lobsters to enter and exit traps. Daily escape rates of 0.8 to 1.8% are reported by Yang and Obert (1978), Davis and Dodrill (1980), and Lyons and Kennedy (1981). We estimated weekly escape rates of 5.5% and 11.9% from the above information. Those rates compare favorably with a disappearance rate of 10% after one week calculated for shorts and legal lobsters by Ehrhardt *et al.* (Submitted). According to the latter authors, dissappearance after four weeks varied between 62% for legal lobsters and 67% for shorts. The fact that disappearance rates were similar between shorts and legal lobsters indicates that both groups underwent a similar process. If that process were related to handling and confinement mortality, then differences attributable to differences in survivorship between shorts and legals would have been observed in the above percentages. In the absence of accurate estimates for handling mortality, in the analyses we have arbitrarily adopted a handling mortality range due to mechanical factors of 0 to 30% per month and we have assumed that handling mortality in the present fishery ranges from 3 to 6% per month.

Bait Efficiency

The commercial lobster fishery is almost exclusively a trap fishery with the most popular baits being fish heads or cowhide. However, sublegal-size (<76.2 mm CL) lobsters (shorts) have been used as attractants (bait) for legal-sized lobsters since as early as the 1950s. Up to 60 percent of the spiny lobster traps operated in the Florida Keys now use shorts in place of fish heads or cowhides (Ehrhardt *et al.*, Submitted). Incidence of the use of shorts as bait is greater in the upper and middle Keys where shorts are more abundant and therefore more readily available to fishermen operating in those areas. From a sample of 4,112 trap pulls carried out during the 1990-1991 fishing season in the above regions, 1,967 shorts were used as bait representing 47.8% of short usage.

Several studies have demonstrated the effectiveness of shorts as attractants (Yang and Obert, 1978; Lyons and Kennedy, 1981; Kennedy, 1982). Heatwole *et al.* (1988) demonstrated that traps baited with live shorts caught three times as many lobsters as did traps baited with cowhide, fish heads, cat food, liquified mullet and a commercial bait made from herring. Heatwole *et al.* (1988) concluded that: "... the powerful attraction of confined lobsters cannot be matched by food attractants at the present level of fishing effort". Based on data from Heatwole *et al.* (1988) we have calculated a catch efficiency factor of 2.38 using shorts as bait relative to traps baited with cowhide, or that cowhide bait is only 0.42 as efficient as using shorts as attractant of legal lobsters in standard traps. In addition, catch efficiencies of standard traps and traps with escape gaps reported by Hunt and Lyons (1985) showed that escape gaps of 2 1/8" and 2 1/4" caught 47% and 89% fewer legal lobsters relative to standard traps as a consequence of short escapement (Figure 3). Since a 2 1/8" escape gap has been proposed for the fishery, then in our analysis we use 0.45 as a maximum relative catch efficiency factor of traps with escape gaps and using cowhide as bait.

Recruitment Size and Recruitment Age

Considering the recruitment processes and growth that spiny lobster undergo in south Florida (Menzies and Kerrigan, 1980; Lyons, 1981; Lyons *et al.*, 1981), our yield-per-recruit calculations assume that juveniles >30 mm (CL) long on the average recruit to the fishery as shorts at an age (t_r) of 8 months from postlarval settlement. Furthermore, it was assumed that on the average individuals recruit to the exploited phase at age (t_c) 20 months when they reach legal size of 76.2 mm (CL). Of course, in the model any combination of t_r and t_c can be adopted.

Yield Per Recruit

Yield-per-recruit formulations were derived from a standard catch in numbers equation

$$C_t = N_t \ (F_t / F_t + M) (1 - \exp(-(F_t + M))) \ (1)$$

where N_t is the population size in numbers at age t in months at the beginning of a month, and C_t is the catch in numbers at age t accumulated at the end of a month. F_t is the instantaneous effective fishing mortality rate during t, which is expressed in terms of commercial mortality rates for traps using shorts and cowhide as baits. Because only a fraction of the total traps used in the fishery use shorts as attractants and because shorts are more efficient than cowhide in attracting legal lobsters, a formulation for F_t was developed to incorporate all the above factors. Thus:

$$F_t = FN_t \bullet SHFR + FN_t \bullet CHEFF \bullet (1\text{-}SHFR)$$

where FN_t = total nominal fishing mortality rate applied to the fishery in units of traps using shorts as attractants; SHFR = fraction of total traps using shorts as attractants; and CHEFF = catch efficiency of traps using cowhide as bait.

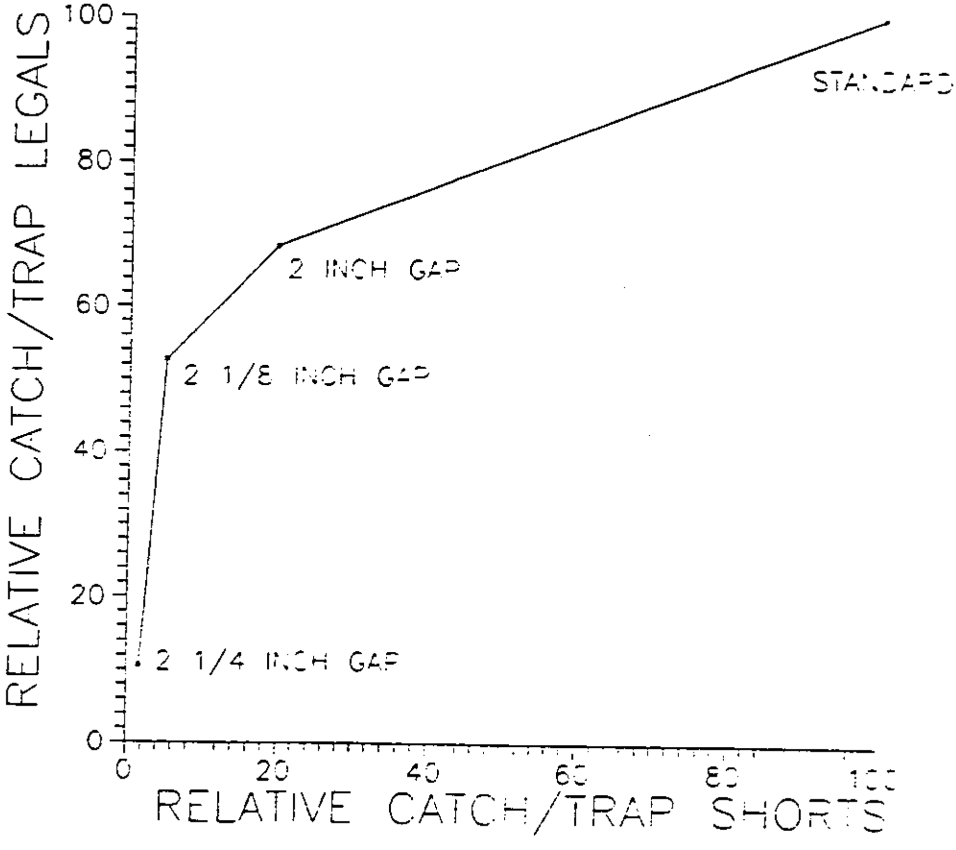

Figure 3. Relationship between catch per trap of legal lobsters and short lobsters for traps with different size escape gaps relative to a standard trap.

