REPORT FOR THE SPANNER CRAB PROJECT
(FIRDC grant no. 86/63)

by Dr Steven J. Kennelly
30th July, 1990

The discussion below, and the attached papers and documents summarize the progress I have made during my research into the biology and fishery for spanner crabs in NSW.

For this very new fishery, those aspects of the species' biology most relevant to its management and continued exploitation are its distributions, abundances and rates of growth. Unfortunately at the start of this project, we knew none of this information for the NSW stock. As a first step I designed, completed, analysed and wrote up for publication a series of manipulative field experiments designed to determine the best sampling strategy for estimating the distributions, abundances and rates of growth of spanner crabs. These experiments involved estimating the relative abundances of this species in the fishing grounds (10m to 100m depth off the NSW far north coast) using catch per unit of effort data from baited tangle traps. Multifactorial, orthogonal and nested experimental designs were used to determine the best kind of frame, mesh-size and ply of net, method of hanging nets and the type of bait to catch the greatest number and widest size-range of crabs (see Kennelly & Craig, 1989 - paper 1 in the attached list). Another paper (Kennelly, 1989 - paper 2) describes similar experiments to determine optimal soak-times, in addition to applying cost-benefit and analysis of variance techniques to a pilot survey to determine optimal numbers of replicates and sets of replicates. The work reported in these 2 papers resulted in the development of an optimal sampling strategy which was used to determine the relative abundances of spanner crabs of the widest possible size-range.

I used this sampling strategy in a two year multifactorial survey of the distributions and abundances of spanner crabs throughout the main range of the NSW fishery using chartered commercial vessels. Five locations were censussed every two months to provide data concerning fluctuations in the distributions and abundances of crabs across a variety of depths and spatial and temporal scales (paper 10). Cohort analyses of these data are providing estimates of growth rates of these populations. Berried females were also collected during this survey to allow an estimate of the fecundity of the species, found to be an average of around 100,000 eggs per female during the spawning season (paper 15). During this survey I also gathered replicated readings of water temperature, salinity, current speed and direction, and samples of sediment to determine any correlative influences of these factors on the distributions and abundances of crabs (papers 11 & 12). The measurement of current speed and direction for this work required the invention of a new piece of equipment, about which we have written a paper (see Craig & Kennelly - submitted ms - paper 5). The sediment analyses were done in collaboration with a biosedimentologist at the University of Technology (paper 12)

I also incorporated a large-scale, nested tagging programme into the above survey using T-bar tags on 4,199 male and female spanner crabs (papers 7 & 13). Tag returns from commercial fishermen (304 so far) are providing direct estimates of rates of growth (approx. 12mm per moult for males and 6mm for females). Movements of crabs also are examined and this shows that spanner crab populations north and south of Byron Bay do not mix. This has led to an ancillary electrophoretic study of these populations (see below).

I also gathered data on the landings of legal-sized crabs by professional fishermen for the main spanner crab port in NSW (Ballina) for the entire history of the fishery. In addition to providing a good history, these data are being used in correlations with the survey data to compare the worth of these two different ways of estimating relative abundances (paper 14).

My research on spanner crabs already has had a major impact on the management of this fishery through my recommendation that there be a closure on the taking of spanner crabs in NSW from 20th November until 20th December each year. This closure was designed to protect the berried females and large spawning aggregations of males and females which I detected in the fishing grounds at that particular time of the year from the survey data and tag returns (see attached management submission - paper 9). This recommendation for a closure was implemented by the Department and was very well received by fishermen who now claim that they are detecting improved catches of spanner crabs at times of the year when, in the past, catches were usually low. Whilst this is good news, I feel that it is much too early to be confident of any benefits of the closure as yet.

One aspect of this fishery which became apparent during this project involved the limb damage incurred by spanner crabs upon their removal from commercial tangle-traps. Laboratory and SCUBA - based experiments in the field were done to quantify this mortality of undersize spanner crabs after their removal from tangle traps (see Kennelly et al., in press - papers 3, 4 & 6). This work identified a major problem facing this fishery and has led to a new project (in collaboration with Queensland Dept. of Primary Industry and funded by FIRDC) to develop a new, non-destructive means for the commercial capture of spanner crabs.

When the above data concerning limb mortality during disentanglement became available, I released a paper to the spanner crab fishermen of NSW (see the attached paper, "Some results from the spanner crab research project" - paper 8). This paper was very well received and led to significant discussions among fishermen regarding their methods for disentangling undersize spanner crabs. These discussions led to changes in the practices of many of the fishermen and (probably) reduced mortality due to limb damage.

Other pieces of research on spanner crabs in which I have been involved include: (i) Regular sampling of the commercial spanner crab product at the Sydney Fish Markets to assess seasonal fluctuations in the occurrence of light (recently-moulted) crabs. These crabs cause reduced returns by detracting from the quality of the product. (ii) Heavy metal analysis of spanner crab meat to quantify quite high levels of Cadmium. (iii) Because of the possible separation of populations north and south of Byron Bay (suggested from my tagging programme), I am involved in electrophoretic analyses of these populations with the University of NSW.

All this research can be summarized as follows. First, I set about developing methodologies for the study of those aspects of this species' biology which were most relevant to its continued and enhanced exploitation. I then used these methods to study the species through stratified surveys, a tagging study and laboratory and field experiments. I then examined new problems which arose during this work through further manipulative experimentation (e.g. the limb damage problem). I finally took all this information to management (and the fishermen) by recommending a management plan which was subsequently implemented by the Department. All this forces me to conclude that the successful completion of this comprehensive project should more than justify the faith that FIRDC had in the original granting of this project and its subsequent renewal over the past few years.

I envisage that once all the unfinished publications concerning this work are completed, further adjustments to management strategies may be suggested and implemented. In such situations, my sampling strategy ideally would be used to monitor subsequent characteristics of the exploited populations. This would be, in effect, a very large-scale field experiment directly examining the effects of introduced management strategies.

Publications produced from the spanner crab project so far
(* denotes those papers which are attached)

Publications in refereed journals:

1. *Kennelly, S.J. and J.R. Craig, 1989. Effects of trap design, independence of traps and bait on sampling populations of spanner crabs *Ranina ranina*. Marine Ecology Progress Series, Vol. 51, pp. 49-56.

2. *Kennelly, S.J., 1989. Effects of soak-time and spatial heterogeneity on sampling populations of spanner crabs *Ranina ranina*. Marine Ecology Progress Series, Vol. 55, pp. 141-147.

3. *Kennelly, S.J., D. Watkins and J.R. Craig, in press. Mortality of discarded spanner crabs *Ranina ranina* (Linnaeus) in a tangle-net fishery - laboratory and field experiments. Journal of Experimental Marine Biology and Ecology.

4. Kennelly, S.J., in press. Consequences of the mortality of discarded spanner crabs *Ranina ranina* (Linnaeus) in a tangle-net fishery - laboratory and field experiments. Memoirs of the Queensland Museum.

5. *Craig, J.R. and S.J. Kennelly, submitted manuscript. An inexpensive instrument for measuring benthic current velocity and direction at sea. Estuarine and Coastal Marine Science.

Paper presented at an international conference:

6. Kennelly, S.J., 1990. Consequences of the mortality of discarded spanner crabs *Ranina ranina* (Linnaeus) in a tangle-net fishery - laboratory and field experiments. 3rd International Crustacean Conference, Brisbane.

Popular articles:

7. Kennelly, S.J. and I.W. Brown, 1988. Do spanner crabs migrate? Report on the spanner crab tagging project. Published in: NSW Fishermen's Journal, The Queensland Fisherman, and Australian Fisheries.

8. *Kennelly, S.J., 1989. Some results from the spanner crab research project. Special paper prepared for, and circulated to, the spanner crab fishermen of NSW.

Advice to management:

9. *Kennelly, S.J., 1989. Spanner crab closure. Submission prepared for the Director, FRI and the NSW Division of Fisheries' Offshore Fisheries Manager.

Future publications to be produced from the spanner crab project

10. Kennelly, S.J., in prep. Distributions, abundances and size-structures of spanner crabs *Ranina ranina* using a stratified, randomized survey in an Australian fishery.

11. Kennelly, S.J., in prep. Correlations between relative abundances of spanner crabs and bottom current, temperature and salinity in an Australian fishery.

12. Kennelly, S.J., in prep. Correlations between relative abundances of spanner crabs and sediment characteristics in an Australian fishery.

13. Kennelly, S.J., in prep. Growth and movements of spanner crabs using a stratified tagging study.

14. Kennelly, S.J., in prep. Comparisons between estimates of relative abundances of spanner crabs from a stratified, randomized survey and commercial catch data.

15. Kennelly, S.J. and D. Watkins, in prep. Size-related fecundity of spanner crabs in northern NSW.

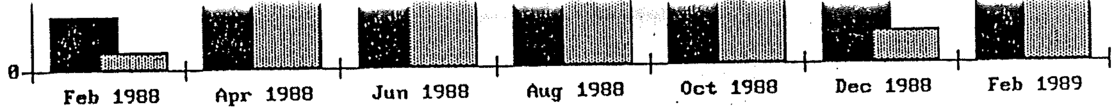


FIG. 2 -

CONDITION OF FEMALE SPANNER CRABS IN DEC. 1988

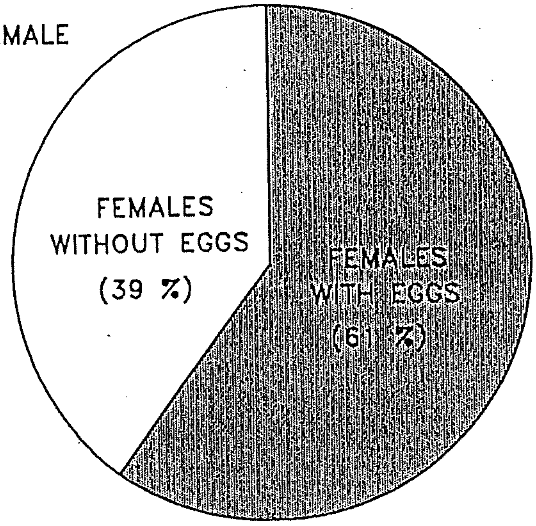
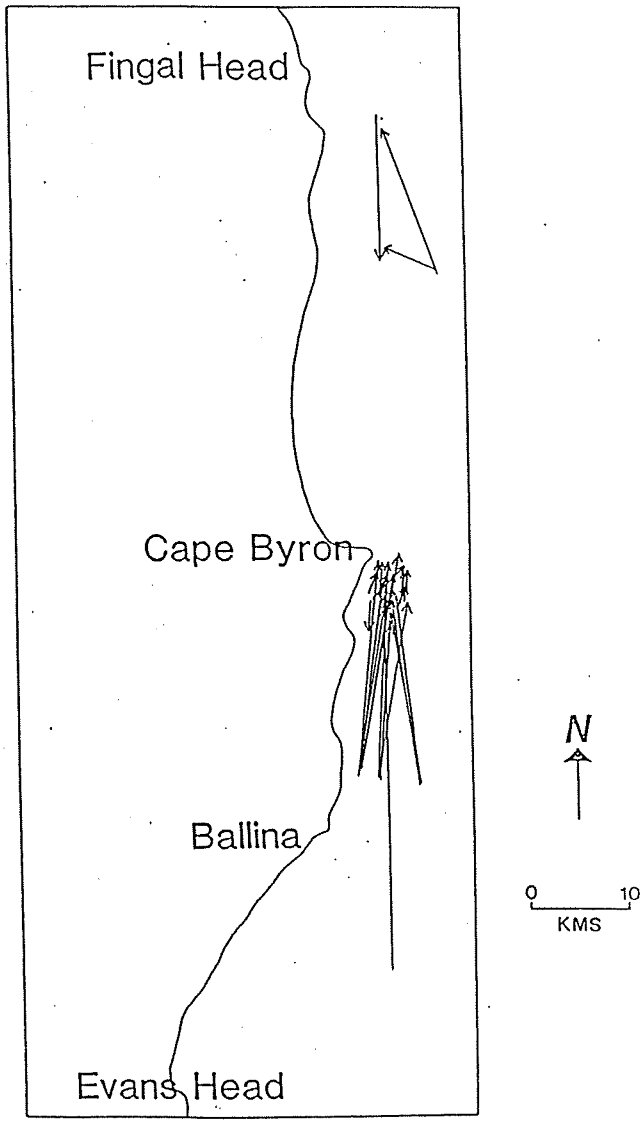


FIG 3 - TAG RETURNS IN DECEMBER 1988



18 September 1990

Margaret River Stabilised Earth

Terry Stanley and Steve Dixon have parted with Ken Brook at Vasse and re established in Margaret River, with one set of equipment. They will be joining the affiliated group and operating as Margaret River Stabilised Earth.

