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Effects of soak-time and spatial heterogeneity on sampling populations of spanner crabs *Ranina ranina*

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ABSTRACT: A series of field experiments was done in spanner crab *Ranina ranina* (Linnaeus) fishing grounds to determine the effects on catch per unit effort (CPUE) of crabs due to soak-time and the species' spatial heterogeneity. Standard and optimally-designed baited tangle-traps were used in a nested experimental design to catch crabs on gear set in place for various periods of time. To determine the degree of spatial and short-term temporal variability in CPUE, replicate sets of traps were set at different locations, depths and times of day. Cost-benefit analyses of this experiment yielded optimal numbers of traps and sets of traps to be used at each location and depth in subsequent sampling. The minimum time one should leave traps in the fishing grounds to achieve maximal CPUE was determined as 60 min. Different locations and depths yielded quite different CPUE's indicating that future surveys should encompass several locations and depths. Time of day had no significant effects on CPUE. Cost-benefit analyses showed that 5 traps on each of 3 sets should be used at each location and depth to optimize CPUE given the limited time availabe to survey a given place. The consequences of this replication on the sizes of standard errors in future sampling were estimated. A uniform and optimal methodology is developed from the results discussed in this and a previous paper which will be used in subsequent censussing of this species' distributions and abundances. Finally I discuss the worth of manipulative experimentation to test specific hypotheses about species which are sampled using baited traps and note the value of cost-benefit analyses of pilot studies in designing surveys of such species' populations.

INTRODUCTION

Fisheries research involving the sampling of populations often employs catch per unit of effort data (CPUE) to estimate relative abundances and age/size structures of exploited populations. This requires accurate estimates of both catch and effort (Collie & Sissenwine 1983; for review see Sissenwine 1984). Although data on catch are relatively simple to obtain as counts and measurements of caught animals, the effort involved in obtaining given catches is often more difficult to quantify and standardize. Ideally, methods should be uniform, unbiased, optimal with respect to the quantity of catch obtained, and replicated in space and time so as to allow reliable estimates of relative abundances and size structures of target species. The focus of many previous studies has been the reliability and accuracy of methods that sample abundances of commercially-important marine species (Larkins 1963, 1964, Jester 1973, Hamley 1975, Kjelson & Colby 1977, Fogarty & Borden 1980; see review by Sissenwine et al. 1983).

There have also been several papers which have assessed baited trapping techniques as a means of estimating relative abundances of exploited populations of large decapods (Thomas 1953, Sinoda & Kobayasi 1969, Miller 1978, 1979, 1981, 1983). These papers point out several factors that may influence such CPUE data apart from the absolute abundances of crabs and lobsters. These factors include the shape of traps, the net used in traps, the bait used, competition between traps, the soak-time of traps (length of time traps are available to animals), and the position of fishing effort in space and time. An earlier paper (Kennelly & Craig 1989) considered the first 4 of these factors in developing a sampling unit which could be used in subsequent sampling of the relative abundances of populations of spanner crabs *Ranina ranina* (Linnaeus) off the east coast of Australia. In the present paper I consider the last 2 of these factors by describing experiments which determine the best deployment of the sampling tool in large-scale, long-term surveys of *R. ranina* distributions and abundances. These experiments involved assess-

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ing effects on the sampling regime due to different soak-times and inherent spatial and temporal variability in the species' distributions.

Ranina ranina are large marine brachyurans found throughout the Indo-Pacific region (Barnard 1950). They are found in coastal waters in depths of 10 to 80 m on sandy substrata in which they bury (Skinner & Hill 1987). Populations of *R. ranina* have been exploited commercially in Hawaii, Japan, the Philippines and recently, the east coast of Australia (Skinner & Hill 1986). There have been, however, only a few studies concerning the biology and ecology of this valuable species (Onizuka 1972, Fielding & Haley 1976, Tahil 1983, Brown 1986, Skinner & Hill 1986, 1987) and so many of the most basic aspects of its biology are unknown, including its distributions, abundances and rates of growth. A first step in obtaining this information is to develop a sampling methodology which can be used in future surveys of populations of this species.

