FACTORS AFFECTING THE GROWTH OF UNDERSIZE WESTERN ROCK LOBSTER, *PANULIRUS CYGNUS* GEORGE, RETURNED BY FISHERMEN TO THE SEA

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ABSTRACT

The Western Australian fishery for the western rock lobster, *Panulirus cygnus*, yielded about 12,400 t, valued at $A100 million, in 1982-83. It is the largest single species fishery in Australia and one of the largest rock lobster fisheries in the world.

During a season, between 16 and 20 million undersize rock lobsters are brought aboard the vessels by normal fishing operations, despite the escape gaps in all professional and amateur pots. All undersize animals must be returned by fishermen to the sea, but to accomplish this it took from a few minutes to hours, depending on the sorting technique used. The negative effects of handling on the survival of the undersize lobsters have been previously reported, but another important aspect is the effect of handling (damage, exposure, and displacement) on the growth rate of returned undersize rock lobsters.

Two laboratory experiments showed that growth increment at the first molt after air exposure was significantly reduced, and in one of the experiments it was also significantly reduced for the second molt after exposure.

Three field tagging trials were conducted with 6,700 undersize rock lobsters. One trial showed that exposure had a significant detrimental effect; the other trial in which exposure was tested, there was a negative, but not significant, trend. Damage (number of appendages lost) and displacement from the home range significantly reduced the growth increment in each of the three tagging trials. The growth increment of damaged animals was inversely proportional to the number of appendages lost by the animal with sizes ranging from 0.33 to 0.48 mm smaller per appendage missing. The losses to the fishery and other associated problems caused by the reduced growth of the undersize lobsters are discussed.

The fully exploited stocks of western rock lobster, *Panulirus cygnus* George, support the largest single species fishery in Australia and one of the largest rock lobster fisheries in the world, averaging 10,000 t for the last 9 yr to 1982-83. In 1982-83 the fishery recorded its best season; the 12,400 t worth about $A100 million, were landed by 780 boats licensed to participate in the industry. The amateur catch from the fishery, estimated at 1.6% of the professional catch (Norton 1981), is considered to be a relatively insignificant component of the total fishery, though it may be locally important and occurs in shallow areas where large numbers of undersize rock lobsters (i.e., those with a carapace length <76 mm and referred to below as undersize) are caught.

Fishing pressure on the rock lobster stock has been increasing steadily during the past 20 yr, even though it has been a limited entry fishery since 1963 (Morgan 1980a, b; Hancock 1981). This has led to the need for constant monitoring of the fishery and the updating of management procedures and regulations to ensure the stability and viability of the rock lobster stock (Bowen 1980; Morgan 1980a, b; Hancock 1981; Morgan et al. 1982). An important component of management of a fully exploited stock is to reduce waste, e.g., by predation and poor handling techniques.

Two of the most important regulations that aid in conservation of the western rock lobster stock pertain to undersize:

1) Compulsory use of a 54 × 305 mm escape gap in each of the 76,000 professional and all amateur pots (traps) in the fishery allows many undersize animals to escape before the pot is pulled (Bowen 1963).
2) Undersize lobsters that do not escape and are brought aboard must be returned to the sea.

Although use of escape gaps reduces the retention of undersize lobsters by over 50% (Bowen 1963; Brown unpubl. data), between 16 and 20 million undersize animals are still handled each season by professional fishermen (Brown and Caputi 1983). The latter authors found that the handling practices of fishermen, which cause exposure, damage

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(number of legs and antennae missing), and displacement of undersize lobsters, resulted in a drop in recapture (mainly due to mortality) of 14.6%. After allowing for the natural mortality expected before the undersize lobsters would reach legal size, the effective reduction that could be expected was 11.4%. For the 1982-83 season, the loss to the fishery could have been in the vicinity of $A8 million.

An aspect of undersize lobster mortality and loss of commercial production that was not discussed by Brown and Caputi (1983) concerns the effect of handling on the growth of these animals. If the growth rate of the undersize lobster is reduced by exposure, damage, and displacement, then it could affect the rock lobster stock and the commercial fishery in a number of important ways as discussed by Davis (1981): 1) The time taken for undersize lobsters to reach legal size would be increased; 2) these animals would enter the commercial fishery at a smaller size than those with unhindered growth; and 3) the size at which these animals would attain maturity would be reduced.