Terry brings back to the group unrivalled experience in SRE construction and is best known for the sure footed confidence displayed throughout the Muja project. He is almost as well known, for parting a certain Collie publican from an awful lot of money one night over a bet that he couldn't run around the block non stop with a bag of spuds on his shoulders.

Steve lives at Prevelly, where prior to becoming involved in SRE, he recently completed his own home in earth blocks. His trade background and experience ensures a well maintained operation, with equipment that will ensure high quality walls.

Having Margaret River Stabilised Earth back in the affiliation is good news for obvious reasons. Most importantly though, it re connects all the affiliates back to the Margaret River SRE phenomenon.

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Mortality of discarded spanner crabs *Ranina ranina* (Linnaeus) in a tangle-net fishery – laboratory and field experiments

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Abstract: Effects of disentanglement from commercial tangle-traps on the mortality of undersize, discarded spanner crabs *Ranina ranina* (Linnaeus) were determined for a fishery in New South Wales, Australia. First, we quantified the damage sustained by discarded crabs due to the three main methods of disentanglement used by commercial fishermen: careful removal, causing no damage; quick removal, where any entangled dactyli are broken off (average 3.95 dactyli per crab); and the fastest method where crabs are pulled off and entangled limbs and dactyli are broken off (average 2.9 dactyli and 0.8 limbs per crab). We then tested effects of these various kinds of limb damage on the mortality of undersize *R. ranina* in an aquarium experiment in which replicate crabs were damaged in three ways and compared to undamaged controls. Finally, we did a similar (though shorter-term) experiment in the field using enclosures buried in the substratum near the commercial fishing grounds. The results showed quite significant rates of mortality due to disentanglement: 60–70% of crabs with one or more dactyli removed died within 50 days, whilst 100% of crabs which lost whole limbs (after being pulled off nets) died after 8 days. We discuss the mortality of such discarded conspecifics in terms of the future success of this fishery and the applicability of size-restrictions by management.

Key words: Aquarium; Decapod; Experiment; Fishery; Mortality; Tangle-net

INTRODUCTION

A major problem encountered in commercial marine fisheries, and the research and management of such fisheries is the effect that fishing has on other non-target organisms (Saila, 1983). Such incidental, discarded catch includes those conspecifics which are outside size and/or sex restrictions imposed by fishery managers. Obviously, the survival of these discarded conspecifics is important to the future status of the target fishery and can be a prerequisite for the success of any size, sex and/or gear restrictions made by management. In this sense, the incidental catch of a fishing method can directly inflence the subsequent success of the fishery. 9/

Fisheries which target on decapod crustaceans are particularly prone to inflicting damage on discarded conspecifics. Such effects have been quantified for several species and noted to be important for the respective target fisheries (Davis, 1981; Durkin et al., 1984; Simonson & Hochberg, 1986; Shirley & Shirley, 1988).

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Several papers have documented the responses of decapods to injury: in some cases, the loss of limbs greatly accelerated moulting (Aiken, 1977); whilst others showed reduced rates of growth (Chittleborough, 1975; Davis, 1981). Despite this work, and a large literature dealing with the voluntary shedding of damaged limbs (autotomy) and subsequent regeneration (e.g. Needham, 1953; McVean, 1976; McVean & Findlay, 1979), few studies have considered the effects of limb damage on the mortality of decapods (but see Simonson & Hochberg, 1986).

Spanner crabs *Ranina ranina* (Linnaeus) are large marine brachyurans found throughout the tropical Indo–Pacific region (Barnard, 1950). They occur in coastal waters in depths of 10–80 m on sandy substrata in which they bury (Skinner & Hill, 1987). Populations of *R. ranina* have been exploited commercially in Hawaii, Japan, the Philippines, the Seychelles and/recently, along the east coast of Australia. These fisheries employ a tangle-net method of capture which relies on the entanglement of limbs onto a net hung over a flat frame (Kennelly & Craig, 1989). Upon retrieval, tangled crabs are removed from the net (often sustaining damage to limbs), legal-sized crabs are retained for market (in New South Wales, > 93 mm eye-orbit carapace length) and undersized crabs are returned to the sea.

Despite a growing literature concerning the biology and fishery of *R. ranina* (Fielding & Haley, 1976; Tahil, 1983; Skinner & Hill, 1986, 1987; Kennelly & Craig, 1989; Kennelly, 1989), there have been virtually no estimates of the mortality of discarded crabs due to damage during removal from tangle traps (but see Onizuka, 1972). This source of mortality is particularly important for fisheries of this particular species as ≈85% of females caught are under the minimum legal size (Kennelly & Craig, 1989), and mortality of this type has the potential to reduce the overall fecundity of the population and consequently, the exploitable stock in the long term. Mortality of undersize male *R. ranina* following disentaglement will directly influence the recruitment of legal-sized crabs into the fishery in the short term.

The present paper considers effects on the mortality of undersize *R. ranina* due to commercial fishing. We firstly quantified the different kinds of damage sustained by crabs during commercial fishing operations. We then tested the effects of these kinds of damage on the mortality of crabs by manipulative experimentation in the laboratory and finally assessed the usefulness of these results by doing a similar (though shorter-term) experiment in the field.

MATERIALS AND METHODS

DAMAGE INCURRED BY DISCARDED CRABS

As mentioned above, *R. ranina* are caught by professional fishermen using nets supported on flat rectangular frames (Kennelly & Craig, 1989). A bait (fish-frame or a group of pilchards) is attached to the centre of each trap and 3–6 trot-lines with 5–10 traps on each are placed on the substratum in the fishing grounds for periods of atleast

at least space

60 min. In New South Wales, individual fishermen are permitted to use 20–30 traps (depending on the number of crew) and usually set out their trot-lines 4–6 times per day. Once traps are on the substratum, crabs are attracted to the bait from down-current and walk onto the net where their limbs become entangled. The kind of net and its method of hanging varies among individual fishermen. Some use one layer of 31-mm mesh hung tightly over frames, but most use 85-mm mesh, 6–12 ply net hung in a double layer. This net is usually hung loosely over the frame with a fall of between 15 to 50 cm to facilitate the entanglement of most sizes of crabs.

Observations of > 20 professional fishermen identified three main methods used to clear entangled crabs from traps. The particular method used by fishermen at any time depended on factors such as the prevailing weather, the time available to clear crabs from traps, the number of crabs caught on traps, or merely personal preference. The three methods of removal were: (i) carefully removed – where no damage was done to crabs; (ii) quickly removed – where any tangled dactyli were broken off at articulation points; or (iii) pulled off (the fastest method) – where crabs' carapaces were siezed and quickly pulled off the net in one motion. Methods i and ii (those that cause least damage to crabs) are those usually used by fishermen to remove legal-sized crabs. Undersize crabs are removed using all three methods.

As part of the present study, undersize *R. ranina* were treated in each of the above three ways by experienced professional fishermen using their own fishing gear. We assessed the extent of limb damage sustained by 20 crabs for each method by recording the number of dactyli and/or whole limbs removed from each crab.

MORTALITY DUE TO LIMB DAMAGE – AQUARIA EXPERIMENT

100 *R. ranina*, which had sustained no visible damage during their careful removal from tangle-traps set off Tallows Beach on the far north coast of NSW, were placed firstly into holding tanks onboard the boat (plastic rectangular containers 64 × 41 × 39 cm deep, fitted with three airstones supplying O_2 at ≈ 4 l/min). Both sexes and all sizes of crabs that are usually caught by professional fishermen were included. Next, crabs were transported from the boat in a motor vehicle to aquarium facilities at Fisheries Research Institute, Cronulla (≈ 700 km distance), within 16 h of capture using a 122 × 61 × 61-cm plastic transport tank filled to 30–40 cm depth with seawater. The water in this tank was sprayed from a height of 20–30 cm, agitating and oxygenating the entire water surface. In the laboratory, the crabs were transferred, with the seawater from the transport tank, to individual aquaria. This water was gradually exchanged with new water over 12 h and the temperature was gradually changed at 1–2 °C per day until 22.5 °C was reached.

The aquaria used for this experiment were round and made of opaque fibreglass 82 cm diameter × 50 cm depth filled with 200 l of seawater (35‰). Each aquarium contained an under-sand filter powered by an airlift water pump (a 15-cm layer of sand placed on plastic mesh over a 6-cm layer of shell grit in which a coiled perforated pipe (one end connected to an airlift) was embedded). Such an under-sand filter ensured good aeration in the substratum and minimized anaerobic areas. Seawater was supplied to the aquaria from a 162000-l header tank at 500–700 l/day. The header tank was replenished four to six times per day by sand-filtered oceanic water. Prior to supply to individual aquaria, the water was preheated in a heat exchanger (with a glass-encased thermostat and heating element) designed to maintain a constant temperature of 22.5 ± 2.5 °C in each aquarium. The water outlet from the airlift, the water inlet from the heat exchanger and the upwelling from an airstone set 5 cm above the substratum in the centre of the tank resulted in a spiral water circulation throughout the tank. Water overflowed from the aquaria through a central stove-pipe, which also removed any floating material from the tank. The spiral circulation pattern also ensured that any debri or waste on the substratum would gather at the base of the central stove-pipe, which was easily flushed away by removing the stove-pipe. All materials used in the aquaria system were inert in seawater and artificial lighting was provided from 0900 until 1700 daily. Crabs were fed daily using fish and prawns and excess food was removed prior to subsequent feeding. The crabs were allowed to acclimate for 2 wk prior to manipulation.

To determine effects of limb-damage on the mortality of *Ranina ranina* in the laboratory, 64 of the crabs were selected at random, measured, sexed, tagged (using harmless loop-tag tied around chelae) and assigned one of four treatments: 16 crabs had one dactylus removed, 16 had four dactyli removed, 16 had two whole limbs removed, and 16 were left as undamaged controls. Limbs were damaged in a fashion similar to that inflicted by professional fishermen. Four replicate crabs of each treatment were placed in each of the four replicate aquaria. Crabs were checked daily for evidence of moulting or death and any moults/dead animals were removed. The experiment was terminated after 50 days.

MORTALITY DUE TO LIMB DAMAGE – FIELD EXPERIMENT

Results from aquaria experiments such as that descibed above confound effects of limb-damage with effects of living under controlled conditions (e.g., damaged crabs may suffer enhanced or reduced mortality while living in aquaria). Consequently, such results may not represent effects that occur in nature. To help validate our laboratory results, we did a short-term manipulative field experiment. This involved placing damaged, undersize crabs (together with undamaged controls) into holding cages buried into the substratum near the main *R. ranina* fishing grounds in NSW.

Four enclosures (1.2 × 1.2 × 0.5 m) were constructed of 25 × 25-mm hardwood and plastic mesh and weighted with bricks. A mesh-size of 6 mm was used to negate any damage to limbs of crabs due to the cages. Using scuba, the cages were buried 150 mm into the sandy substratum at 11 m depth off Byron Bay, NSW (28° 38′ S, 153° 37′ E).

Using professional fishermen and their normal fishing techniques in their usual fishing grounds, 20 crabs were quickly removed from tangle traps (see Method ii above), 20 were pulled off nets (see Method iii above) and 20 were carefully removed as controls (see Method i above). Each crab was identified with a loop tag, measured, sexed and any limb damage was assessed. All crabs were placed in oxygenated seawater in holding tanks on board the boat (the same tanks as those used in the former experiment) until ready for placement into the submerged cages. Five crabs from each treatment were placed in each of the four cages (total of 15 crabs per cage) where they were free to bury into the sand. The four cages were checked after 24 h and all dead crabs were recorded and removed. Unfortunately, longer-term data could not be gathered from these field enclosures after this time as the buried cages lifted out of the sandy substratum.