Yield at age was expressed as:

$$Y_t = C_t W_t \quad (2)$$

where W_t is the average weight of an individual lobster at age t estimated from an age-weight relationship developed from the growth equations and the weight-length relationship.

At equilibrium,

$$N_t = \begin{cases} R_{tr} & \text{if } t = tr \\ \mathop{}\limits_{i=tr}^{t-1} R_{tr} \exp(-\,(FS_i + M)) & \text{if } tr < t < tc \end{cases}$$

where R_{tr} is recruitment in numbers of shorts at age tr and FS_i is the rate of handling mortality of shorts used as attractants.

In this case:

$$FS_i = FN_t \bullet SHFR \bullet D$$

where D is the percentage of short mortality inflicted during t.

From equations (1) and (2), yield-per-recruit may be estimated as:

$$\frac{Y}{R_{tr}} = \exp(-\mathop{}\limits_{i=tr}^{tc-1} FS_i + M) \quad \mathop{}\limits_{t=tc}^{n} (W_t \frac{F_t}{F_t + M} [1 - \exp\{-(F_t + M)\}] \exp(- \mathop{}\limits_{i=tc}^{t-1} F_i + M)) \quad (3)$$

where F_t is replaced by the equation given previously, and n is the maximum age contributing to yield-per-recruit. Equation 3 expresses yield-per-recruit when shorts are used as attractants. To assess the impact of such practice, a ratio of the yield-per-recruit generated by equation 3 and a yield-per-recruit formulation assuming that all shorts escape trapping through escape gaps was developed. In this context we have that the yield-per-recruit ratio, H, is given as:

$$H = (Y/R_{tr}) \,/\, (Y'/R_{tr}) \quad (4)$$

where Y'/R_{tr} is given as:

$$\frac{Y'}{R_{tr}} = \exp(-\mathop{}\limits_{i=tr}^{tc-1} M) \quad \mathop{}\limits_{t=tc}^{n} (W_t \frac{F'_t}{F'_t + M} [1 - \exp\{-(F'_t + M)\}] \exp(- \mathop{}\limits_{i=tc}^{n-1} F'_i + M)) \quad (5)$$ “

where F'_t is effective fishing mortality rate generated by traps with escape gaps and using cowhide as bait and expressed as:

$$F'_t = FN_t \bullet FMOF \bullet CHEFF$$

Computer programs to resolve equations 3, 4 and 5 were developed such that a range of values for short mortality, fishing mortality and fraction of traps using shorts and cowhide as baits could be used to generate yield-per-recruit isopleths and ratios of yield-per-recruit isopleths.

RESULTS AND DISCUSSION

The range of short handling mortality fractions selected for the analyses include the values of 3 and 6% per month adopted as likely values in the present fishery. These two mortality levels represent instantaneous handling mortality rates of 0.27 and 0.56 per nine-month fishing season. These values are considered as moderate to high when compared to natural mortality rates applied to the same time period (0.30 to 0.45). The range for fishing mortality rate was selected to include the values which generate maximum levels of yield-per-recruit, as well as fishing mortality rates corresponding to levels of yield-per-recruit at 10% below the level of maximum yield-per-recruit. The resulting isopleths for minimum and maximum growth characteristics and minimum and maximum natural mortality rates adopted in the analyses are shown in Figures 4 to 7. The yield-per-recruit isopleths demonstrate that at low fishing mortality rates (generally for F less than 0.4 per year) yield- per-recruit is not affected even when extraordinarily high handling mortalities, such as 0.30 per month, are applied to the fishery. This is a consequence of a greater effect of the efficiency of shorts used as bait than biomass losses due to reduced short mortality at lower levels of fishing mortality. As fishing mortality increases, the effect of short mortality is shown by deflection of isopleths to the right with isopleths collapsing more significantly at higher levels of handling mortality (>0.08) and for fishing mortality rates over 0.6, for any combination of growth character and natural mortality rate. Yield-per-recruit is significantly depressed at high to very high levels of fishing mortality, such as F = 1.5 to 3.0, and short handling mortalities greater than 0.08 per month.

In figures 4 and 5, we observe that maximum yield-per-recruit when using the minimum growth equation tends to asymptotic values over a wide range of F-values (values greater than 2.0) when shorts are not used as bait and natural mortality rates are 0.4 and 0.6. The same maximum occurs at instantaneous fishing mortality rates between 1.2 and 1.4 when short handling mortality is 3 or 6% and natural mortality rate is 0.4 and 0.6, respectively.

Figures 6 and 7 show yield-per-recruit estimated with the maximum growth equation. Under this condition, maximum yield-per- recruit when shorts are not

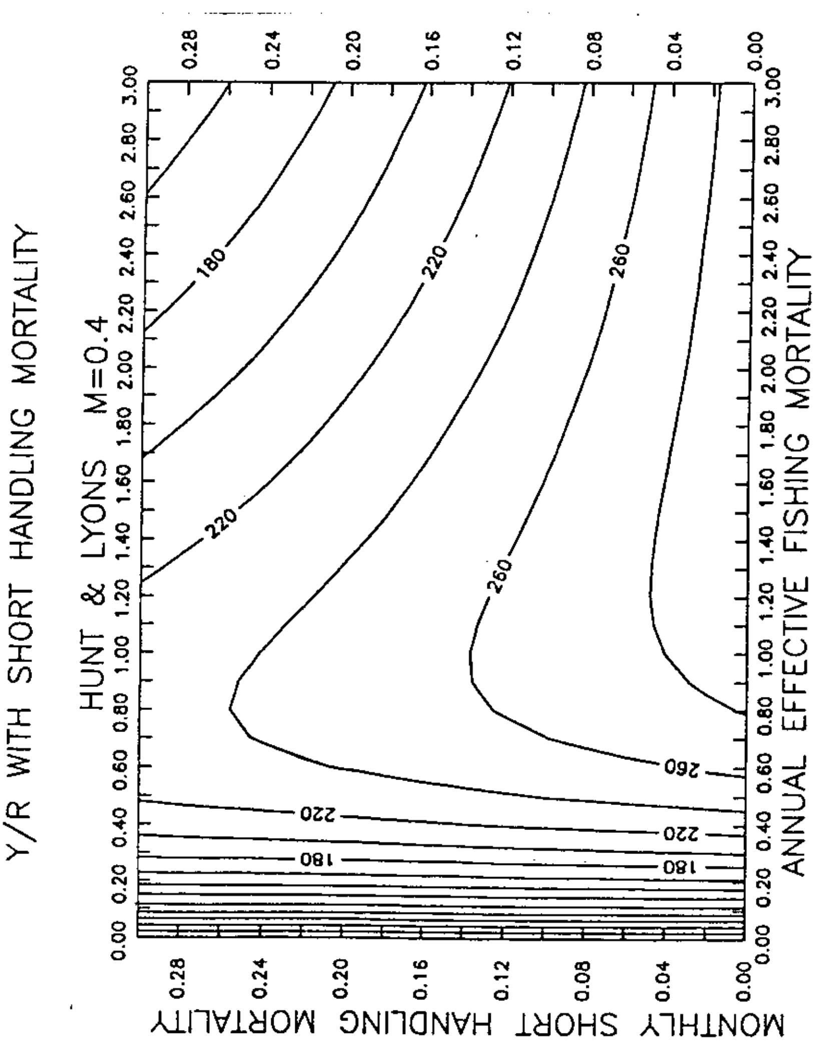

Figure 4. Yield-per-recruit isopleths (grams) for spiny lobster as a function of fishing rate and handling mortality when shorts are used as attractants using the growth equation fit to FNDR data and natural mortality rate M = 0.4.