Other researchers have shown that the growth rate of crustaceans generally and rock lobsters in particular is affected by a variety of environmental factors such as food availability, temperature, photoperiod, molt phase, injuries, shelter availability, salinity, and others (Chittleborough 1974a, 1975, 1976; Aiken 1980). Far less information is available on the effects of commercial and recreational fishing practice on the growth rates of exploited rock lobster or other crustacean populations (Davis and Dodrill 1980; Davis 1981). Information that is available deals almost exclusively with the injury (damage) component of fishing activities or experimentation. Injury, recorded as the loss of appendages, has been shown to affect significantly the growth of rock lobsters *P. cygnus* (Chittleborough 1975) and *P. argus* (Davis 1981) and the shore crabs *Hemigrapsus oregonensis* and *Pachygrapsus crassipes* (Kuris and Mager 1975).

This paper reports effects of three major components of the capture and release experience (i.e., damage, exposure, and displacement) on the growth rate of undersize lobsters caught from commercially fished populations of *P. cygnus*. The effect of the various components was examined by tagging lobsters that were exposed for various periods and were displaced at different distances from their place of capture, with any damage being recorded. Growth of experimental animals between release and subsequent recapture was compared with that of control lobsters which had not been exposed, damaged, or displaced. Laboratory experiments were also conducted in which undersize lobsters were exposed for various periods and their growth rates subsequently monitored over the next two molts.

Consequences to the industry of any reduction in growth rate are discussed in the light of results from this research and the findings reported by Brown and Caputi (1983).

LABORATORY EXPERIMENTS

Materials and Methods

Exposed undersize lobsters were maintained under otherwise near optimal growing conditions of excess food, adequate shelter, and protection from potential predators (see also Chittleborough 1975) and their molt increment and intermolt period compared with those of unexposed animals.

Undersize lobsters (72-75 mm carapace length) were collected from the field and transported in aerated seawater tanks to the laboratory in January 1978. Each animal was examined for size, sex, and damage. Sixty undersize lobsters with no damage or maximum of one appendage missing were selected and marked with numbered squares of Dymo Scotch Tape,[2] fixed to the dorsal side of the carapace with Repco Super Glue and placed in open circulation seawater tanks. Aquaria were checked daily for molts, and animals were fed to excess on whole live mussels and fresh fish. If molting had occurred, the exuvia was removed and the newly molted animal left for a week to harden before measuring and renumbering. In January 1979, each animal was allowed to undergo a minimum of two molts before the entire group (Group I, consisting of 4 subgroups of 15 animals) was given exposures of 0, 15, 30, or 60 min at a temperature of 34°-35°C. Animals that died prior to exposure were not replaced.

After exposure, undersize lobsters were returned to their tanks and were checked daily for any molts or deaths. Feeding and renumbering was continued as for pre-exposure. Every animal that survived was allowed at least two molts before the experiment was terminated.

A second group of undersize lobsters (Group II, consisting of 5 groups of 12 animals), collected in June 1978, were treated in the exact manner as described for Group I with the exception that exposures of 0, 15, 30, 60, or 120 min at 20°-21°C took place 18 mo later, in December 1979.

[2]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

Results

In the January 1979 exposure experiment (Group I), all eight undersize animals exposed for 60 min died before the second molt after exposure, while one animal died from each of 0-, 15-, and 30-min exposure categories leaving 7, 10, and 7 animals respectively.

An analysis of variance on growth increment at the first molt after exposure showed that exposure was significant ($P < 0.01$) after other factors (e.g., sex, damage, initial size), which may have affected growth, were taken into account. However, at the second molt after exposure, the effect of exposure on growth increment was not significant ($P > 0.05$). An analysis of variance on the time taken (days) between the last molt before exposure and first molt after exposure (intermolt period) resulted in exposure being not significant. Exposure was also not significant for the following intermolt period.