Results

Damage incurred by discarded crabs

Crabs that were carefully removed from traps (by professional fishermen) showed no damage to dactyli or limbs (Fig. 1). Crabs that were "quickly removed" lost an average of 3.95 dactyli (SE = 0.26) and no limbs per crab. Crabs that had been "pulled off" nets lost an average of 2.9 dactyli (SE = 0.35) and 0.8 limbs (SE = 0.15) per crab.

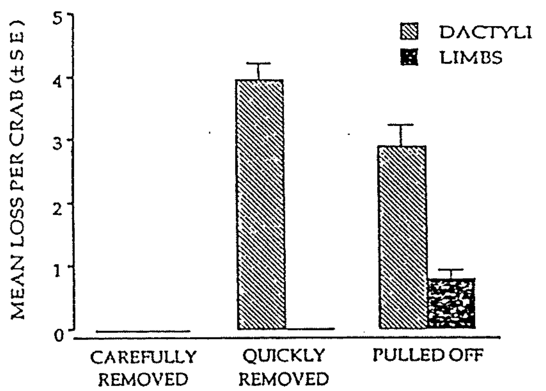

Fig. 1. Loss of dactyli and whole limbs of *R. ranina* due to removal from commercial tangle-traps using three methods of disentanglement (n = 20 for each method).

Mortality of damaged crabs in the laboratory

Crabs in all treatments in the aquarium experiment showed 12.5% mortality at one time (after 18 days), due to a breakdown in the aeration system at this time (Fig. 2). Control crabs showed no other mortality during the experiment. Crabs that had whole limbs removed showed 100% mortality 8 days after the start of the experiment. Crabs that had one dactylus or four dactyli removed showed the same mortality (62.8%) after

50 days. Whilst crabs with four dactyli removed tended to die sooner than was the case for crabs with only one dactylus removed, this was not ~~significantly~~ significant. There were no significant differences among replicate aquaria, allowing us to pool data across aquaria ($\chi^2 = 4.22$, $P > 0.5$). The relationships among treatments shown in Fig. 2 (i.e.,

statistically

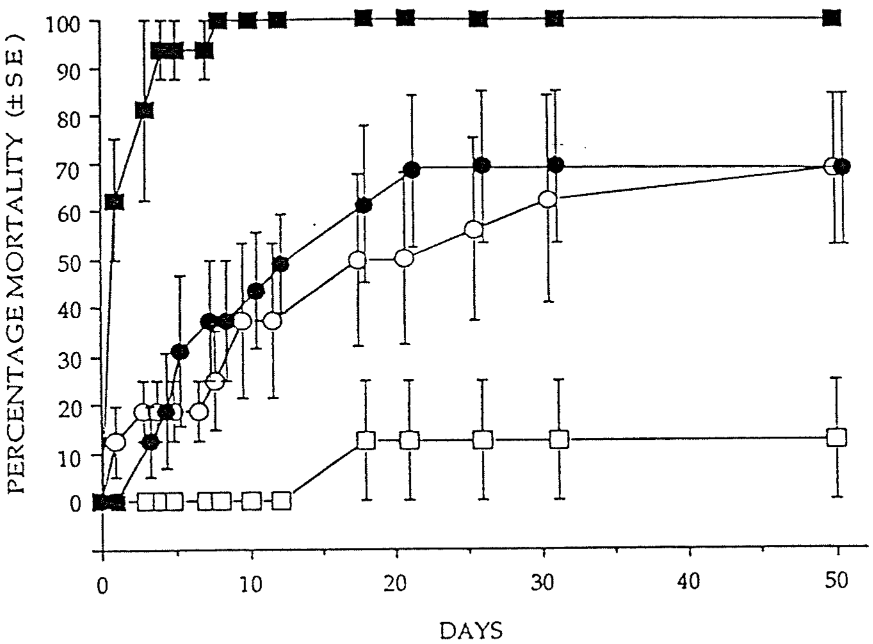

Fig. 2. Mortality of *R. ranina* in aquaria due to various levels of limb damage (n = 16 for each treatment). Treatments are: crabs with two limbs removed (■), four dactyli removed (●), one dactylus removed (○), undamaged crabs (□).

greater mortality for crabs with two limbs removed than that for crabs with one more dactyli removed, which in turn showed greater mortality than that for undamaged crabs) were statistically significant in one-factor ANOVA of the data ($P < 0.01$ for all analyses – separate analyses were done for data gathered on each day dead crabs were recorded, i.e., Days 1, 3, 5, 6, 8, 9, 11, 13, 19, 22, 27, 32 and 50).

MORTALITY OF DAMAGED CRABS IN THE FIELD

In the field enclosures, 35% of those crabs that had been "pulled off" nets were dead within 1 day whilst 5% of crabs that had been quickly removed had died (Fig. 3). No crabs that had been carefully removed died in this experiment. A one-factor ANOVA of the data showed that these short-term effects were statistically significant ($F = 9.21$, $P < 0.01$).

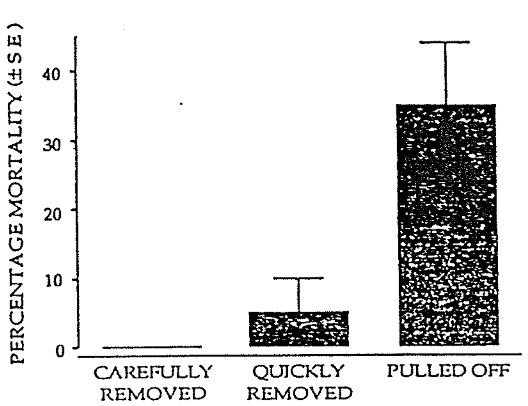

Fig. 3. Mortality during a 24-h period of *R. ranina* in field enclosures following removal from tangle-traps using three methods of disentanglement (n = 20 for each treatment).

Discussion

Data from the laboratory experiment on the mortality of undersize *R. ranina* due to limb damage showed fairly good correlations with data from the field experiment. After 1 day in the field, 5% of those crabs that had been quickly removed from nets had died (Fig. 3) (these had an average damage of 3.95 dactyli removed – Fig. 1), whilst after 3 days in the laboratory, 6% of crabs with four dactyli removed had died (Fig. 2). After 1 day in the field, 35% of crabs that had been pulled off nets had died (these had an average damage of 2.9 dactyli and 0.8 limbs removed – Fig. 1), whilst after 1 day in the laboratory, 62% of crabs with two limbs removed had died (Fig. 2). The fact that these field and laboratory results are similar show that the presently used methods of disentanglement from tangle-traps of undersize, discarded *R. ranina* cause significant mortality.

A problem with the field experiment involved the loss of the buried cages after lifting out of the substratum. This was probably an effect of bioturbation – the enclosed crabs stirred up the sand whilst burrowing and over a period of days led to the cages emptying of sand. Once exposed, the cages were at the mercy of currents and surge and were quickly lost. Such bioturbation is a very real problem when doing longer-term experiments of this kind and should be considered in any future field enclosure experiments involving burrowing crabs. Nevertheless, the purpose of this particular trial was to simply help validate the laboratory results and this was apparent after 24 h.

In the only other laboratory study of the mortality of *R. ranina* due to limb damage, Onizuka (1972) found 70% mortality of crabs with one limb removed, 9.3% mortality of crabs with four dactyli removed and 7.7% mortality of crabs with one dactylus removed. Few comparisons can be made between Onizuka's unpublished report and the present paper, however, as details of the experimental design, timing, aquarium facilities, etc., were not given. Nevertheless, Onizuka's results are in agreement with our conclusion that substantial mortality acts on *R. ranina* following their removal from tangle-traps and subsequent limb injury. Reasons for this mortality were not addressed by Onizuka nor ourselves but could be hypothesized to be due to general stress, or blood-loss before clotting.

Unlike many other decapods, *R. ranina* showed no evidence in this nor any other study (pers. obs.; Kennely & Craig, 1989; Kennelly, 1989) of being able to autotomize limbs. During regular sampling and experimental work described in this and previous papers, *R. ranina* were exposed to a variety of stresses (removal from nets, exposure to air, storage in holding tanks in boats, cars, aquaria, etc.) where autotomy could have been expected to occur. Despite these stresses, no autotomy occurred. The reason for such an apparent lack of autotomy is unknown but Weiss (1982) noted that the anomuran *Emerita talpoida* (Say) exhibited a very weak autotomy reflex and poor regenerative ability after removal of limbs. Weiss (1982) and Needham (1953) have suggested that the evolution of such weaknesses may be related to *E. talpoida's* burrowing habit where limbs could be easily lossed whilst digging. A similar explanation may be appropriate for *R. ranina* which also remains buried most of the time.

It is known from previous work (Kennelly & Craig, 1989) that 75–95% of the catch of *R. ranina* on commercial tangle-traps are discarded. The results from the laboratory results presented here indicates that all these discarded crabs could be expected to die if they are "pulled off" nets. If the crabs are "quickly removed", one may expect ≈60% of these crabs to die, implying that the majority of the discarded catch may die before growing to legal size. It should be noted that these figures are probably underestimates of total mortality due to fishing as they take no account of the susceptibility of crabs due to predation as they sink to the substratum, nor increased vulnerability of damaged crabs when they are on, or in, the substratum. Turtles are particularly voracious predators of *R. ranina* when the crabs are in the water column (pers. obs.) and bleeding, discarded crabs could be expected to attract such feeding.

Before using the results from the present paper to evaluate the effects that mortality due to disentanglement may have on the future of the *R. ranina* fishery, we must make a very important assumption: that estimates of the relative abundances of legal-sized crabs and undersize crabs derived from Kennelly & Craig's (1989) CPUE data (and observations of commercial fishing) are true indications of the abundances and size-structures of the natural population. If this is the case, then the great proportion (75–95%) of the total catch that is discarded by commercial fishermen may lead to a significant decline in the size of the exploitable population in the very short term. Further, for this species, whose female population is mostly smaller than the minimum legal size (Kennelly & Craig, 1989), this mortality may lead to a large decline in the fecundity of the population and, ultimately, an overall decline in the exploitable stock. Finally, any benefits of minimum size restrictions for this species may be largely negated by the mortality of discarded conspecifics. These negative conclusions would not apply, however, if only a very small fraction of the total population is exploited by fishermen.

Unpublished data from a tagging study suggests that this is not the case.

The solution to this problem in this fishery is to develop a trap which either does not involve the entanglement of limbs, or at least reduces damage due to removal to a minimum. Alternative traps are currently being developed and will be described elsewhere.

Acknowledgements

This study was funded by the Fishing Industry Research and Development Council (Grant 86/63) to whom we are most grateful. We sincerely thank J. Lavis, J. Spedding and K. McKay for the use of their vessels and expertise. T. Butcher assisted with the scuba work, A. Simpson assisted with the construction of the field enclosures and S. Colosimo assisted with maintenance of aquaria. We thank R. Kearney and I. Brown for helpful discussions and N. Otway and R. Kearney for critically reading the manuscript.

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Title: An inexpensive instrument for measuring benthic current velocity and direction at sea

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Keywords: benthic; current measurements; current meters; direction; velocity

Running Head: Measurement of benthic currents

N.B. This manuscript is intended to be a NOTE.

ABSTRACT

An instrument which measures the velocity and direction of benthic water currents at depths of up to 80 m is described. Characteristics of this meter include: (i) readings are not affected by water flow during sinking nor retrieval; (ii) it is portable; (iii) it operates unattended; (iv) it is inexpensive; and (v) it requires only simple maintenance. A timing circuit which operates 2 time periods in succession is used to activate and de-activate a revolution-counter and a fluid-filled compass which are mounted on a special frame and vane-system. In the field, the instrument accurately measured average current velocities of up to 3.5 metres per second. Data are presented which describe fluctuations in the speed and direction of benthic currents at 3 depths in each of 5 locations along the east coast of Australia.