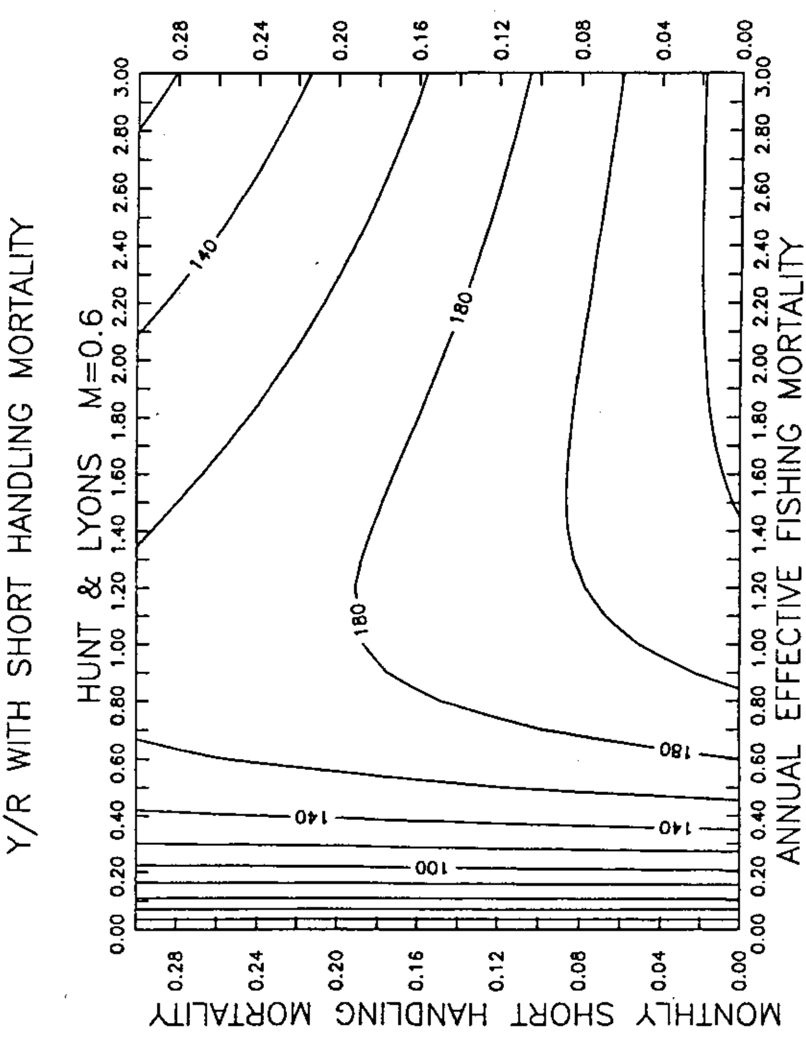

Figure 5. Yield-per-recruit isopleths (grams) for spiny lobster as a function of fishing rate and handling mortality when shorts are used as attractants using the growth equation fit to FNDR data and natural mortality rate M = 0.6.

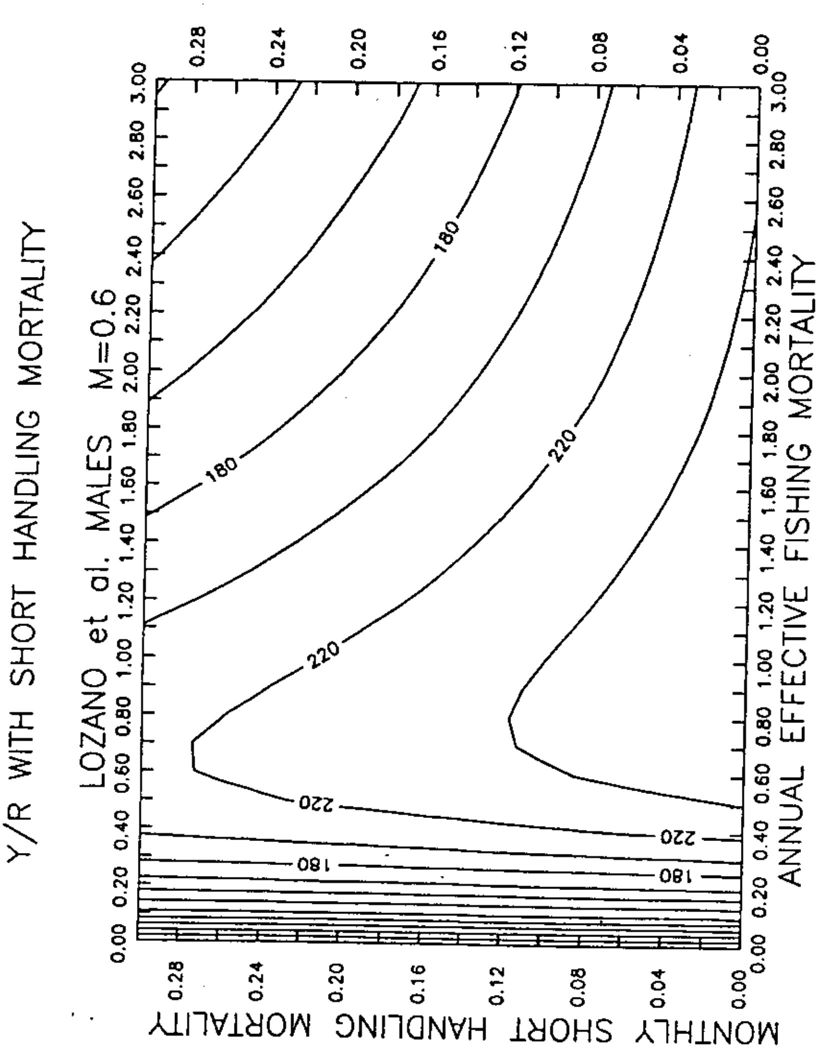

Figure 6. Yield-per-recruit isopleths (grams) for spiny lobster as a function of fishing rate and handling mortality when shorts are used as attractants using the Lozano *et al.* growth equation and natural mortality rate M = 0.4.