In the December 1979 exposure experiment (Group II), one animal died in the 0-, 15-, 30-, and 120-min exposure categories and two died from the 60-min exposure before the second molt after exposure. In this experiment, exposure had a significant effect on the growth increment for both the first ($P < 0.001$) and the second ($P < 0.01$) molts after exposure. An analysis on the intermolt period for the first molt after exposure showed no significant effect due to exposure, but exposure was significant ($P < 0.05$) for the following intermolt period, mainly due to the low number of days between molts for animals in the 120-min exposure category.

TAGGING TRIALS

Materials and Methods

There are two main events in the commercial fishery for *P. cygnus* which follow molting by a large proportion of the population. The first event is in November-December when maturing 4-5 yr old pale-shelled animals known locally as "whites" move offshore into deeper water, where the breeding stock is generally situated. During the "whites" fishery, about 40% of the total catch is taken (Morgan 1980b). The second event is in March-April when postmolt, dark-shelled, sedentary animals called "reds" are captured (George 1958; Morgan 1977). As already mentioned in Brown and Caputi (1983), account had to be taken of these two periods when planning tagging trials as the migratory "whites" could be more mobile and in a physiologically different state than nonmigratory "reds" and hence their growth could be affected differently by handling practices (i.e., causing exposure, displacement, and damage). With these possible differences in mind, three tagging trials were conducted at Two Rocks, Western Australia (lat. 31°29.7′S, long. 115°31′E), avoiding the period of the full moon, when catches are at their lowest (Morgan 1974, 1977): 1) migratory "whites" phase—26 November to 10 December 1978; 2) nonmigratory "reds" phase—19 February to 10 March 1979; and 3) migratory "whites" phase—16 November to 9 December 1979.

An area consisting of shallow limestone reefs (6-18 m depth) within 6 km of shore and stretching from Two Rocks Marina to the mouth of Moore River was fished with standard wire beehive pots without escape gaps (Bowen 1971; Morgan and Barker 1974). Pots were baited daily with a variety of fresh fish; heads of Australian salmon, *Arripis trutta*; and bullock hocks.

Tagging Trial A

An experimental area was established, consisting of a grid on which pots were set and undersize lobsters could be displaced distances of 0, 230, 460, 910, 1,370, and 1,830 m from a base line of experimental pots where they were captured (Brown and Caputi 1983). Pots were pulled each morning during the trial, weather permitting. Undersize (66 to <76 mm) lobsters were tagged with a numbered western rock lobster tag (Chittleborough 1974b) and their carapaces measured to the nearest 0.1 mm. Also recorded was the animal's damage, sex, and the depth and bottom type where it was caught and released. Grid areas were generally fished only once to avoid recapturing previously tagged animals. Recaptures of tagged animals were made by commercial fishermen who were paid a reward for the tag and market value for the animal if it had molted to legal size. See Brown and Caputi (1983) for complete details of experimental procedures. Number of releases for this trial was about 1,500.

Tagging Trial B

Procedure for trial B was the same as trial A except that the 1,370 m transect was not set and exposure categories of 0, 30, 60, 120, and 180 min were also examined. Exposed undersize lobster were placed in plastic prawn baskets (lug baskets; commonly used by fishermen to sort their catch) and exposed to air for the desired period before release at one of the displacement transects. About 2,300 tagged animals were released.

Tagging Trial C

Similar procedures were followed as for trials A and B, but only the 1,830 m and a new 3,660 m transects were set and exposure categories of 0, 15, 30, 60 min were used. Because parasite infection was observed on some animals (6.3% of releases), its presence was recorded as it could affect growth. The infection is a combination of a fungus (*Fusarium* sp.) and a bacteria (*Vibrio* sp.), which causes black lesions in the exoskeleton, usually in areas that have been damaged (e.g., tail fans and appendages). Infections were scored on an ordered scale of 0-6, with 0 indicating no infection. About 2,900 tagged animals were released.

Results

Figure 1 shows mean size (carapace) increment related to month of recapture for each of three tagging trials. In tagging trials A and C (November-December releases), February was the first month when there was evidence of molting in animals recaptured (Fig. 1); therefore, subsequent analyses on size increment only used recaptures from February onwards. In tagging trial B (February-March releases), May was the first month when there was evidence of molting (Fig. 1), so only data from this month onwards was used for the analyses.