There have been many studies which outline methods for measuring current velocities in lakes and oceans. These current meters range from simple vanes and pendulum-systems used in shallow waters (which rely on current drag and often a priori estimates of current velocity - Pritchard and Burt 1951; Foerster 1968; Kjerfve and Medeiros 1989), through the more complex thermistor flowmeters (La Barbara and Vogel 1976; MacIntyre 1986) to the quite sophisticated and expensive ocean-going devices poineered by Pettersson (1929) and Ekman (1932). Unfortunately, no previously-described current meters satisfied the criteria required in our study of the correlative effects of benthic current speed and direction on the feeding habits of the burrowing spanner crab Ranina ranina (Linnaeus) (see also Kennelly and Craig, 1989; Kennelly 1989). Necessary characteristics of a current meter for this purpose were: (i) it had to measure simultaneously the velocity and direction of water currents close to the substratum (i.e. without any confounding effects of water flow as the device sank nor during retrieval); (ii) it could be used in depths of up to 80 m in oceanic waters; (iii) it could be carried and deployed easily from small (7 m) fishing vessels; (iv) it could be left in position to record water currents while the vessel attended other equipment nearby; and (v) it had to be inexpensive. To satisfy these criteria the instrument described below was constructed (see Figs. 1 and 2).

FIGS 1+2 HERE PLEASE

A horizontial fin (22 cm long x 30 cm wide) and vertical fin (30 cm high x 17 cm long) were mounted at one end of an aluminium tube (42 cm long x 3.5 cm diam.). The tube was pivoted on a vertical wire passing through a hole at the tube's centre of gravity. This wire was attached vertically through the centre of a rectangular frame (1.2 m long x 0.8 m high) constructed of 15 mm diameter steel. This frame was mounted on a horizontial 1.2 m square frame for stability. The vertical frame was anchored to the substratum by two, 5 kg weights attached to the base. These weights, and a small float attached to the top of the frame, ensured an upright orientation of the frame while sinking and upon reaching the substratum. To store the instrument on the vessel, the vertical frame was folded flat onto the horizontial frame, the horizontal fin was removed and the 4-bladed propeller was folded flat. This meant that when not in use, the instrument occupied a space 1.2m x 1.2m x 100mm high, allowing us to store the instrument flat on the deck of the vessel beneath other equipment.

A propeller-driven counter was mounted at the end of the tube opposite the fins and was used to record current velocity. This counter was a General Oceanographic meter (model No. 2031) fitted with a 200 mm diameter, 4-bladed propeller (blade width = 19mm). Once in position on the bottom, this counter was started and stopped by a locking mechanism powered by an electric servomotor (Star Servo model No. S-402). The internal mechanism of the servomotor was protected from salt water by an O-ring seal between the servo-motor shaft and the housing and by having the housing filled with a light oil. Current direction was recorded using a fluid-filled, Engineer lensatic compass mounted on the fins. The card of this compass was left free to rotate or was locked onto the housing using a locking mechanism (separate but similar to that used on the propeller) powered by the servomotor.

The action of the servomotor (and the locking mechanisms for the propeller and compass) was controlled by a special timing mechanism. A power supply (8 AA-sized batteries) and electric timing circuit were mounted in a cylindrical waterproof housing (13.5 cm long x 7.5 cm diam.) constructed of 1.5 mm aluminium. This housing was mounted on the vertical

FIG 3 HERE PLEASE

Upon recovery, average benthic current velocity was calculated from the change in the counter-reading which had occurred after deployment. The rate (in m/sec) at which the propeller rotated was calculated from a calibration curve and equation which had been previously determined by hand-hauling the instrument through seawater at known velocities (Fig. 3). The benthic current direction was simply read off the locked compass.

FIG 4 HERE PLEASE

An example of the data obtained using this instrument is given in Fig. 4. Two replicate readings of current velocity and direction were taken at each of 3 depths in 5 locations off the east coast of Australia in August 1988. At this time, benthic current velocity showed no latitudinal trend as the greatest velocities were recorded at the northern and 2 southern locations, whilst locations in the centre of the sampling area had small current velocities. Current velocity at these 5 locations tended to be greatest at deeper sites. Finally, at sites with greater current velocities, we obtained more consistent readings of current direction (tending to be southerly), indicating that when current velocity was small, the movement of water close to the substratum did not occur in any particular direction.

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CAPTIONS TO FIGURES

Fig. 1. Side view. Two 5 kg weights (A) combine with a float (B) ensure upright orientation of the rectangular vertical frame (C) and the square horizontal frame (D). The clock-hand (E) on the timer indicates the functioning of the timer after resetting. This is seen through the O'ring sealed perspex lid (F) of the timer and power supply housing (G). A movable magnet (H) on the side of the housing switches the power supply. The cable (I) conducts electricity to the servomotor (J) which rotates the shaft of the locking mechanism (K); this engages a 3-toothed cog (L) onto the 4-bladed propeller (M) that drives the revolution counter (N). Vertical (O) and horizontal (P) fins and the pivoting cable (Q) orientate the instrument into the prevailing current.

Fig. 2. Rear view. Vertical (A) and horizontal (B) fins and a buoyancy container (C) balance the instrument. The servomotor (D) rotates the shaft (E) of the locking mechanism for the propeller (F) and a pulley (G) that coils a cable (H) to raise or lower a pin and spring (I) which unlocks or locks the compass card (J).

Fig. 3. Calibration curve used to convert readings of the number of revolutions of the instrument's propeller to velocity (m/sec).

Fig. 4. Mean current speed and direction recorded in each of 3 depths in each of 5 locations off the NSW coast in August, 1988. Each pie diagram shows the range of current direction at that location/depth (in black).

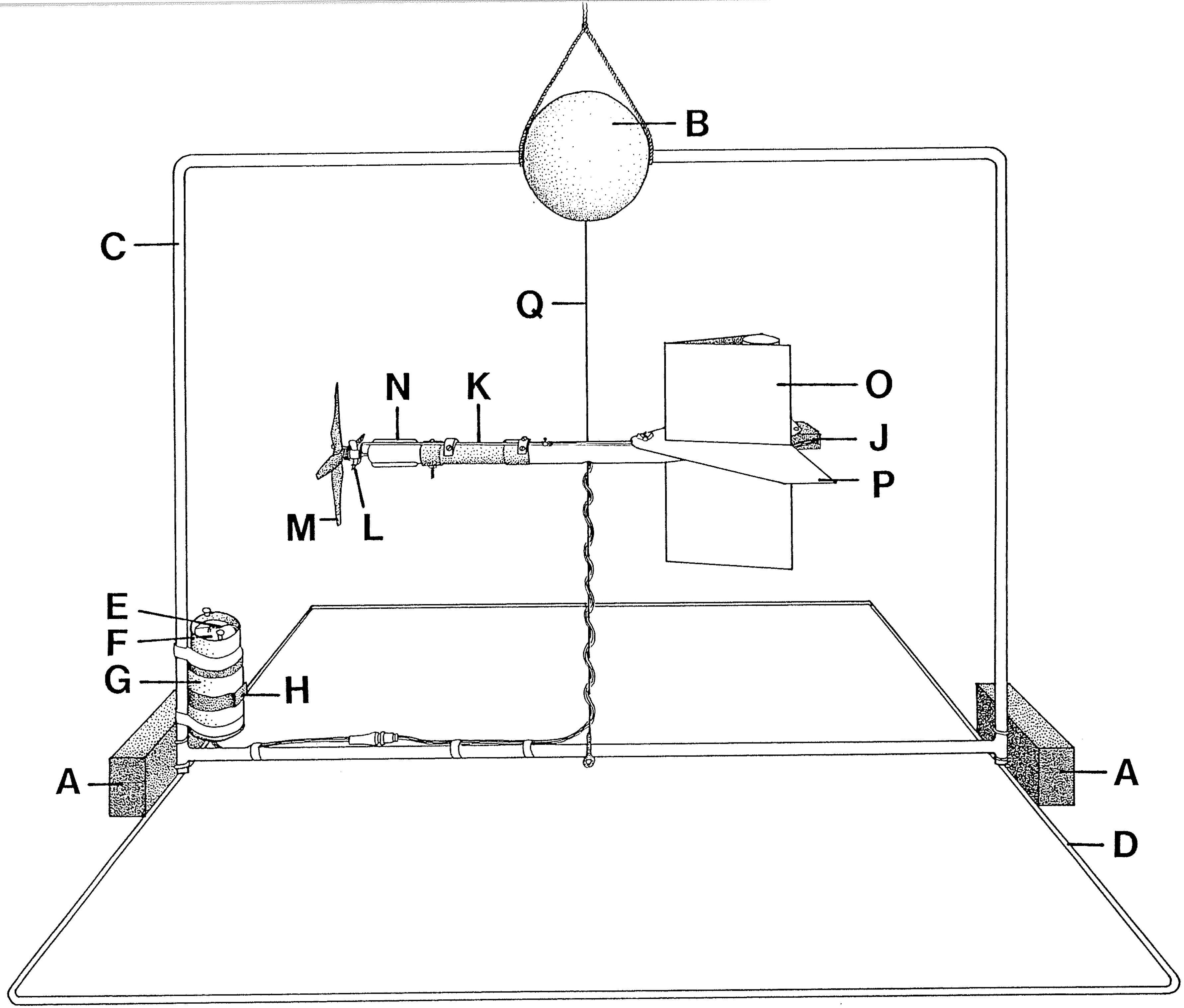


FIG 1

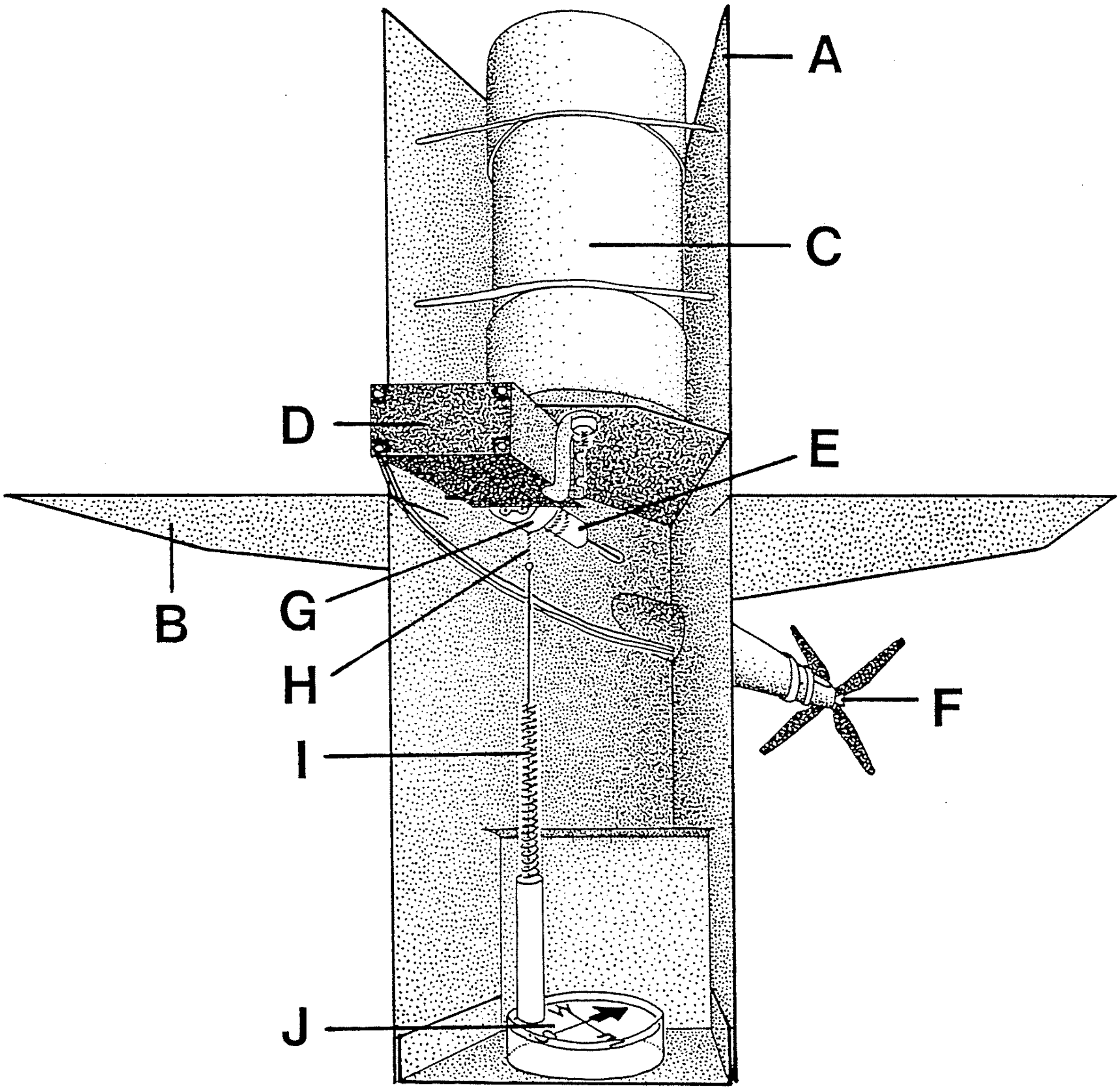


FIG 2

SPANNER CRAB FISHERMEN OF N.S.W.