There are several reasons why the CPUE of crabs in baited traps may asymptote with increasing soak-times, e.g. fading bait odour, saturation of traps with caught crabs, loss of bait by being eaten, and the capture of all available crabs, and such effects have been examined in many fisheries (e.g. Sinoda & Kobayasi 1969, Munroe 1974, Fogarty & Borden 1980, Powles & Barans 1980). In the present study I compare the CPUE of *Ranina ranina* on baited traps left for various periods to determine the period which maximizes catches of individuals.

Spatial heterogeneity in the distributions and abundances of target species directly influences estimates of CPUE and therefore measures of relative abundances. To account for such variability, it is necessary to replicate one's sampling strategy such that it provides the most reliable and representative results unter the logistic restrictions of limited time and/or money. The choice of optimal numbers of replicates can be easily calculated using well-established cost-benefit analyses of data from pilot surveys (Snedecor & Cochran 1967, Winer 1971, Saila et al. 1976, Underwood 1981). These techniques have been successfully used in a variety of habitats from desert and terrestrial plains (Robinette et al. 1974, Caughley et al. 1976) to kelp forests and coral reefs (Kennelly & Underwood 1984, 1985, Fowler 1987). Here I present cost-benefit and variance analyses on data from a pilot survey of distributions and abundances of *Ranina ranina* which provide the optimal degree of spatial replication and replication throughout the day which may be used in subsequent surveys.

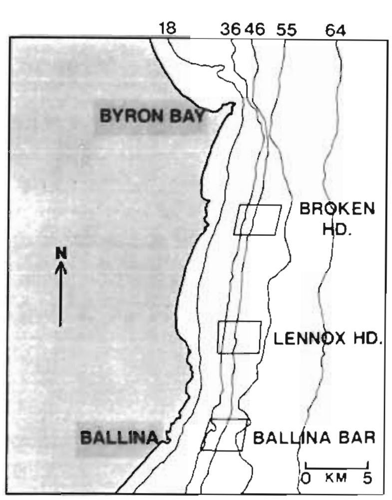

Fig. 1. Locations of study sites. Depth contours are in metres

MATERIALS AND METHODS

This study was done off the north coast of New South Wales, Australia, in the same fishing grounds as those used by commercial fishermen. To obtain CPUE data, we used modifications of commercial fishing methods. Traps were square frames 1.2×1.2 m and made of mild steel with 85 mm, 4-ply net doubly hung over each frame with a standard 230 mm drop. This type of trap catches the most crabs and the widest size-range of crabs (Kennelly & Craig 1989). One bait (fish-skeleton) was placed in the middle of each trap. Five traps were set out 60 m apart along a trot-line placed cross-current on the substratum in the area or depth to be sampled (60 m is the distance at which neighbouring traps are independent; Kennelly & Craig 1989). These sets of traps were left for given soak-times during which individual *Ranina ranina* were attracted to the bait and became entangled on the net before reaching the bait. When traps were hauled, crabs were disentangled, counted, measured (eye-orbit to carapace length), sexed and returned to the sea.

Expt 1 – Effects on CPUE due to soak-time. Four replicate sets with 5 traps on each were set randomly off Lennox Head, NSW (28° 47'S; 153° 39'E) (Fig. 1) for periods of 15, 60 and 120 min. Sets of traps were placed so that returned crabs could not subsequently be caught on traps left for longer periods.

Expt 2 (pilot survey) – Effects on CPUE due to different times of day, depths and locations. Three replicate sets with 5 traps on each were set out at each of 2 depths (40 and 60 m), in the morning and afternoon off Broken Head (28° 43'S; 153° 39'E), Lennox Head (28° 48'S; 153° 38'E) and Ballina Bar (28° 53'S; 153° 37'E) (Fig 1). A minimum soak-time of 60 min was used as this was the optimal soak-time found from Expt 1.