The results of an analysis of variance (ANOVA) on size increment for each of three tagging trials is shown in Table 1. In this analysis recapture month, sex, color, displacement, and exposure were treated as factors while size at release, damage, and level of parasite infection were treated as covariates. The analysis enables the significance of these factors and covariates to be determined after effects of other factors and covariates are taken into account.

In tagging trial A, after taking the effects of other factors into account (e.g., sex, recapture month, etc.), the size increment per appendage missing was smaller by 0.48 mm with standard error of 0.04. This is also evident from Figure 2 which shows the relationship between mean size increment and numbers of appendages missing for all recaptures from February to June 1979. Size increment in tagging trial C was also smaller by 0.48 mm per appendage missing with standard error of 0.004 (see Figure 3), while that for tagging trial B was 0.33 mm smaller (standard error of 0.07).

From the ANOVA, size increments of displaced compared with nondisplaced animals were smaller by 0.32, 0.65, and 0.27 mm for tagging trials A, B, and C respectively.

Exposure in tagging trial C, after other factors were taken into account by the ANOVA, resulted in increments smaller by 0.83, 1.34, and 2.30 mm for 15-, 30-, and 60-min exposure respectively, when compared with the zero exposure category. This can also be seen from Figure 3 which shows the mean size increment for animals recaptured after February 1980 related to exposure and number of appendages missing. While the effect of exposure on growth was not significant for the February-March 1979 trial B, size increments were smaller by 0.62 and 0.73 mm for 30- and 60-min exposures respectively, compared with unexposed animals.

Mean size increment of males was larger than females by 0.95, 1.34, and 0.76 mm for the three tagging trials. Although the size at release of all animals was between 66 and 76 mm, there was still a highly significant decrease in size increment due to size at release of 0.25, 0.36, and 0.20 mm for every 1 mm increase in size at release. Difference in color, i.e., dark-shelled vs. pale-shelled animals, was significant in tagging trial A with pale-shelled animals having a greater size increment by 0.65 mm, but this was not evident in tagging trial C. In tagging trial C, level of parasite infection of the animals was found to have had a detrimental effect on growth.

DISCUSSION AND CONCLUSIONS

Exposure

Exposing undersize rock lobsters to the atmosphere was detrimental to their growth increment at the first molt after exposure in both laboratory and field tagging trials. In the December laboratory experiment (Group II) the effect of exposure was still significant at the second molt after exposure. Tagging trial B (February-March 1979) resulted in exposure not having a significant effect on growth despite the presence of a negative trend between exposure and size increment. This may have been due to the fact that only 7 of the 110 animals recaptured in May-June 1979 had been exposed; this is the period when many of the undersize lobsters would have undergone their first postexposure molt (Fig. 1). Since there is a closed season from 1 July to 14 November, no recaptures were made until the time of the second postexposure molt in November-December 1979, by which time the combined effects of two molts may have masked the effect of the exposure treatment. However, this was not the case in tagging trial C (November-December 1979), which was held at the start of the fishing season, where the effect of exposure on the first molt which occurs