SOME RESULTS FROM THE SPANNER CRAB RESEARCH PROJECT

FROM: DR STEVE KENNELLY

Attached to this sheet are some figures that I thought you would be interested in, showing various pieces of information that we've got on death rates of throwaway crabs and rates of growth of male crabs.

Figure 1 shows the damage done to undersize spanner crabs when they are removed from dillies with 85mm 9-ply net hung double and loosely. A professional fisherman and a deckhand carefully removed some crabs, taking care not to remove any flippers or legs. The fishermen then removed some crabs fairly quickly (breaking off the tangled flippers). As you can see, an average of about 4 flippers were broken off from each crab when this was done. Finally, the fishermen were told to "rip off" undersize crabs without worrying too much about damage. When this was done an average of about 3 flippers and 1 leg were removed from each crab.

Figure 2 shows the rates of death of crabs that had various kinds of damage done to them. In aquarium tanks in Sydney we put in crabs that had 2 legs removed, some with 4 flippers removed, some with 1 flipper removed and some with no damage at all. As you can see from the graph, 100% of crabs with 2 legs taken off died after 8 days; 70% of crabs with 4 flippers removed were dead after 20 days; 60% of crabs with only 1 flipper removed were dead after 50 days; and 10% of undamaged crabs died (probably due to our salt water system).

Figure 3 shows the results from our SCUBA experiments done off Byron Bay last June in which we buried holding cages into the bottom and put in crabs that were either carefully removed, quickly removed or ripped off. The results showed that 40% of crabs that were carefully removed had died after 10 days, while 100% of crabs that were ripped off were dead.

Figure 4 shows the data we have on the growth of spanner crabs from your tag returns so far. As you can see, these male spanner crabs grew fairly quickly (around an average of <u>1mm every 14 days</u> - remembering that growth of crabs occurs in stages or moults). This means that it probably takes spanner crabs about <u>2 years to reach legal size</u> and that they grow to be about <u>4-5 years old</u>. The tagging data we have so far also has shown that the crabs move at an average of about <u>100m per day</u>.

This sort of information shows the importance of your tag returns, so keep sending them in.

Figure 5 shows that longer spanner crabs weigh proportionately more than shorter crabs (the relationship is a curve). This information (plus the fact that they can grow fairly quickly) makes you think that an increase in the size limit should lead to a better return (in $$). This would only happen, of course, if the undersize crabs that are thrown back are alive and can grow to marketable size.

Well, this information is just to give you an idea of the sort of thing we've been doing lately and to give you something to think about.

Thanks alot for all your help in the past and in the future,

Steve.

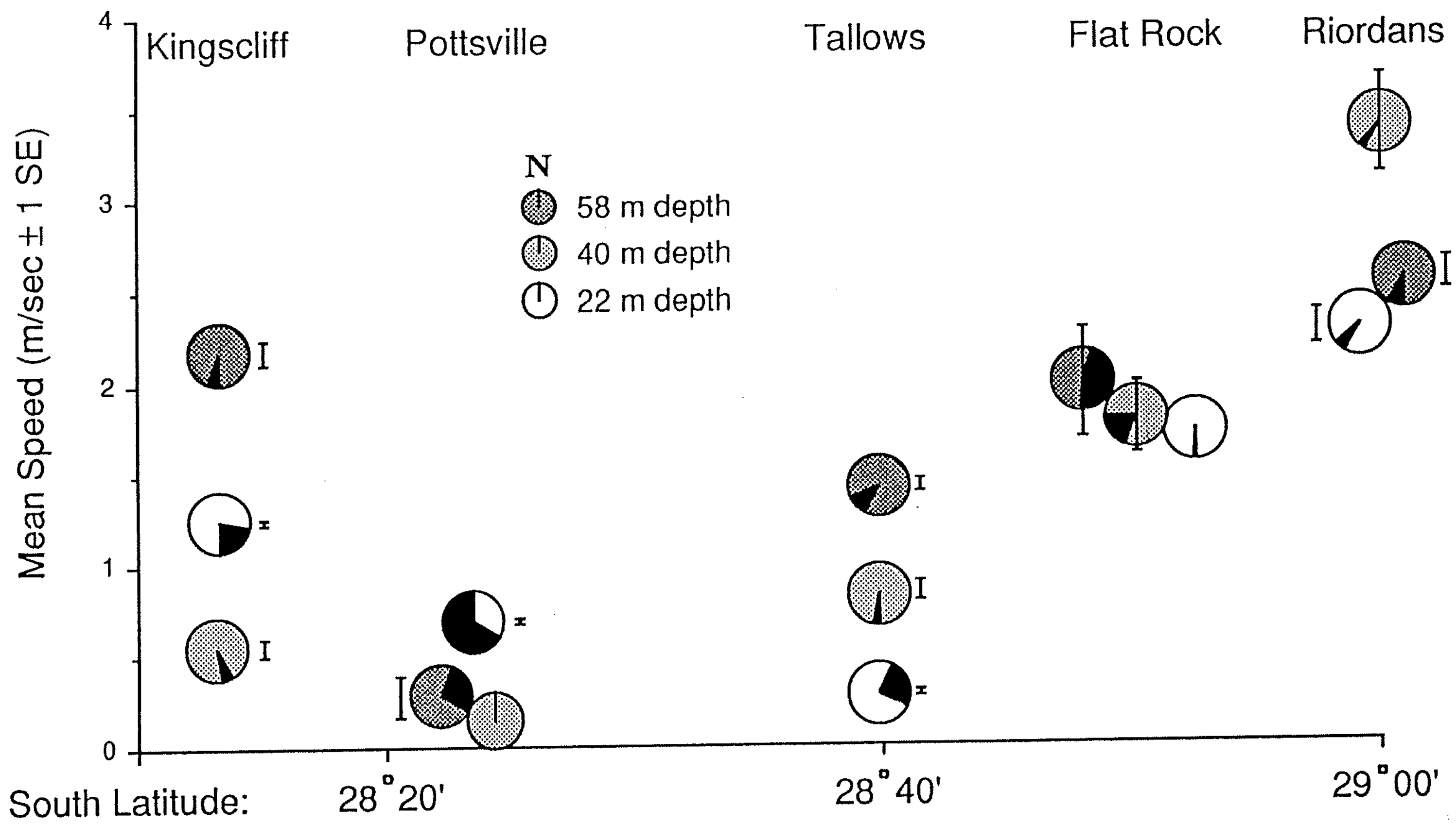

Kingscliff
Pottsville
Tallows
Flat Rock
Riordans
N
58 m depth
40 m depth
22 m depth
Mean Speed (m/sec ± 1 SE)
0
1
2
3
4
South Latitude:
28°20'
28°40'
29°00'