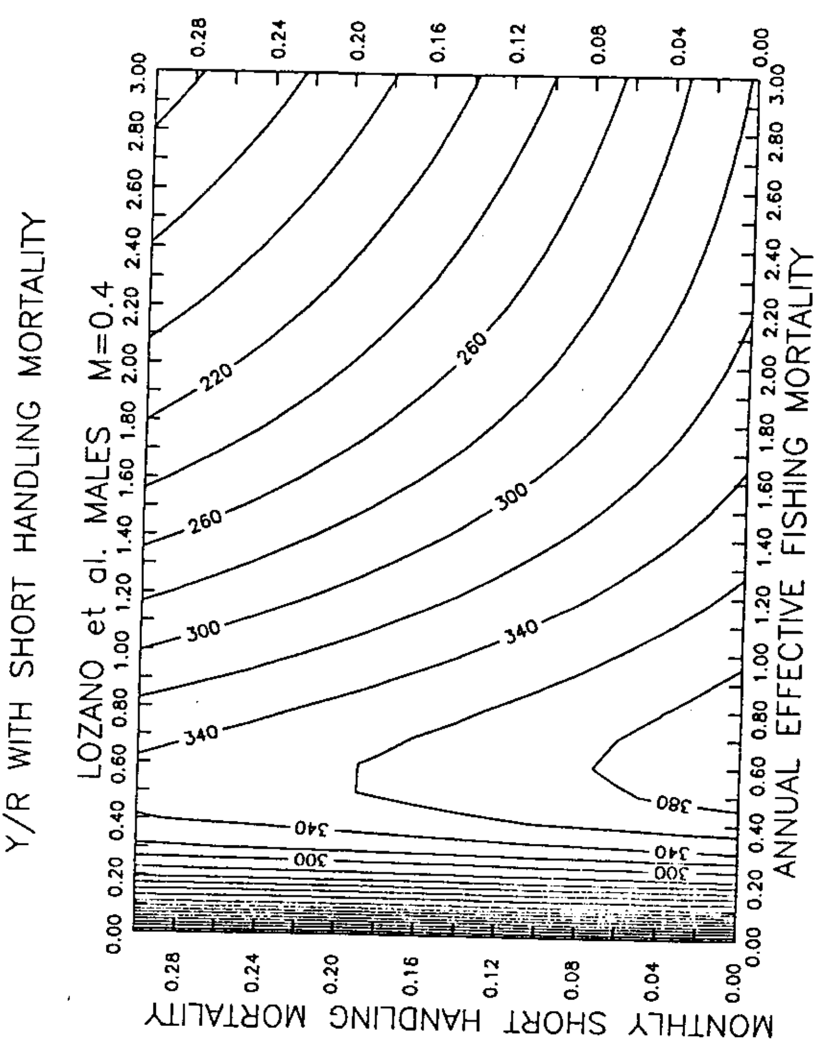

Figure 7. Yield-per-recruit isopleths (grams) for spiny lobster as a function of fishing rate and handling mortality when shorts are used as attractants using the Lozano *et al.* growth equation and natural mortality rate M = 0.6.

used as bait and natural mortality rates are 0.4 and 0.6 occurs at instantaneous fishing mortality rates of 1.2 and 1.7, respectively. Maximum yield-per-recruit when short handling mortality is 3% and natural mortality rate is 0.4 and 0.6 is obtained at instantaneous fishing mortality rates between 0.60 and 0.90, respectively. Under the same conditions but with handling mortality set at 6% per month, instantaneous fishing mortality rates generating maximum yield-per-recruit are 0.60 and 0.80. Given that a fishing mortality rate of 1.32 was reported for the fishery in 1975 (Warner *et al.*, 1977) when landings were 3.1 million kilograms, and since landings for 1990 (last season with available statistics) were 2.7 million kilograms in spite of large increases in the number of traps operated in the fishery, then we can assume that the most likely fishing mortality rate for the fishery should be slightly below 1.3. If this is the case, then we can conclude from the range of isopleths presented in the figures that the present fishery is most likely operating at maximum yield-per-recruit levels. Figures 8, 9, 10 and 11 show yield-per-recruit isopleths for the growth and natural mortality ranges adopted in this analyses and for the fishery under the assumption that escape gaps have been adopted and therefore, short handling mortality is not a factor. Under these conditions yield-per-recruit was estimated according to equation 5 where traps operated with a rounded-off fishing efficiency of 0.45 approximately corresponding to cowhide efficiency relative to those generated by shorts (0.42). In Figures 8 and 9, yield-per-recruit estimated under conditions of minimum growth and natural mortalities of 0.4 and 0.6 is asymptotic, reaching a plateau at 294.7 and about 234 grams, respectively, beyond which increases in yield-per-recruit may not be significant in spite of very large increases in fishing mortality. In figures 10 and 11, yield-per-recruit estimated under conditions of maximum growth and natural mortality rates of 0.4 and 0.6 has a maximum of 393.3 and 259.2 grams, respectively, with corresponding instantaneous fishing mortality rates of 1.1 and 1.7.

The isopleths in Figures 12, 13, 14 and 15 indicate yield-per-recruit generated by the most likely values of mortality and efficiency factors in the actual exploitation scheme of the fishery using shorts as attractants, measured as a fraction of the hypothetical yield-per-recruit that might be generated by the much less efficient traps equipped with escape gaps. Thus, a 0.9 isopleth indicates that the present scheme is generating only 90% of the yield-per-recruit suggested by the traps using escape gaps; a 1.0 isopleth indicates no gains, while a 1.1 isopleth indicates a 10% gain in yield-per-recruit under the present fishery exploitation, etc. An assessment of yield-per-recruit gains or losses due to the use of shorts as attractants or cowhide as bait may be obtained by locating the values of fishing mortality rates generating maximum yield-per-recruit (Fmax) and 90% of maximum yield-per-recruit (Figure 9). The resulting fishing mortality values are presented in Table 1 for combinations of growth and natural mortality characters and by handling mortality fractions.