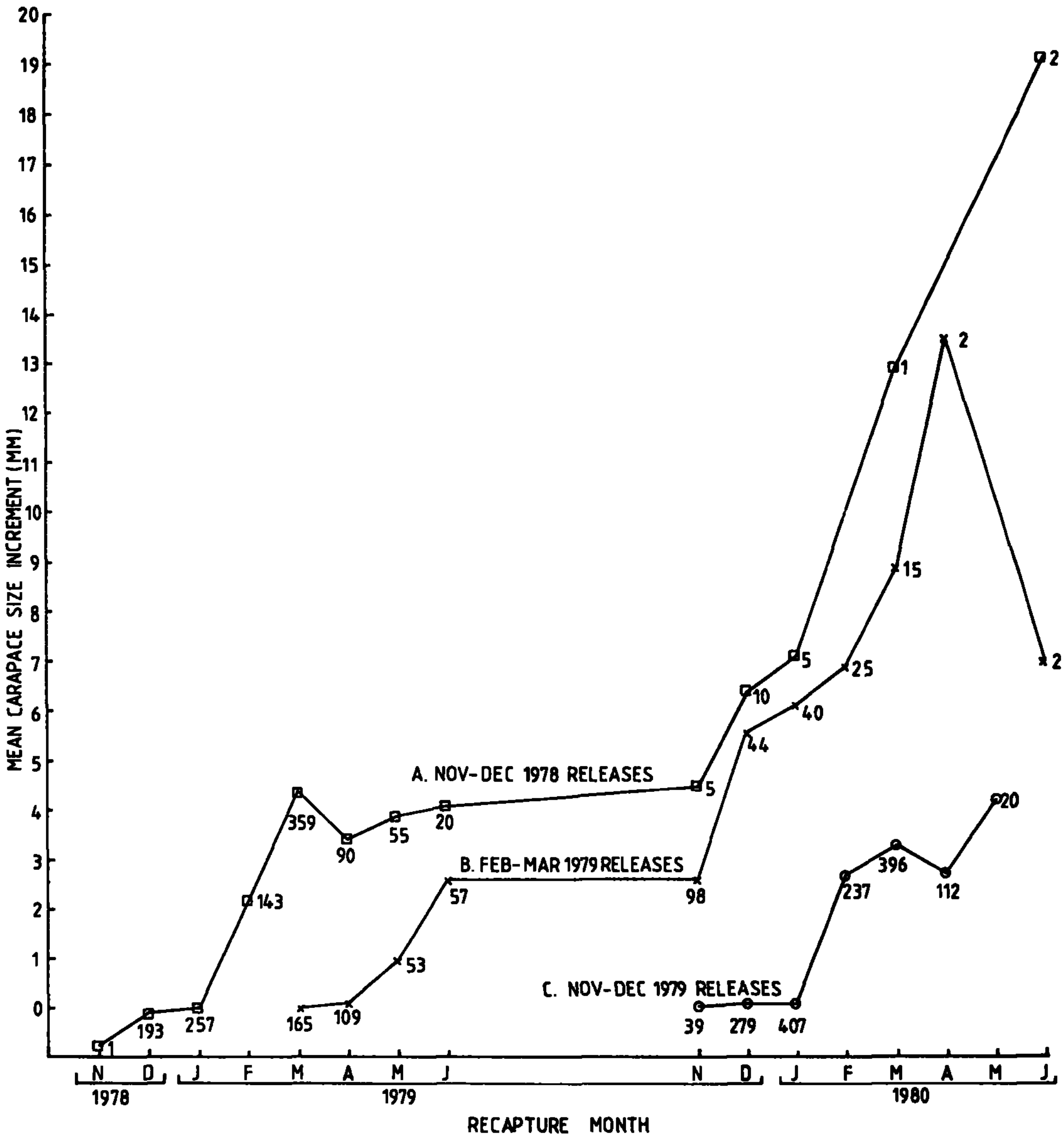

FIGURE 1.—The mean size (carapace) increment by month of recapture and the sample size involved in calculating it shown next to the points, for the three tagging trials at Two Rocks.

around February was clearly evident in animals caught from February 1980 onwards (Fig. 3, Table 1).

Damage

Damage to undersize rock lobsters was clearly shown to have a detrimental effect on growth (Table 1), which was directly proportional to the level of damage (Figs. 2, 3).

Chittleborough (1975) found that growth increment of *P. cygnus* was reduced under laboratory conditions when four or more legs were removed and repetitive loss of two or more limbs led to precocious molting with reduced molt increments leading to an overall reduction in growth. Davis and Dodrill (1980) and Davis (1981) undertook research on the effect of injuries (limb loss) produced by amateur and professional fishermen and natural causes (e.g., predators, molting accidents, etc.) on the growth rate of *P. argus* populations in the wild. They found that