FIG 4

FIGURE 1 - DAMAGE OF SPANNER CRABS DURING REMOVAL

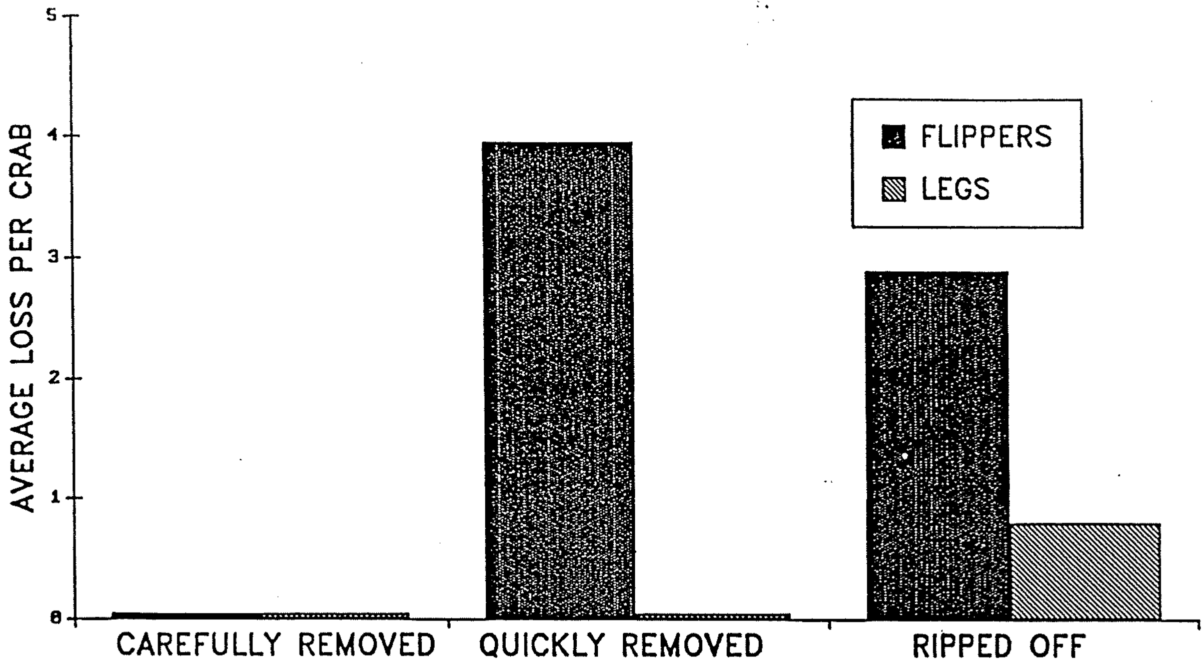


FIGURE 2 - SPANNER CRAB LIMB DAMAGE - AQUARIA EXPERIMENTS

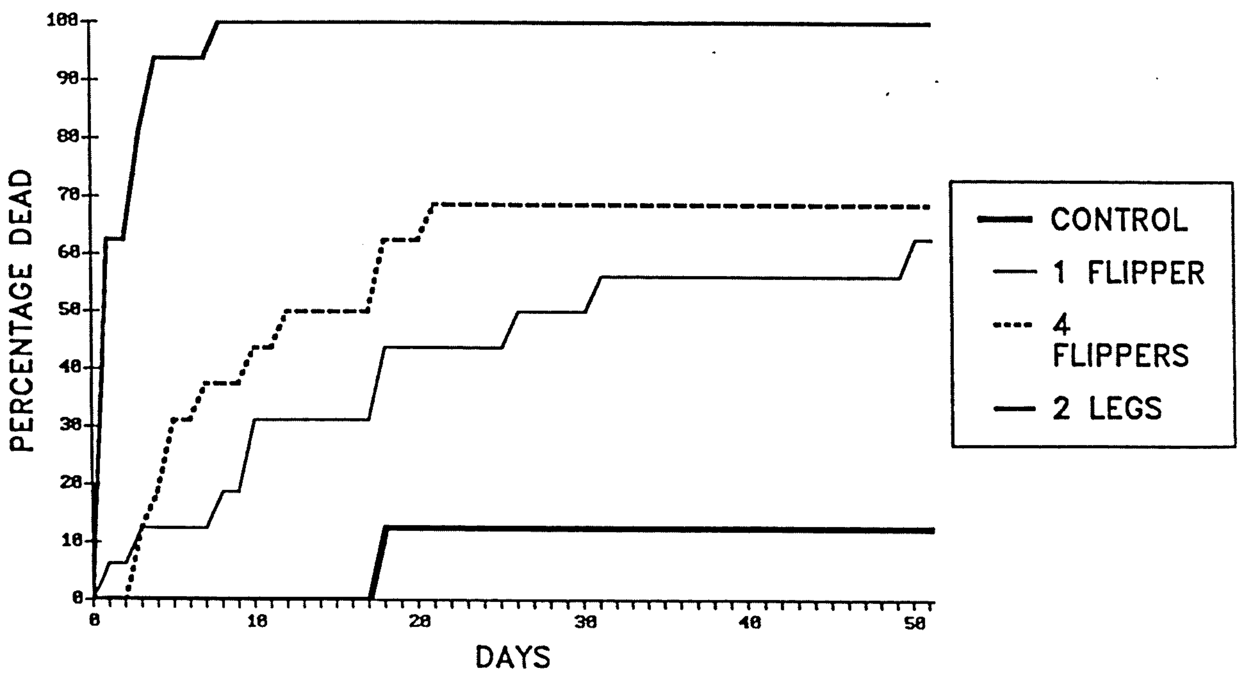


FIGURE 3 - PERCENTAGE MORTALITY OF SPANNER CRABS SCUBA EXPERIMENTS

	DAY 1	DAY 10
CAREFULLY REMOVED	0%	0%
QUICKLY REMOVED	5%	40%
RIPPED OFF	35%	100%

FIGURE 4 -

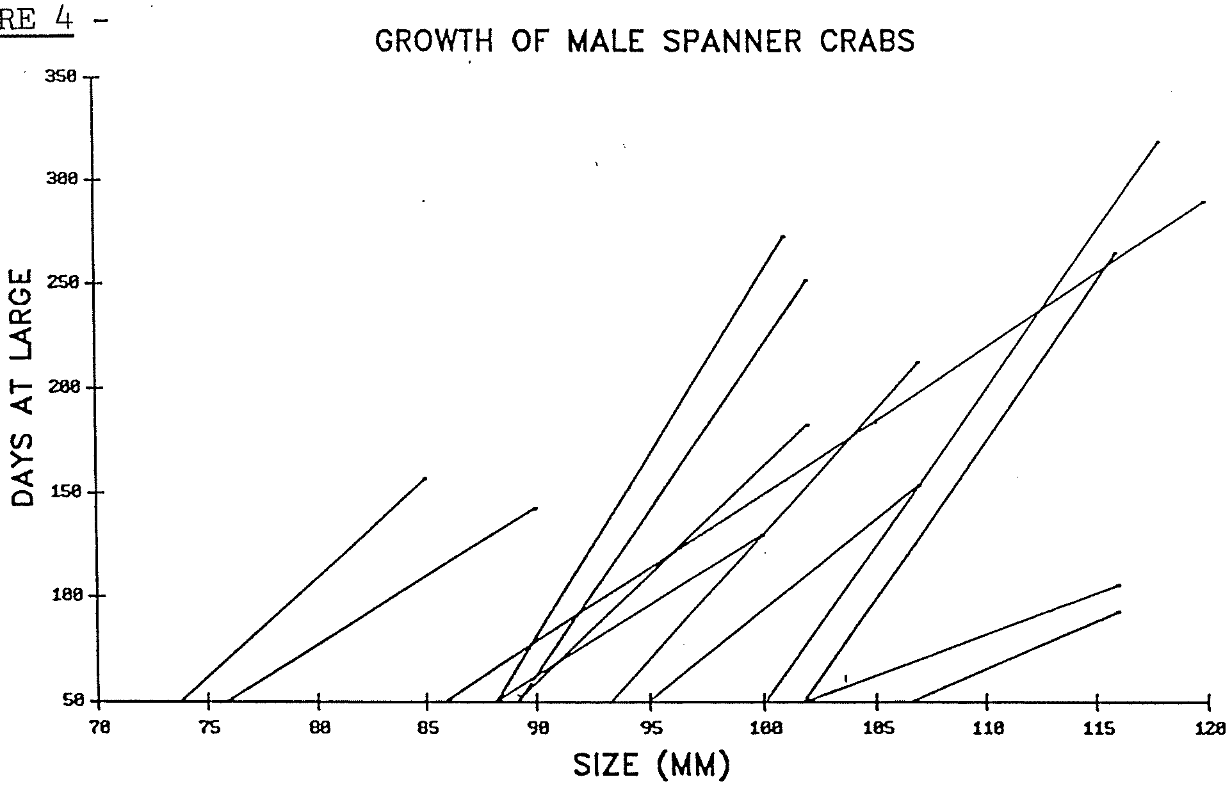
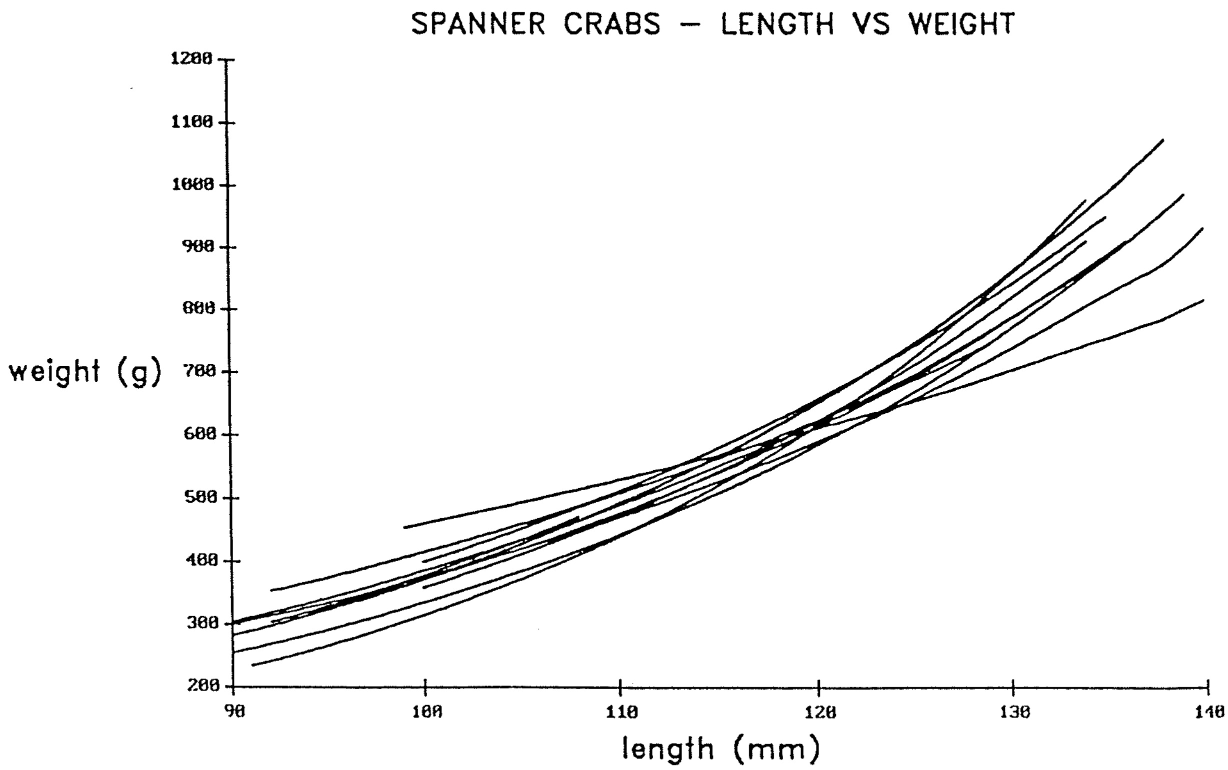


FIGURE 5 -



To: Bob Kearney
From: Steve Kennelly
Date: 20/2/89
Re: Spanner crab closure

The problem experienced by NSW fishermen is that fisherman who live near the border of NSW/Queensland (i.e. Kingscliff/Tweed Heads up to Southport) and who are permitted to fish in NSW waters but usually fish in Queensland waters, come down during the closure in Queensland and fish a large congregation of crabs off Cape Byron. This accumulation apparently occurs every year at about this time (Nov-Dec). This leads to a substantial increase in fishing effort in this patch of crabs, and the consequent death of all legal-sized crabs and unknown mortality on undersize male and female crabs due to handling. As it happens, most females also have eggs at this time. The NSW fishermen are concerned that this large fishing effort may endanger the NSW stock.

The most up-to-date scientific data we have gathered show that there was indeed a large increase in numbers of male crabs at the relevant location (Byron Bay - Tallows) during the closure period (20 November - 20 December, 1988) (Fig. 1). Fewer females were caught at this time, but of those that were caught, 61% had eggs (Fig. 2). This time of the year is also known to be the only time when females carry eggs. Reduced catches of females off Tallows Beach in December (Fig. 1) may be due to the females not feeding during this breeding time and are therefore unavailable for capture. Data from our tagging study shows that of those tagged crabs returned by professional fishermen during the closure, most were caught at Tallows (Fig. 3). This shows firstly that many crabs moved to Cape Byron during Nov/Dec and secondly (and more importantly), the enormous effort by professional fishermen which concentrated off Tallows Beach during this time.

It therefore seems that crabs accumulate off Cape Byron and Tallows during the breeding season (Nov/Dec), and that fishermen throughout the fishery know about it. During the closure in Queensland, those fishermen who fish in Queensland waters come down to fish off Cape Byron and substantially increase the effort acting at that place.

A closure on the taking of spanner crabs at this time (20 Nov - 20 Dec) will: (i) stop the substantial conflict among fishermen from different parts of NSW during this period; (ii) protect a substantial proportion of the catchable population while they congregate off Tallows during the breeding season; (iii) protect those females with eggs that are caught, sold or damaged during handling; and (iv) give crabs some time to disperse after their congregation and, after the closure, with only the "usual" NSW-based fishing effort. This should protect a large portion of the stock at this, the most crucial time of the year. One disadvantage with the closure is that it will mean a cessation in the supply of spanner crabs just before Christmas, at which time the price is usually quite high.

Should this closure be implemented, our continued sampling throughout this year and in Dec (1989) will determine the effectiveness of this closure as we will have independently censussed populations with and without a closure. It may yet come to pass that our final results will recommend an extension of the closure, a lifting of the closure, a closure only at Tallows Beach or even some new management tool such as a new form of trap which reduces handling damage.

The reason why no recommendation was made before last year's closure period was simply because I did not have the data to do so. As of only a few weeks ago, after assimilating data gathered during December last year, I am now in a position to recommend a closure for this year for the same period as the closure in Queensland.