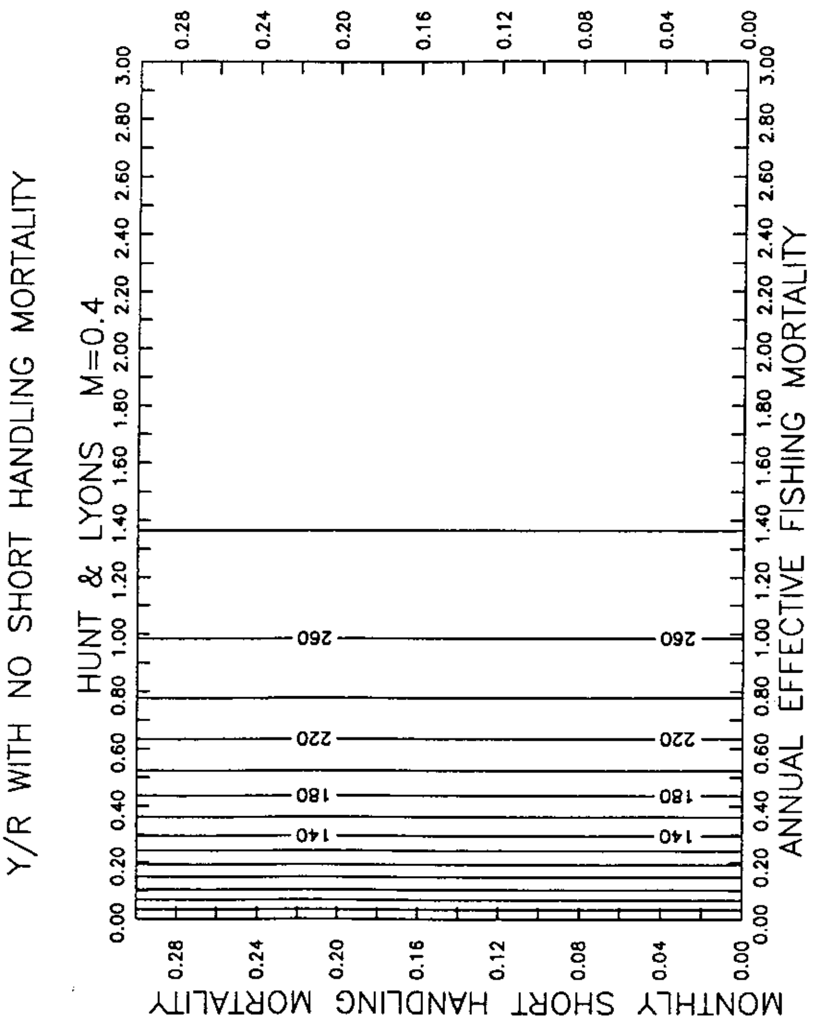

Figure 8. Yield-per-recruit isopleths (grams) for spiny lobster as a function of fishing rate and handling mortality when shorts are not used as bait in the fishery assuming growth follows the equation fit to FDNR data and natural mortality rate M = 0.4.

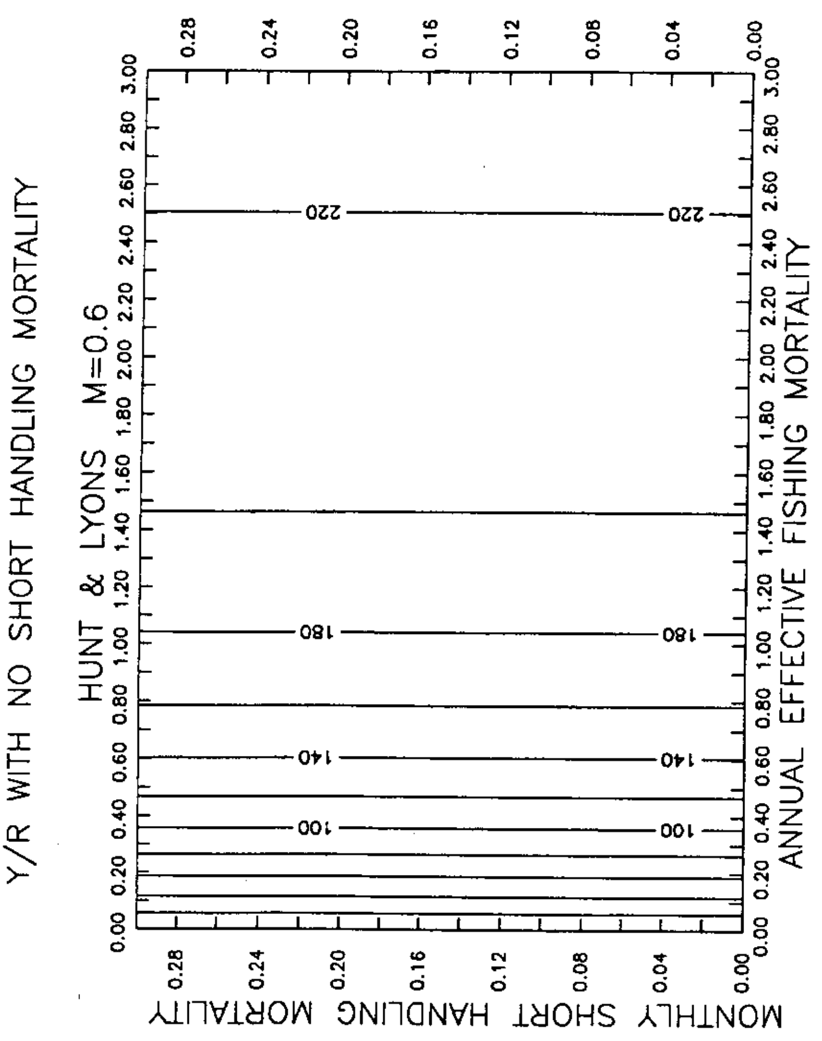

Figure 9. Yield-per-recruit isopleths (grams) for spiny lobster as a function of fishing rate and handling mortality when shorts are not used as bait in the fishery assuming growth follows the equation fit to FDNR data and natural mortality rate M = 0.6.