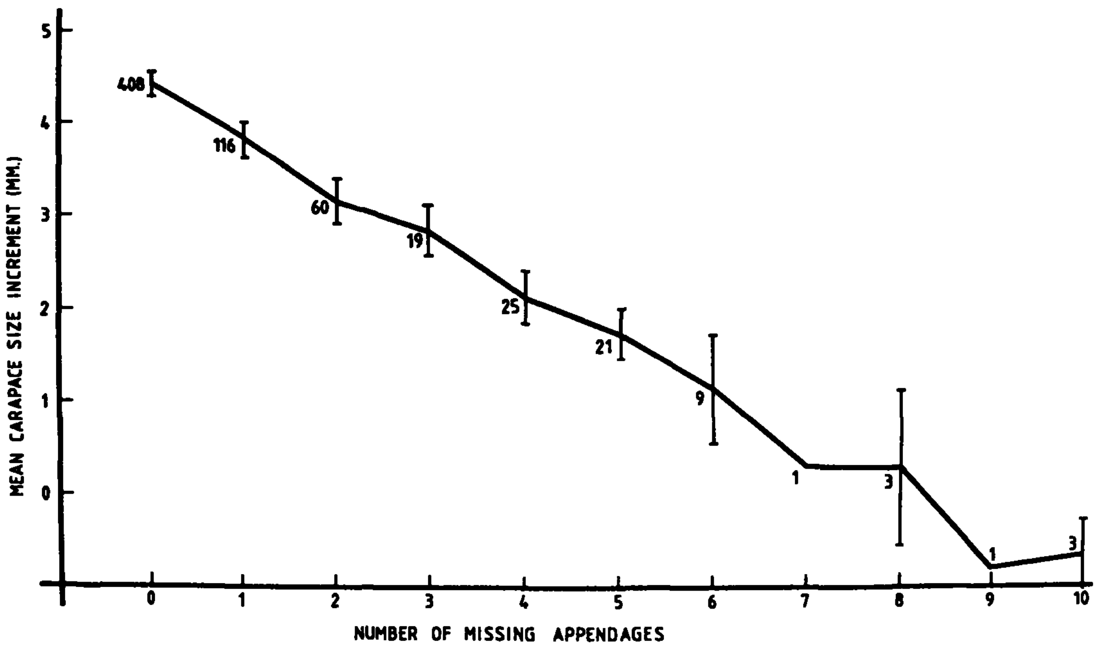

FIGURE 2.—Two Rocks, November-December 1978. The relationship between the mean size increment and number of appendages missing for recaptures from February to June 1979, with the sample size and standard error from the mean shown at each point.

TABLE 1.—The results of the analysis of variance on size increment for the three tagging trials at Two Rocks with the level of significance denoted by: NS, *, **, *** meaning not significant, $P < 0.05$, $P < 0.01$, and $P < 0.001$ respectively, and NA means not applicable.

Factor/covariate	Nov.-Dec. 1978	Feb.-Mar. 1979	Nov.-Dec. 1979
No. missing appendages	***	***	***
Displacement	*	*	*
Exposure	NA	NS	***
Recapture month	***	***	***
Sex	***	***	***
Size at release	***	***	***
Color	**	NA	NS
Parasite infection	NA	NA	***
Sample size	687	335	636

the growth rate of injured animals was significantly lower than that of uninjured animals, due to reductions in molt increment and an increase in intermolt period. Their research did not demonstrate any proportional relationship between the degree of injury and the degree of molt increment depression as had been shown for *H. oregonensis* and *P. crassipes* (Kuris and Mager 1975) and also in this study on *P. cygnus*. Davis (1981) stated that growth rate of *P. argus* with minor injuries, five or fewer appendages missing, was almost identical to the growth rate of more seriously injured animals that were missing up to nine legs and both antennae.

Displacement

The displacement of undersize rock lobster was also found to significantly affect size increment in each of the three tagging trials. This was probably due to movement of animals from their home range (Chittleborough 1974c) which could have interrupted their normal feeding behavior and thus may have contributed to a decrease in food intake and hence growth.

Overall Effect

In general the handling of undersize rock lobsters by fishermen which causes them to be exposed to the atmosphere, damaged and displaced beyond their home range, not only affects their survival (Brown and Caputi 1983) but also affects growth of those that survive. As discussed in Davis (1981), this reduction in growth may result in:

1) The undersize lobsters staying below the legal size for a longer period than necessary with some being subject to natural mortality in this extra period before entering the fishery.
2) Those animals which do enter the fishery would do so at a reduced size, hence harvestable yield would be reduced.