Analyses of data. Data from both experiments were treated in a similar way to that outlined in Kennelly & Craig (1989). For each trap, I calculated the percentage of crabs caught in each of the following size-classes:

males: ≤79, 80–89, 90–99, 100–109, 110–119 and ≥120 mm; females: ≤69, 70–79, 80–89, 90–99, 100–109 and ≥110 mm. I also calculated the percentage of crabs that were male and ≥93 mm (i.e. crabs usually retained by fisherman for sale), the total number of crabs caught on each trap and the mean size of each sex caught on each trap.

Each of these 16 sets of data for each experiment was tested for homogeneity of variances (Cochran's test) and analysed in the relevant 2-factor analysis of variance (Expt 1) or 4-factor analysis of variance (Expt 2). Sets of data with heterogeneous variances were transformed using arc-sine or natural logarithms and re-analysed. Means were compared using Ryan's tests. Those sets of data (either transformed or untransformed) which satisfied Cochran's test and which showed significant effects in the analyses of variance and Ryan's tests are presented below.

To determine optimal numbers of sets and traps for sampling *Ranina ranina* at any period and location, cost-benefit analyses were done for 14 sets of data from Expt 2 (sets of data concerning mean sizes of crabs were not used). The standard cost-benefit procedure was followed (e.g. Snedecor & Cochran 1967, Winer 1971, Underwood 1981, for similar treatments of these analyses see Kennelly & Underwood 1984, 1985). The product of 2 sums was minimized to determine the optimal number of sets and traps in these analyses with 2 levels of replication (replicate sets at any location/depth and replicate traps within each set). These sums are the total cost of each sampling period and the variance of the estimated mean of each sampling period.

The restricting cost in this study is the amount of time available during the basic sampling period at sea. The total time available to sample one depth at one location is 2 h. The time taken to manoeuvre between sets (i.e. set out and retrieve) is 20 min, and the time taken to clear and sample one trap is 4 min 30 s. The variance for estimated means in any experimental design may be determined from the appropriate means square in the analysis of variance, by methods discussed by Winer (1971) and Underwood (1981).

RESULTS

Expt 1

Of all sets of data analysed in this experiment, only the total number of crabs showed any significant effects due to soak-time (analysis of variance; $p < 0.05$; Table 1). Significantly more crabs were caught after 60 min and 120 min than after 15 min (Fig. 2). There was no significant difference between traps left for 60 and 120 min.

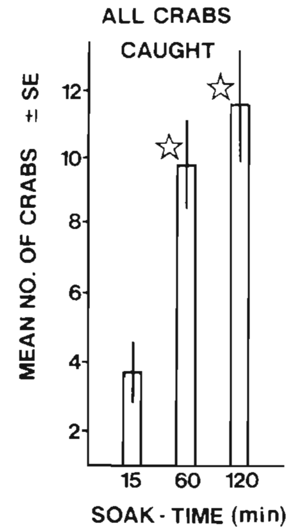

Fig. 2. *Ranina ranina*. Effect on CPUE of numbers due to different soak-times (n = 20). In this and subsequent figures, ☆ indicates a significant difference among means (Ryan's test, $p < 0.05$)

Table 1. *Ranina ranina*. Summary of 2-factor analysis of variance to determine the effect of different soak-times on CPUE of spanner crabs. In this and subsequent tables, ns: non-significant ($p > 0.05$), ** significant ($p < 0.01$), * significant ($p < 0.05$)

Treatment	df	Total no. of crabs
Soak-time	2	**
Sets	9	*
Residual	48	

Ryan's test: 15 min < 60 min = 120 min (see Fig. 2)

All other sets of data showed no significant effects due to soak-time

Expt 2

The total number of crabs caught varied among places and depths (significant interaction in analysis of variance $p < 0.05$; Table 2). Significantly more crabs were caught off Broken Head in shallow water than anywhere else (Fig. 3A). There was no effect of fishing at different times of the day (analysis of variance; $p > 0.05$). There was no significant effect for the percentage of retainable crabs, except that none were caught in deep water early in the day off Lennox Head (Fig. 3B).