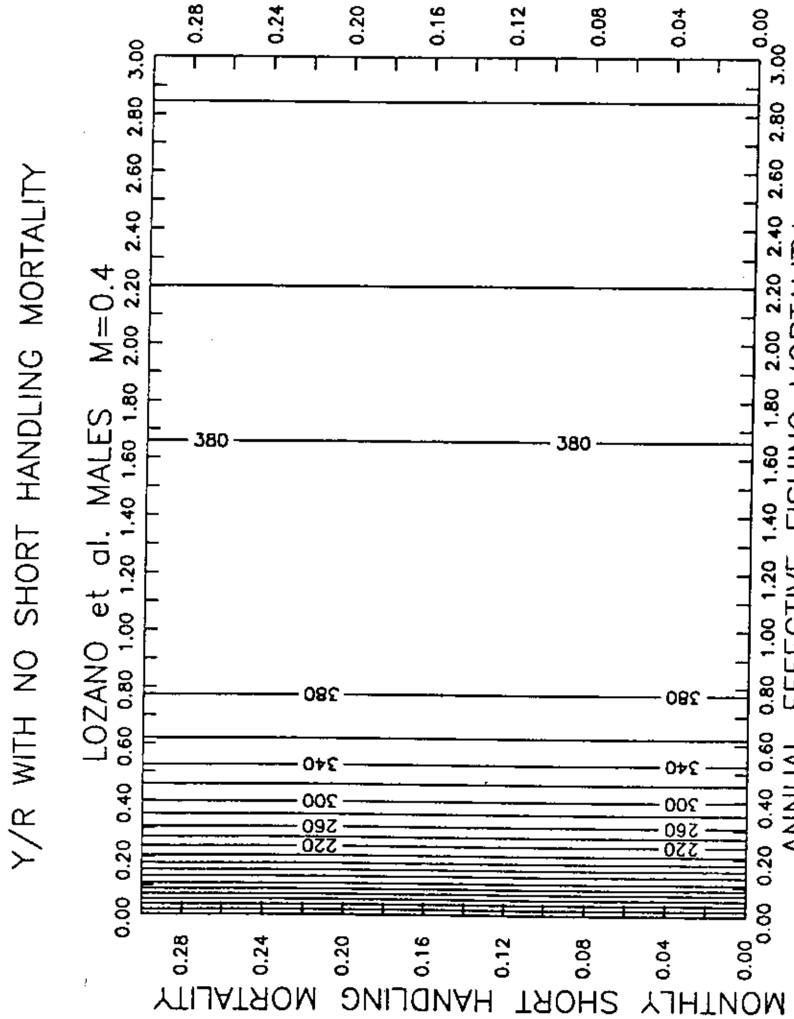

Figure 10. Yield-per-recruit isopleths (grams) for spiny lobster as a function of fishing rate and handling mortality when shorts are not used as bait in the fishery assuming growth follows the Lozano *et al.* equation and natural mortality rate M = 0.4.

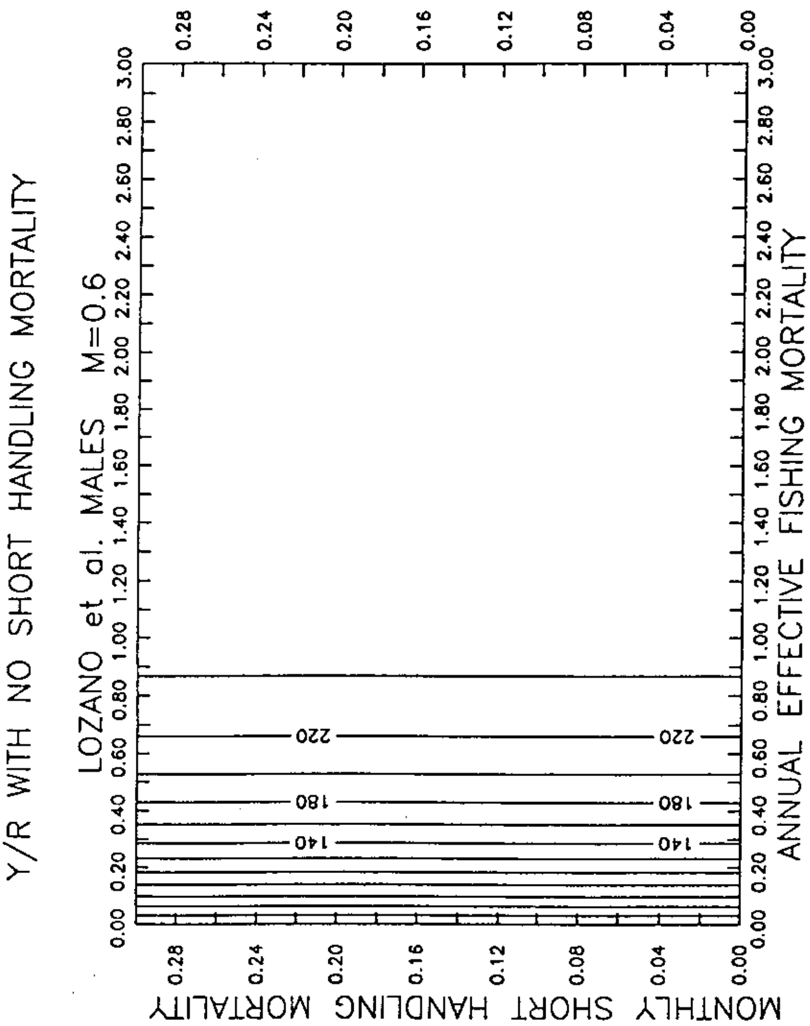

Figure 11. Yield-per-recruit isopleths (grams) for spiny lobster as a function of fishing rate and handling mortality when shorts are not used as bait in the fishery assuming growth follows the Lozano *et al.* equation and natural mortality rate M = 0.6.

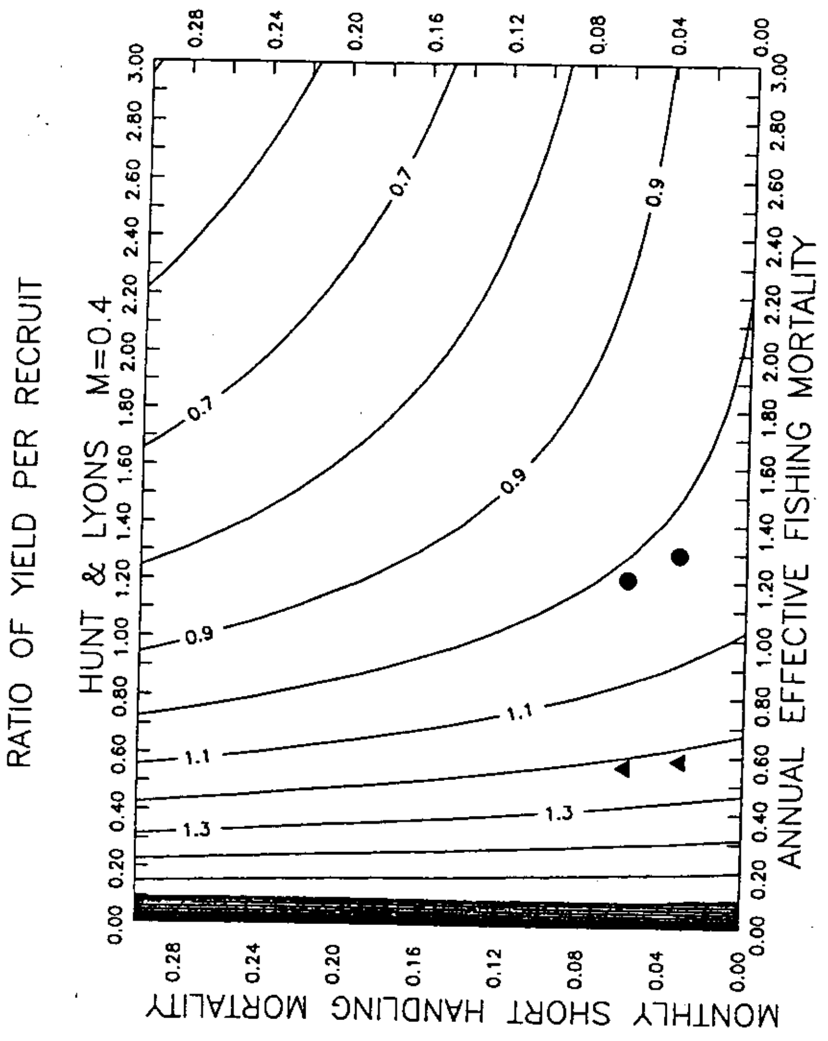

Figure 12. Ratio of yield-per-recruit under present conditions to yield-per-recruit when shorts are not used as bait isopleths for spiny lobster as a function of fishing rate and handling mortality, assuming growth follows the equation fit to FDNR data and natural mortality rate $M = 0.4$. The circles denote ratio yield-per-recruit levels at F_{max} while the triangles denote yield-per-recruit levels at $F_{.9}$ for 0.03 and 0.06 monthly short handling mortalities.