FIG. 1 -

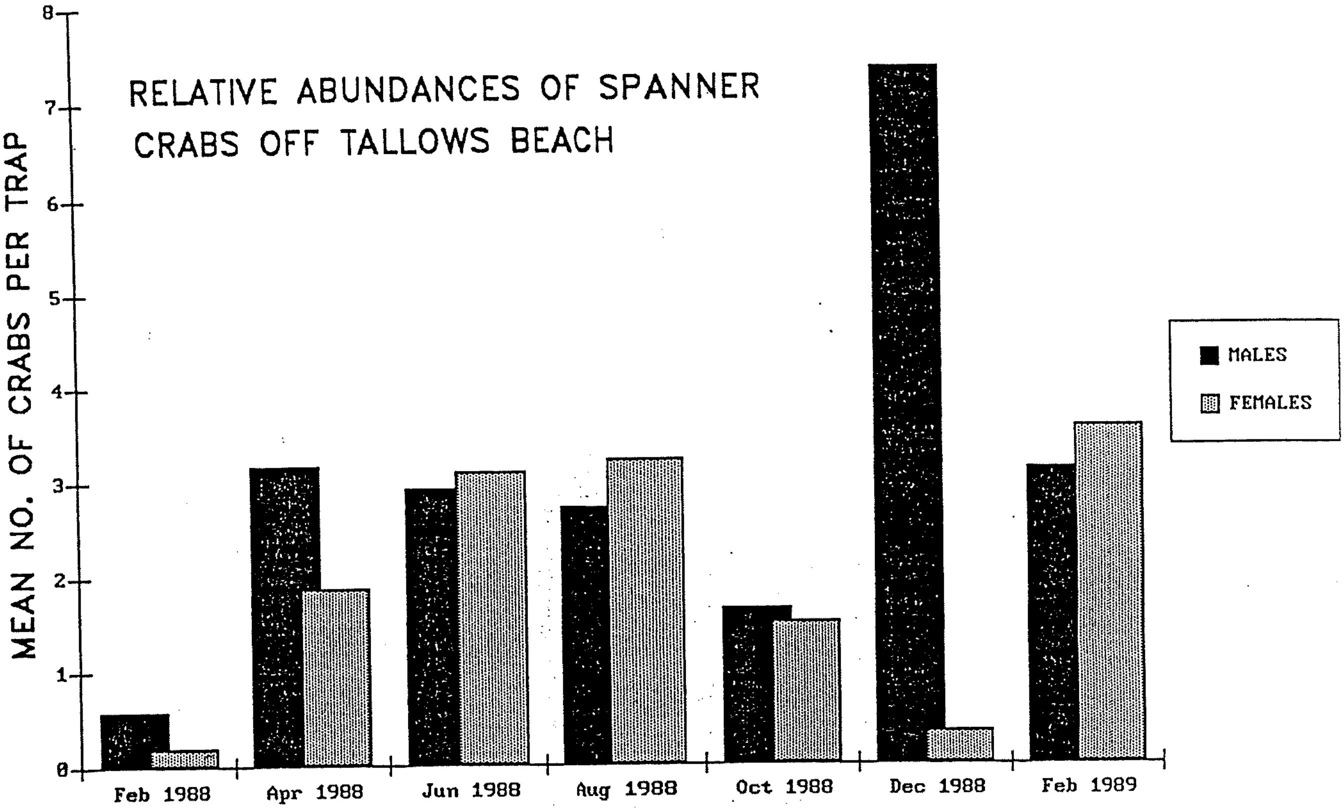


FIG 3 - TAG RETURNS IN DECEMBER 1988

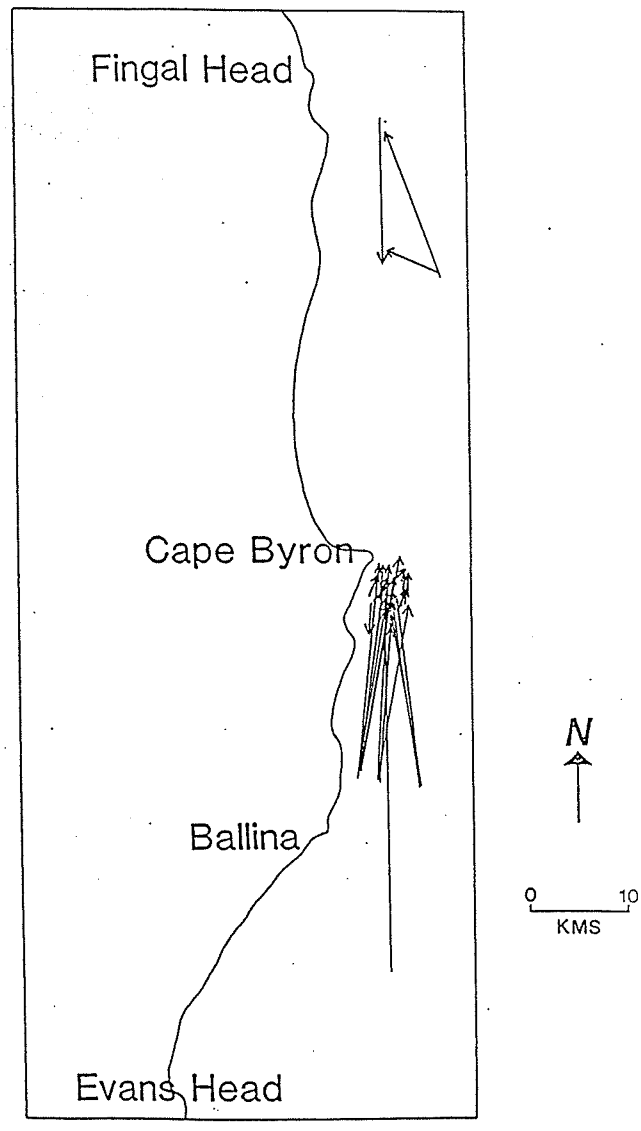
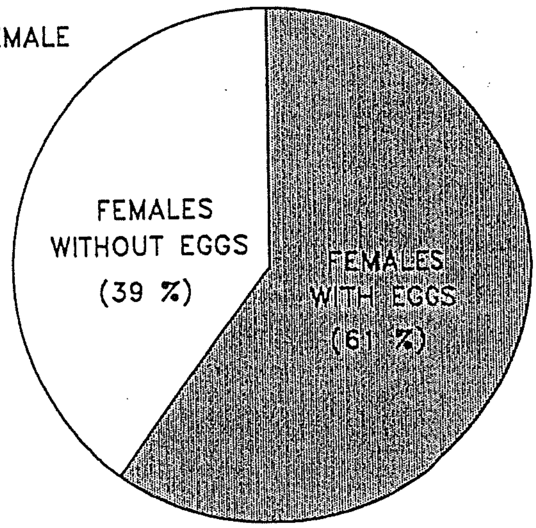


FIG. 2 -

CONDITION OF FEMALE SPANNER CRABS IN DEC. 1988



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Effects of trap design, independence of traps and bait on sampling populations of spanner crabs *Ranina ranina*

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ABSTRACT: Techniques were developed in several field experiments which quantify relative abundances and size-structures of populations of spanner crabs *Ranina ranina* (Linnaeus) using catch per unit of effort data (CPUE) from baited trapping. Effects on CPUE due to 2 shapes of traps, 3 mesh-sizes and 2 strand-thicknesses of nets, and 2 methods of hanging nets were investigated in a fully-orthogonal manipulative experiment. Replicates of these treatments were randomly located in each of 3 depth ranges in the *R. ranina* fishing grounds off the east coast of NSW, Australia. The time required and damage incurred by crabs during removal from various types of traps were quantified. Independence of data from replicate traps was investigated by comparing CPUE from traps set in close proximity with traps set individually. Effects of bait on CPUE were investigated by using different kinds of bait on replicate traps. Results showed that traps with 85 mm, 4-ply net hung doubly caught significantly more *R. ranina* than all other combinations of mesh, ply and methods of hanging nets. This trap also caught proportionately more crabs of commercial value than other traps. The presence of a metallic border around traps did not have any significant effect on CPUE. Small-meshed traps caused more dactyli to be removed from crabs during disentanglement, but more whole limbs were removed from crabs caught on larger meshes. Larger meshes also required significantly more time to clear crabs. Traps set 60 m apart caught as many crabs as traps set much further apart – indicating true independence between replicates. Bait-type had no significant effect on CPUE. Middle-depths in the fishing grounds had significantly more *R. ranina* available for capture than shallower and deeper grounds at this time of sampling. We derived an optimal sampling strategy to be used in subsequent sampling of distributions and abundances of *R. ranina* and stress the worth of field experimentation in testing specific hypotheses about this species' ecology and fishery.

INTRODUCTION

The efficiency of gear in catching target species is of inherent concern to commercial fishing, fisheries research and resource management (Jester 1977, Sissenwine & Kirkley 1982). Fisheries research involving the sampling of populations of animals usually 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 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. Experiments to assess methods that sample abundances of commercially-important marine species have been conducted in many fisheries (Larkins 1963, 1964, Jester 1973, Hamley 1975, Kjelson & Colby 1977, Fogarty & Bordin 1980; see review by Sissenwine et al. 1983).

Several papers have dealt with methods that sample exploited populations of large decapods using CPUE data from baited trapping (Thomas 1953, Sinoda & Kobayasi 1969, Miller 1978, 1979, 1981, 1983). These papers point out several factors that may influence catches, apart from the absolute abundances of crabs and lobsters, including 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. In this paper we consider the first 4 of these

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kinds of traps were used in a stratified, fully orthogonal design. The nets used on individual traps were of all possible combinations of: 3 different mesh-sizes (25 mm, 85 mm, 150 mm); 2 different strand thicknesses (thin – 4- to 6-ply and thick – 12-ply); and 2 ways of hanging the nets (a single layer and 2 layers of net). All these combinations were hung on both square frames (with a metallic border) and X-shaped frames (with a thin, nylon border) to isolate any effects on CPUE of metallic borders.

These 24 different traps were arranged into 3 sets of 8 traps. The 8 traps on each set were spaced 60 m apart. Each set contained all traps of a given mesh-size arranged randomly. Each set was left on the substratum for a soak-time of ca 90 min before collection, sampling, rebaiting, re-randomizing the order of traps along a set, and re-setting the gear in a new location. Over a period of 4 d in July 1987, each of these sets of traps was set 5 times at random in 3 depth ranges: shallow (16 to 24 m), mid-depth (32 to 40 m) and deep (54 to 60 m). Because the 24 traps had to be arranged in groups of similar mesh sizes, catch rates may be correlated across the 8 different traps on a set and within mesh sizes. This can affect the analyses of variance, causing some tests to be too liberal and others too conservative. This possibility was investigated by a Tukey's test of non-additivity (Scheffé 1959) – see below.

Expt 1b – Effects of different types of gear on clearing time and damage to crabs. Two replicates of each of the 24 different traps were sampled for the time taken to disentangle crabs from traps by one operator. This was recorded as the average time taken per crab, per trap-lift. Two replicates of each of the 24 different traps were also sampled for the amount of damage incurred to each crab upon removal. This was recorded as the number of dactyli and/or whole limbs removed per crab, per trap-lift.

Expt 2 – Effects on CPUE due to competition among traps for crabs and types of bait. To determine if CPUE is affected by competition among neighbouring traps joined together in a single set, we laid out 2 sets containing 6 traps each placed 60 m apart and compared these to 12 individual traps spaced by more than 120 m. Commercial fishermen claim that at 60 m apart, traps do not compete, and this was confirmed by us in a pilot experiment using traps set at 10, 50 and 100 m apart (unpubl.). The traps used in this experiment were square-framed with 85 mm, 4- to 6-ply net doubly hung – the optimal kind of trap determined in Expt 1 (see 'Results'). All gear was set for a soak-time of 90 min in each of 2 random locations (Places 1 and 2), retrieved, sampled and then the whole procedure repeated.

Incorporated in this experimental design was a test for differences in CPUE due to different baits which

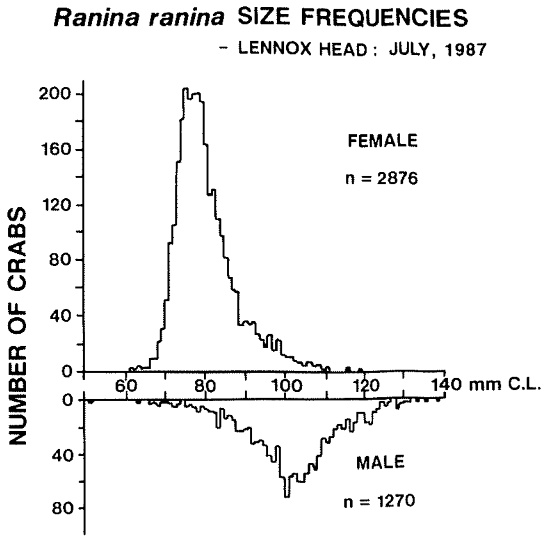

Fig. 2. *Ranina ranina*. Size-structure of the population of males and females at the study site

would be available in future sampling. Within each group of 6 traps (whether in a set or individually), 2 were baited with mullet *Mugil cephalus* (Linnaeus), 2 with blackfish *Girella tricuspidata* (Quoy & Gaimard) and 2 with morwong *Cheilodactylus douglassii* (Hector).

Analyses of data. The measurements of all *Ranina ranina* obtained in Expt 1a were combined to determine the overall size distribution of the population studied. Females were generally smaller and more abundant than males (Fig. 2), and so size-classes for subsequent analyses of data were different for each sex. From the data from each replicate trap in Expts 1a and 2, we derived the percentage of crabs caught in each of the following size-classes: males: $\leqslant$ 79, 80–89, 90–99, 100–109, 110–119 and $\geqslant$ 120 mm; females: $\leqslant$ 69, 70–79, 80–89, 90–99, 100–109 and $\geqslant$ 110 mm. Further, and of particular interest to commercial fishermen, the percentage of crabs that were male and $\geqslant$ 93 mm were determined for each trap (those crabs that are usually retained for sale). We also determined the total number of crabs caught on each trap.