There were proportionately more large males (> 120 mm) caught off Ballina Bar than all other places (Fig. 4A). Proportionately more medium-sized males (90–99 mm) were caught off Broken Head in shallow water early in the day than anywhere else (Fig. 4B). The only other significant effect was for small female crabs (70–79 mm) where there were proportionately more in deep water off Broken Head, both early and late in the day (Fig. 4C).

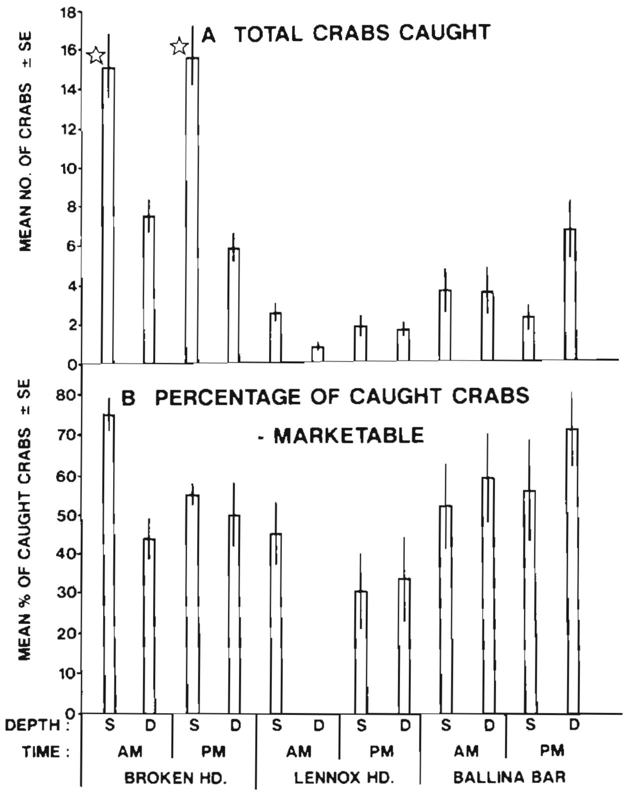

Fig. 3. *Ranina ranina.* Effects on CPUE of (A) total numbers of crabs and (B) percentage of retainable crabs, due to depth, time of day and in different locations (n = 15)

given in Table 3. Sampling an experiment several times would reduce these standard errors.

DISCUSSION

The results reported here permit the development of techniques for sampling populations of *Ranina ranina* that are optimal with respect to soak-time and the species' spatial heterogeneity and catchability throughout the day.

Traps left for short periods (15 min) caught far fewer crabs than those left for 60 and 120 min. Further, there were no detectable differences in catches between traps set for 60 and 120 min, indicating that after 60 min, traps caught as many crabs as they were likely to in that place at that time. Because the tangle-net method of capture precludes escape of tangled crabs, a soak-time of 60 min is sufficient for the capture of those crabs able to be caught in this experiment. In applying this result to other places and times, one must assume that the results obtained here are applicable to other populations of spanner crabs. Whilst it would be ideal to repeat this experiment at other places and times, this is impractical and I must conclude from these, the only available data, that a uniform soak-time of 60 min is sufficient for subsequent sampling. The lack of significant effects due to soak-time on the proportions of different sizes and sexes of *Ranina ranina* indicates that different sizes and sexes of this species travel to, and are entangled on, traps at similar rates.

Results from Expt 2 indicate a marked degree of spatial heterogeneity in abundances of *Ranina ranina*. Total numbers of crabs caught, percentages of retainable crabs, large and medium-sized males, and small females varied among localities ca 9 km apart (Figs. 3 and 4). There were also substantial differences in the CPUE of crabs at different depths. One must conclude,

Table 2. *Ranina ranina.* Summaries of 4-factor analyses of variance to determine effects on CPUE of spanner crabs due to fishing in different places (P), at different times of the day (T) and in different depths (D)