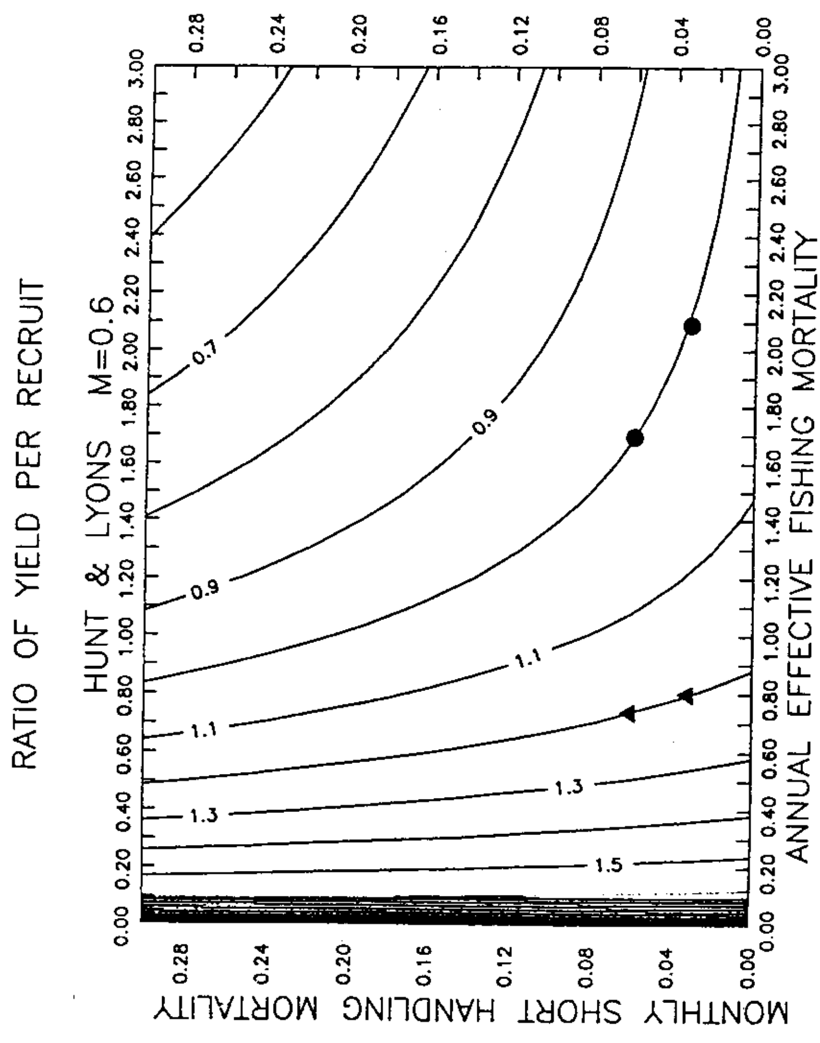

Figure 13. Ratio of yield-per-recruit under present conditions to yield-per-recruit when shorts are not used as bait isopleths for spiny lobster as a function of fishing rate and handling mortality, assuming growth follows the equation fit to FDNR data and natural mortality rate M = 0.6. The circles denote ratio yield-per-recruit levels at F_{max} while the triangles denote yield-per-recruit levels at $F_{.9}$ for 0.03 and 0.06 monthly short handling mortalities.

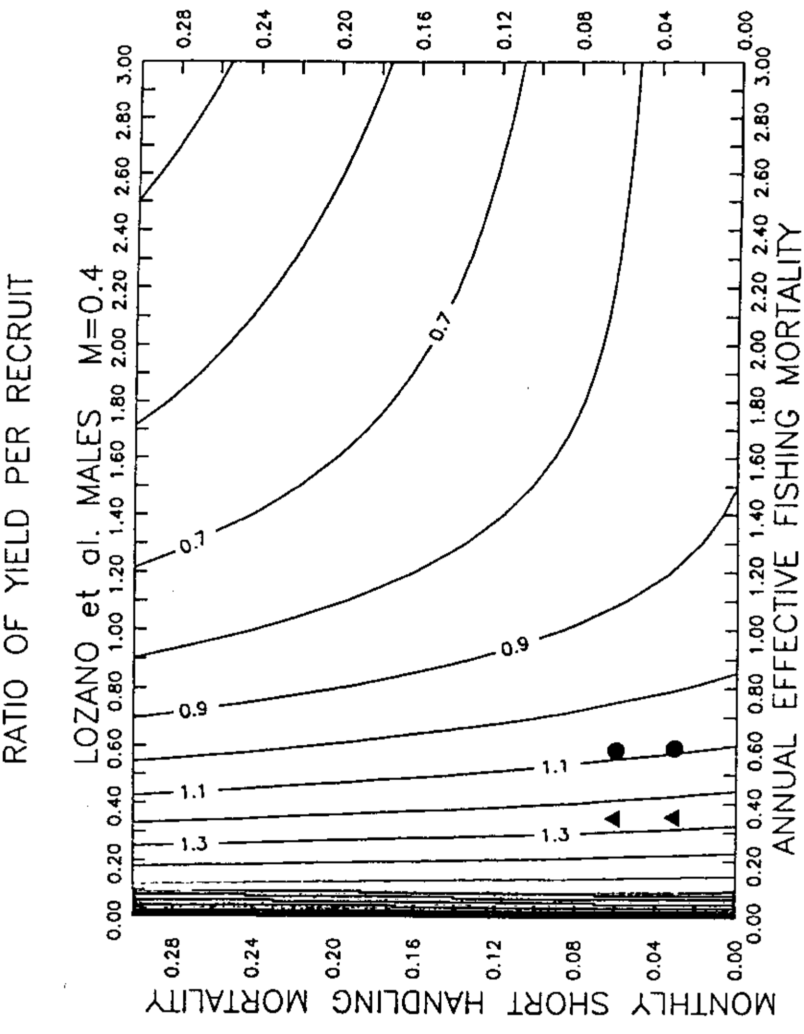

Figure 14. Ratio of yield-per-recruit under present conditions to yield-per-recruit when shorts are not used as bait isopleths for spiny lobster as a function of fishing rate and handling mortality, assuming growth follows the Lozano *et al.* equation and natural mortality rate M = 0.4. The circles denote ratio yield-per-recruit levels at F_{max} while the triangles denote yield-per-recruit levels at $F_{.9}$ for 0.03 and 0.06 monthly short handling mortalities.