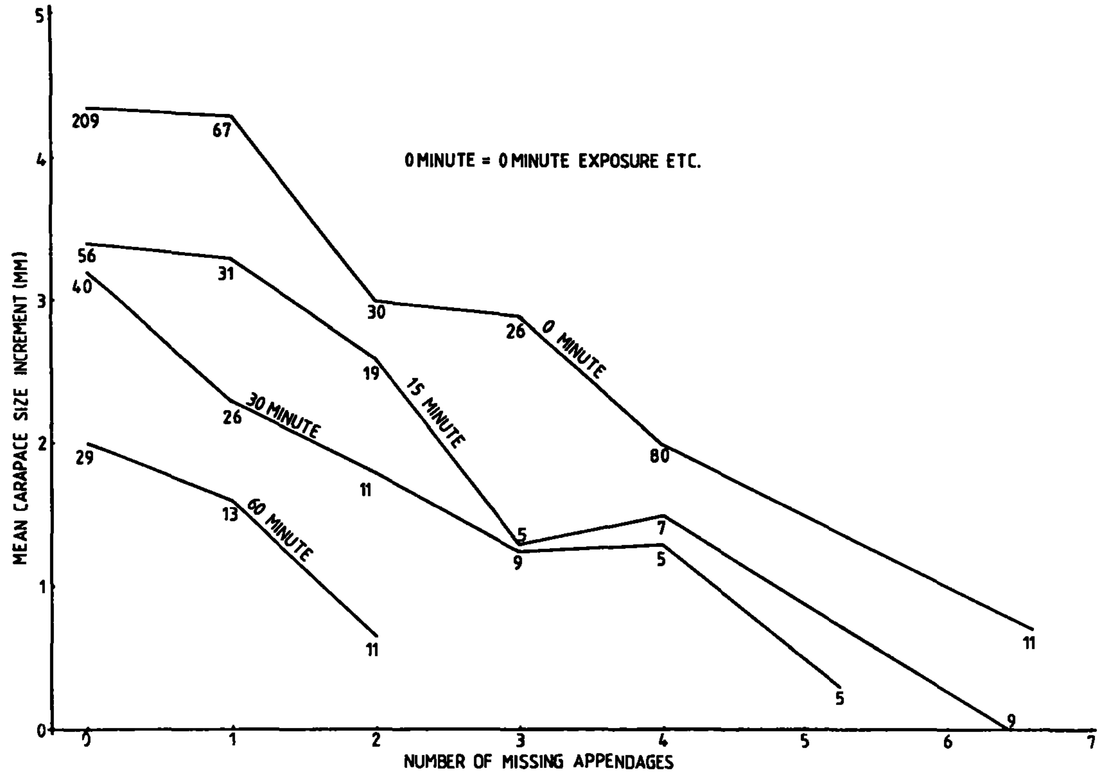

FIGURE 3.—Two Rocks, November-December 1979. The mean size increment related to exposure categories and number of missing appendages for animals recaptured from February 1980 onwards. Exposure and missing appendages categories with less than five individuals have been combined and are plotted at the mean appendage level. The sample sizes are shown next to the points.

3) Size of these animals on reaching maturity would also be reduced, which would cause a decrease in fecundity directly proportional to their reduced size (Morgan 1972). The time they would take to reach maturity would probably not be affected since age appears to determine maturity rather than size (Chittleborough 1974d).
4) Affected animals would remain undersize for longer, thereby increasing the possibility that they could undergo multiple capture and handling. Multiple handling would result in increased mortality and further reduced growth.

These factors, when added to the estimate of 14.6% reduction in recapture rate (most likely due to mortality) of the returned undersize lobsters during the fishing season (Brown and Caputi 1983), constitute a serious loss to the fishery. In addition, any mortality and reduced growth which may occur as a result of lifting the animals to the surface and returning them to the sea would also need to be added to the above loss. This loss could not be quantified as both experimentals and controls in the tagging experiments experienced this.

As mentioned by Brown and Caputi (1983), use of more effective escape gaps and an education program to encourage fishermen to return their undersize rock lobsters immediately to the sea while their vessel remained in the immediate vicinity of where the pot was pulled would help to overcome this serious source of industry created wastage. Both these approaches are currently being examined with a view to reducing the numbers of undersize lobsters that are handled and the time they are kept on board the vessels.

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