Treatment	df	Total no. of crabs	% of retained crabs	% of females 70–79 mm	% of males > 120 mm	% of males 110–119 mm	% of males 100–109 mm	% of males 90–99 mm
Place	2	••	••	••	••	•	••	••
A.m. vs p.m.	1	ns	ns	ns	ns	ns	ns	••
Depth	1	ns	ns	ns	ns	ns	ns	ns
Sets	24	••	ns	ns	ns	ns	ns	ns
P × T	2	ns	ns	ns	ns	ns	ns	ns
P × D	2	•	•	••	ns	ns	••	•
T × D	1	ns	ns	ns	ns	•	ns	ns
P × D × T	2	ns	ns	ns	ns	ns	ns	ns
Residual	142							

All other sizes of females and males showed either heterogeneous variances or no significant effects in analyses of variance

Cost-benefit analyses to determine optimal numbers of sets and traps per set

The optimal numbers of replicate traps and numbers of replicate sets to be sampled at any place are summarized in Table 3. Having determined the appropriate numbers of replicate sets and traps, the standard error for the mean of data in any sample period may be estimated as the square root of the variance calculated from the variance equation. The anticipated sizes of standard errors for sampling an experiment once are

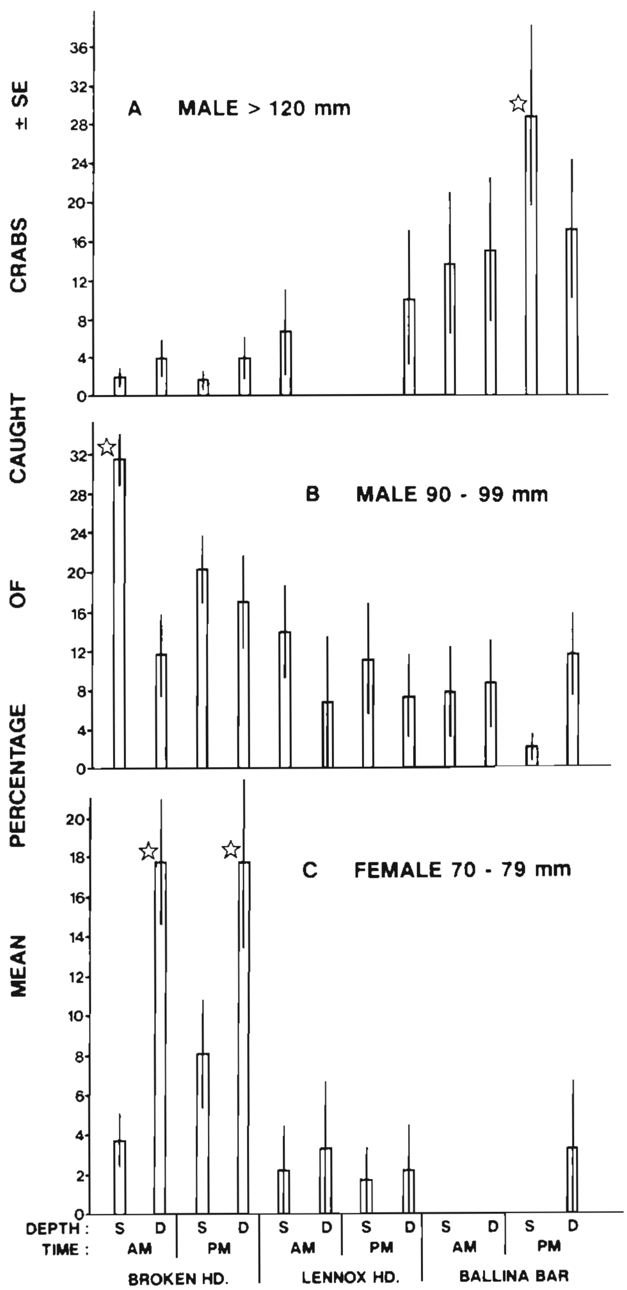

Fig. 4. *Ranina ranina.* Effects on CPUE of (A) percentage of male crabs ⩾ 120 mm, (B) percentage of male crabs 90–99 mm and (C) percentage of female crabs 70–79 mm due to depth, time of day and in different locations (n = 15)

therefore, that any future monitoring of populations should be conducted at several sites and several depths. The time of sampling during daylight hours was not important: there were no consistent differences in catch rates of various sizes and sexes of crabs between morning and afternoon samples.