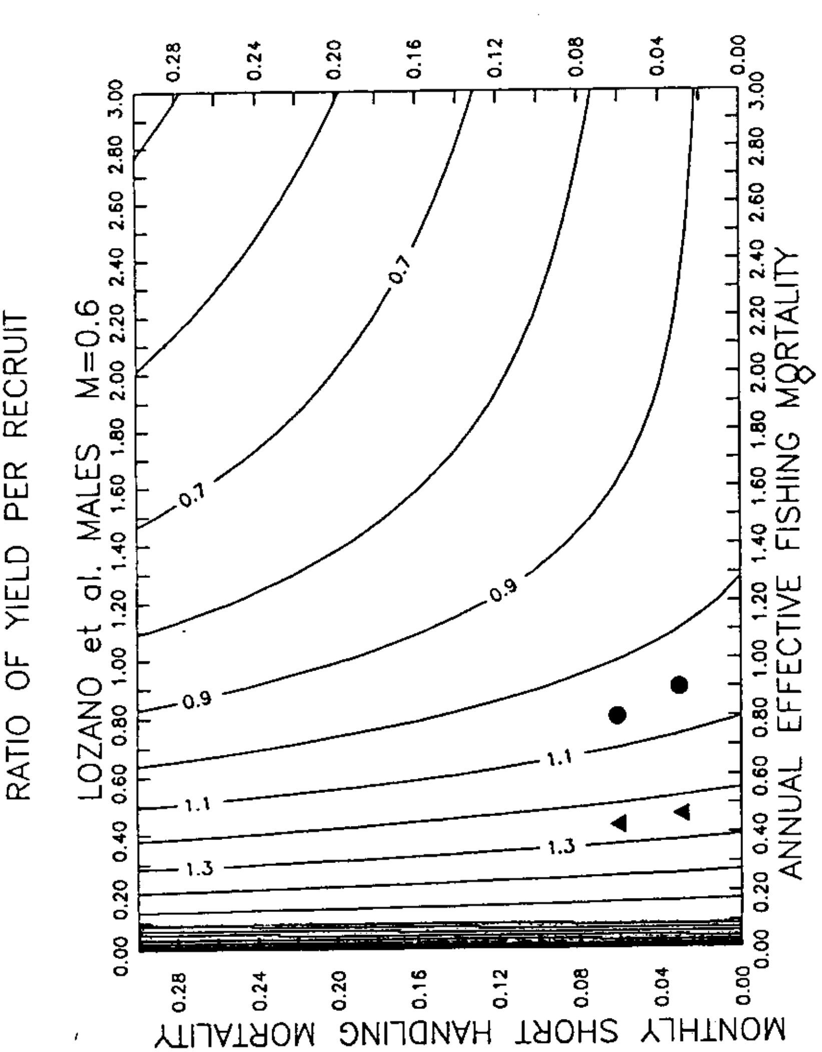

Figure 15. Ratio of yield-per-recruit under present conditions to yield-per-recruit when shorts are not used as bait isopleths for spiny lobster as a function of fishing rate and handling mortality, assuming growth follows the Lozano *et al.* equation and natural mortality rate M = 0.6. The circles denote ratio yield-per-recruit levels at F_{max} while the triangles denote yield-per-recruit levels at $F_{.9}$ for 0.03 and 0.06 monthly short handling mortalities.

Table 1. Instantaneous annual fishing mortality rates corresponding to maximum yield-per-recruit (F_{max}) and to 90% of maximum yield-per-recruit ($F_{.9}$) according to growth and natural mortality characteristics as well as handling mortality fractions.

A. Growth according to FDNR data.

		Handling	**Mortality**	**Fraction**
	M = 0.4	0.00	0.03	0.06
F_{max}		2.80	1.30	1.20
$F_{.9}$		1.17	0.59	0.55
	M = 0.6			
F_{max}			2.10	1.70
$F_{.9}$		1.85	0.80	0.72

B. Growth according to Lozano and Briones (1991)

		Handling	**Mortality**	**Fraction**
	M = 0.4	0.00	0.03	0.06
F_{max}		1.10	0.60	0.60
$F_{.9}$		0.57	0.35	0.35
	M = 0.6			
F_{max}		1.70	0.90	0.80
$F_{.9}$		0.80	0.45	0.42

Yield-per-recruit ratios for optimum management values of fishing mortality (F_{max} and $F_{.9}$) at monthly handling mortality fractions of 0.03 and 0.06 are indicated by the black dot (F_{max}) and by the triangle ($F_{.9}$) in Fgures 12 through 15. We observe that isopleth ratios are greater than 1.0 in all cases implying there are gains from modest (2 to 5%) to significant (21 to 27%) in long term yield-per-recruit associated with the use of shorts as attractants.

CONCLUSIONS

As a result of the greater efficiency of traps using shorts as attractants over gains in biomass by increasing short survivorship with traps using escape gaps, yield-per-recruit of the fishery using shorts is consistently higher than that for the hypothetical fishery using escape gaps under optimum exploitation scenarios. The observed differences are due fundamentally to differences between nominal and effective mortality schedules generated by the two baiting systems. That is, with the same number of traps deployed in the fishery the effective fishing mortality rate of traps using shorts as attractants is much greater than the effective fishing mortality generated by traps with escape gaps, and that difference offsets significantly yield-per-recruit losses due to short handling mortality.

Two options are available to match effective fishing mortalities: 1) increase the number of traps with escape gaps used in the fishery; or 2) fish for a longer time. Both of these options appear to have negative impacts on an already congested fishery. In fact, Option 1 does not offer a realistic solution while Option 2 requires keeping traps in the water for a longer time to realize the same capture as in the exploitation scheme using shorts as attractants. Extended soaking time results from the less efficient character of traps with escape gaps which generate lower catch per soaking time. Consequently, adoption of Option 2 will require more fishing trips per season with the obvious extra investment in manpower, fuel and equipment. Additionally, by keeping traps set for longer time periods the overall operational life of the traps will be reduced and the probability of losing traps increases; both of these effects have negative compounded economic impacts on the fishery. The fact that traps have to be serviced for a longer time to generate a similar catch per trap per season implies that fishermen participating in the multi-species fishery system in south Florida will have to accommodate other fishing activities to a potentially new lobster fishing scheme. Among the most affected lobster fishermen will be those that are also involved in stone crabbing and mackerel fishing.

In the analyses, we did not consider other important factors associated with lobster trapping which on the average will render the use of short as attractants more efficient than the use of escape gaps. Among the most salient items are: 1) traps with escape gaps and making use of cowhide or other types of baits will attract stone crabs which can easily enter traps through gaps. It is a well-known fact that traps containing stone crabs limit their catchability of lobsters, 2) escape rates from existing trap designs are high reducing the probability of mortality due to confinement and starvation of trapped lobsters; and 3) traps are refuge for lobsters thereby preventing an excess of natural mortality due to predation. Escape gaps studies have shown a significant decrease in the number of sublegal and legal lobsters captured, a condition that may be associated with the lost value of traps as refuge. The preceding factors were not included in the analyses because there is insufficient information for modelling such processes, however, as specific information is collected through time, it will be easy to modify and incorporate the above factors in the mortality equations developed in this work.

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