To properly conduct sampling at any location and depth, one must use suitable replication of sets of traps and traps per set. The cost-benefit analyses of data from Expt 2 showed that to best sample the total numbers of crabs at a given location and depth requires 5 traps on each of 3 sets (Table 3). This yields an estimated standard error of 24.3 % of the mean for one census. To best sample individual size-classes of different sexes requires greater replication: e.g. the optimal replication required to maximize the proportion of the catch that is retainable is 2 sets of 13 traps. This shows that the proportion of retainable crabs varies among individual traps greater than it varies between sets. If I was concerned with censussing only the commercial catch, this level of replication would be used. Because I am concerned with surveying whole populations of *Ranina ranina*, however, I need to employ that replication suggested from total catches: 3 sets of 5 traps. The consequences of this replication on estimates of the standard errors associated with various size-classes and sexes of crabs is included in Table 3. Whilst most standard errors using this replication are quite large, it is the maximum allowable replication given the time available for sampling and, in any case, these standard errors would decrease as many sample periods are included in a long-term survey.

The field experiments described in this paper and in Kennelly & Craig (1989) have led to the development of a methodology which can be used to most accurately quantify the distributions and relative abundances of *Ranina ranina* in their fishing grounds off the coast of New South Wales. This method involves the use of 5 replicate traps made of flat steel and covered by a double layer of 85 mm, 4-ply net, set at distances of 60 m apart long a trot-line. Three such sets of traps should be used at each depth in each location in the particular survey under examination. The kind of bait and the time of day that sampling occurs is of small consequence, but traps should be left in place for a minimum of 60 min. In this fashion, the benefits from one's sampling effort in terms of catch rates of *R. ranina* will be maximized, and the best possible picture of this species' distributions and abundances can be derived. Further, these methods will also permit continued monitoring of populations of *R. ranina* following the implementation of future management strategies.

In this paper (and Kennelly & Craig 1989) manipulative experiments assessed most of the sources of error incurred when estimating the relative abundances of organisms using CPUE from baited traps. Such information allowed the development of optimal methods for obtaining estimates of relative abundances. Thomas (1953) and Miller (1983) note that this sort of information is a pre-requisite for any meaningful large-scale monitoring of populations of such species. The work presented here also illustrates the worth of pilot surveys in providing a priori estimates of the spatial and temporal heterogeneity inherent in the distributions of

Table 3. Summary of cost-benefit analyses of data from Expt 2

	Total no. of crabs	% of retained crabs	% of females 100–109 mm	% of females 90–99 mm	% of females 80–89 mm	% of females 70–79 mm	% of males > 120 mm	% of males 110–119 mm	% of males 100–109 mm	% of males 90–99 mm	% of males 80–89 mm
Variance among sets	3.04	–31.1	–10.4	–31.5	58.8	–2.4	–9.8	0.1	–15.3	3.4	8.6
Variance among traps	11.8	1095.7	205.9	484.3	205.2	88.7	410.9	192.5	632.9	280.1	220.7
Optimal no. of sets	3	2	2	2	4	2	2	1	2	1	2
Optimal no. of traps	5	13	10	9	4	13	14	79	14	20	11
Mean in pilot expt	5.5	47.8	3.1	9.5	7.6	5.0	8.6	8.1	22.1	12.2	5.7
Estimated SE (%)	24.3	10.8	72.6	35	68.8	29.8	36.5	19.8	17.5	34.1	66.4
Estimated SE using 3 sets of 5 traps (%)	24.3	16.6	103	49	75.6	45.5	57.4	44.2	27.5	36.4	73.6

species. Such estimates allow the design of sampling regimes which estimate relative abundances and distributions in the most cost-effective and accurate way.

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