The data from each experiment were firstly tested for homogeneity of variances (Cochran's test), then analysed in the relevant 5-factor analysis of variance (Expt 1a) or 4-factor analysis of variance (Expts 1b and 2); means were then compared using Ryan's tests (Ryan 1959). Those sets of data with homogeneous variances that showed significant effects in the analyses of variance and subsequent Ryan's tests are presented below. These data were also analysed using a 4-factor version of Tukey's test for non-additivity to test the significance of interactions between set and trap-shape, ply and hanging. No such interactions were in

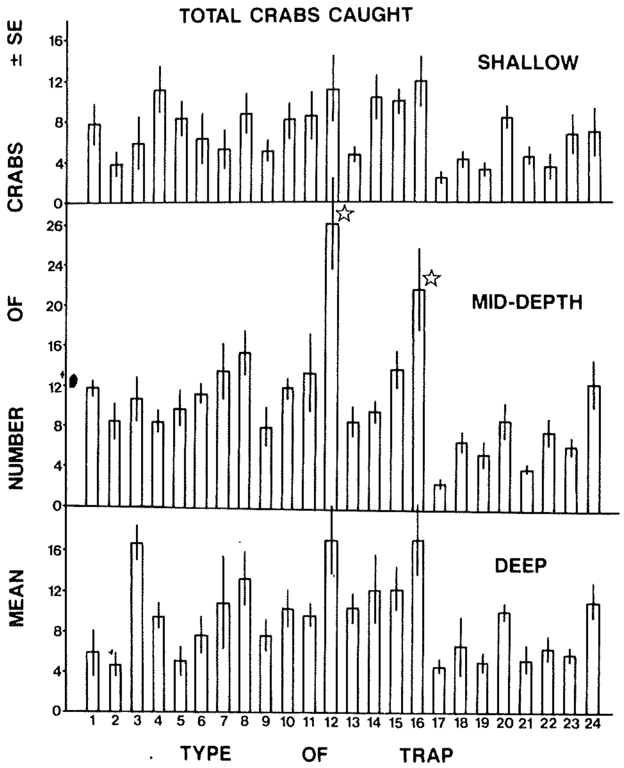

Fig. 3. *Ranina ranina*. Effects on CPUE of numbers due to 24 types of traps at each of 3 depths ($n = 5$). In this and subsequent figures, ☆ indicates a significant difference among means ($p < 0.05$). See Table 1 for the identity of each trap

Table 1. Legend for Figs. 3, 4, 5 and 6. Identity of the 24 different traps used in Expt 1

Number on x-axis	Type of trap: Hanging	Ply	Shape	Mesh
1	single	thick	square	25 mm
2	double			
3	single	thin		
4	double			
5	single	thick	X-shaped	
6	double			
7	single	thin		
8	double			
9	single	thick	square	85 mm
10	double			
11	single	thin		
12	double			
13	single	thick	X-shaped	
14	double			
15	single	thin		
16	double			
17	single	thick	square	150 mm
18	double			
19	single	thin		
20	double			
21	single	thick	X-shaped	
22	double			
23	single	thin		
24	double			

evidence ($p > 0.05$), allowing the treatment of this experiment as a fully orthogonal design.

RESULTS

Expt 1

Overall, more crabs were caught in the middle depth than in shallow or deep water (Fig. 3; cf. Table 1 for identities of traps). There was a significant interaction between depth, mesh, ply and method of hanging nets, and no significant effects due to the shape of traps (i.e. the presence of a border around traps) ($p < 0.05$, Table 2). Ryan's test revealed that Traps 12 and 16 caught more crabs than any other trap. These traps were the square and X-shaped traps (respectively), doubly-hung with 85 mm, 4-ply net.

The percentage of the total catch that would have been retained for sale (marketable crabs) showed fewer significant effects due to trap design than the total catch (Fig. 4). The analysis of variance revealed significant interactions between depth, mesh and ply, and between depth, shape and ply (Table 2), but these differences could not be identified using Ryan's tests. The only significant effect was found in shallow water (where there were fewer crabs overall) where the 150 mm nets caught proportionately more retainable crabs.

The percentage of the catch that were male and 100–109 mm (medium-sized) showed significant interactions between mesh and ply and between mesh and hanging in the analysis of variance ($p < 0.05$, Table 2). Ryan's tests on these means showed that there were proportionately less of this size-class caught in deep water than in shallow water, and that the 150 mm net caught fewer of these deep water crabs than the other mesh sizes (Fig. 5).

The percentage of the total catch that were females less than 69 mm, females 70–79 mm, females 80–89 mm and males 110–119 mm showed several significant interactions in the respective analyses of variance (Table 2) but differences among means could not be identified using Ryan's test.

The time taken to clear crabs from traps was different for different traps (significant interaction in the analysis of variance, $p < 0.05$, Table 3), with significantly more time required to clear crabs from the 150 mm mesh traps (Fig. 6a). The damage to crabs during the clearing of traps also differed for different kinds of traps (analysis of variance, $p < 0.05$). Significantly fewer dactyli were damaged in Traps 17 to 24 (the traps with 150 mm nets) than in other traps (Fig. 6b). This result was reversed for damage done to whole limbs, however,

Table 2. *Ranina ranina*. Summaries of 5-factor analyses of variance to determine effects of different traps 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	% of retained crabs	% of females 80–89 mm	% of females 70–79 mm	% of females <69 mm	% of males 110–119 mm	% of males 100–109 mm
Depth	2	**	**	**	**	**	ns	**
Mesh	2	**	**	*	ns	ns	*	**
Shape	1	ns	*	ns	ns	ns	ns	*
Ply	1	**	ns	**	ns	*	ns	ns
Hanging	1	**	ns	ns	ns	ns	*	ns
D × M	4	ns	**	ns	**	ns	**	ns
D × S	2	ns	ns	**	ns	ns	ns	*
D × P	2	ns	ns	**	*	ns	ns	ns
D × H	2	ns	ns	ns	ns	ns	ns	ns
M × S	2	ns	ns	ns	ns	ns	ns	ns
M × P	2	ns	ns	ns	ns	ns	ns	**
M × H	2	**	ns	ns	**	ns	ns	**
S × P	1	ns	ns	ns	ns	ns	ns	ns
S × H	1	ns	ns	ns	ns	ns	ns	ns
P × H	1	**	ns	ns	ns	ns	ns	ns
D × S × H	2	ns	ns	ns	ns	ns	ns	ns
D × M × S	4	ns	ns	ns	ns	ns	ns	ns
D × M × P	4	**	ns	*	ns	ns	ns	ns
D × P × H	2	ns	ns	ns	ns	ns	ns	ns
D × M × H	4	ns	ns	ns	ns	ns	ns	ns
D × S × P	2	ns	ns	**	*	ns	ns	ns
M × S × P	2	ns	ns	ns	ns	ns	ns	ns
M × S × H	2	ns	ns	ns	ns	ns	ns	ns
M × P × H	2	ns	ns	ns	ns	ns	ns	ns
S × P × H	1	ns	ns	ns	ns	ns	ns	ns
D × M × S × P	4	ns	ns	ns	ns	*	ns	ns
D × M × S × H	4	ns	ns	ns	ns	ns	ns	ns
D × M × P × H	4.	**	ns	ns	ns	ns	ns	ns
D × S × P × H	2	ns	ns	ns	ns	ns	ns	ns
M × S × P × H	2	ns	ns	ns	ns	ns	ns	ns
D × M × S × P × H	4	ns	ns	ns	*	ns	ns	ns
Residual	281							

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

where Traps 19 and 21 resulted in greater losses of limbs (Fig. 6c).

Expt 2

Whilst several sets of data showed significant interactions in the analyses of variance of this experiment (Table 4), only 2 sets of data showed any significant differences among means using Ryan's tests. In no analysis were there consistent influences due to bait.

Many more crabs were caught at Place 2 than at Place 1 (Fig. 7a). Ryan's test revealed no differences among means of different baits or between sets of traps and individual traps. The percentage of the total catch that were retainable for sale showed a significant effect at Place 1 where there were few crabs (Fig. 7b). Here traps set individually caught proportionately fewer retainable crabs than traps in sets.

DISCUSSION

The experiments described in this paper identified the optimal tool for estimating relative abundances of *Ranina ranina* using a baited trapping technique. This was a flat-framed trap with doubly-hung, 4-ply netting with a mesh-size of 85 mm. This design caught significantly more crabs per trap-lift than any other kind of trap. The 4-ply net hung doubly probably entangles limbs of *R. ranina* better than thicker nets and better than nets hung singly. A mesh size smaller than 85 mm may permit some crabs to walk over the net undeterred, and a larger mesh-size may allow some crabs to avoid entanglement. The presence or absence of a border around traps did not significantly affect CPUE.

The fact that there were few effects on the different size-classes of male and female crabs due to different traps indicates that various traps tended to fish equally as

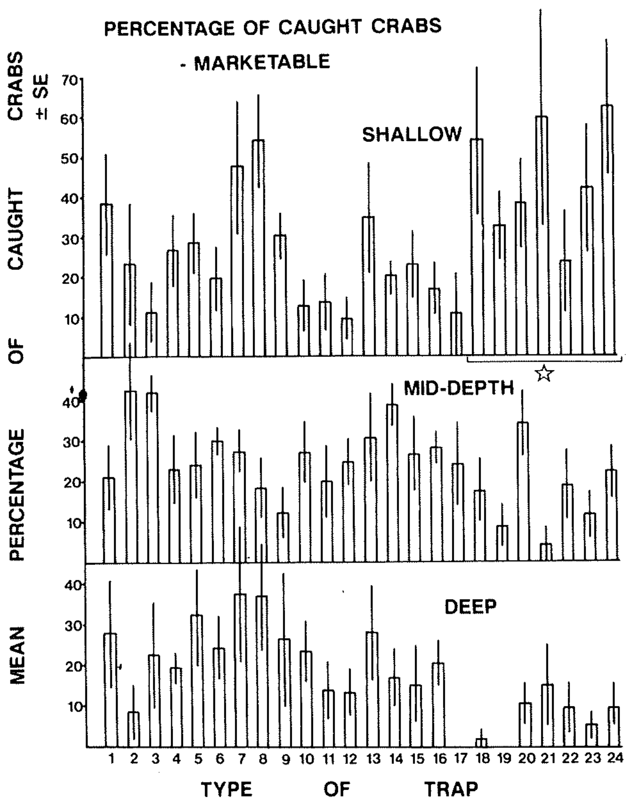

Fig. 4. *Ranina ranina.* Effects on CPUE of the percentage of retainable crabs due to 24 types of traps at each of 3 depths (n = 5). See Table 1 for the identity of each trap

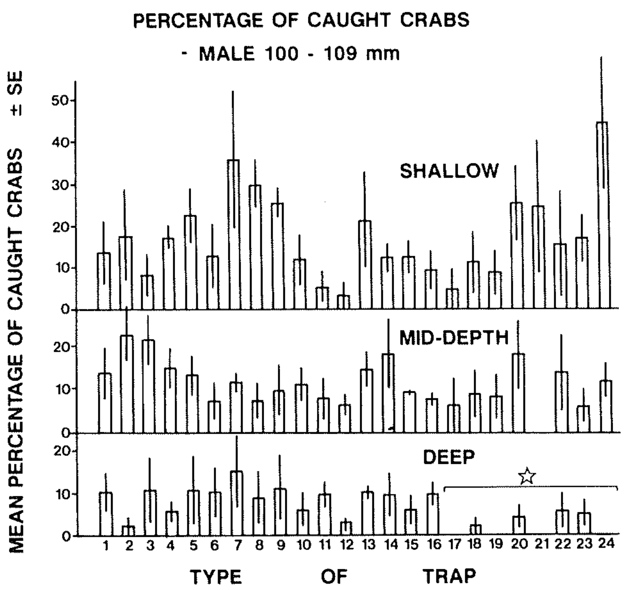

Fig. 5. *Ranina ranina.* Effects on CPUE of the percentage of male crabs 100–109 mm due to 24 types of traps at each of 3 depths (n = 5). See Table 1 for the identity of each trap

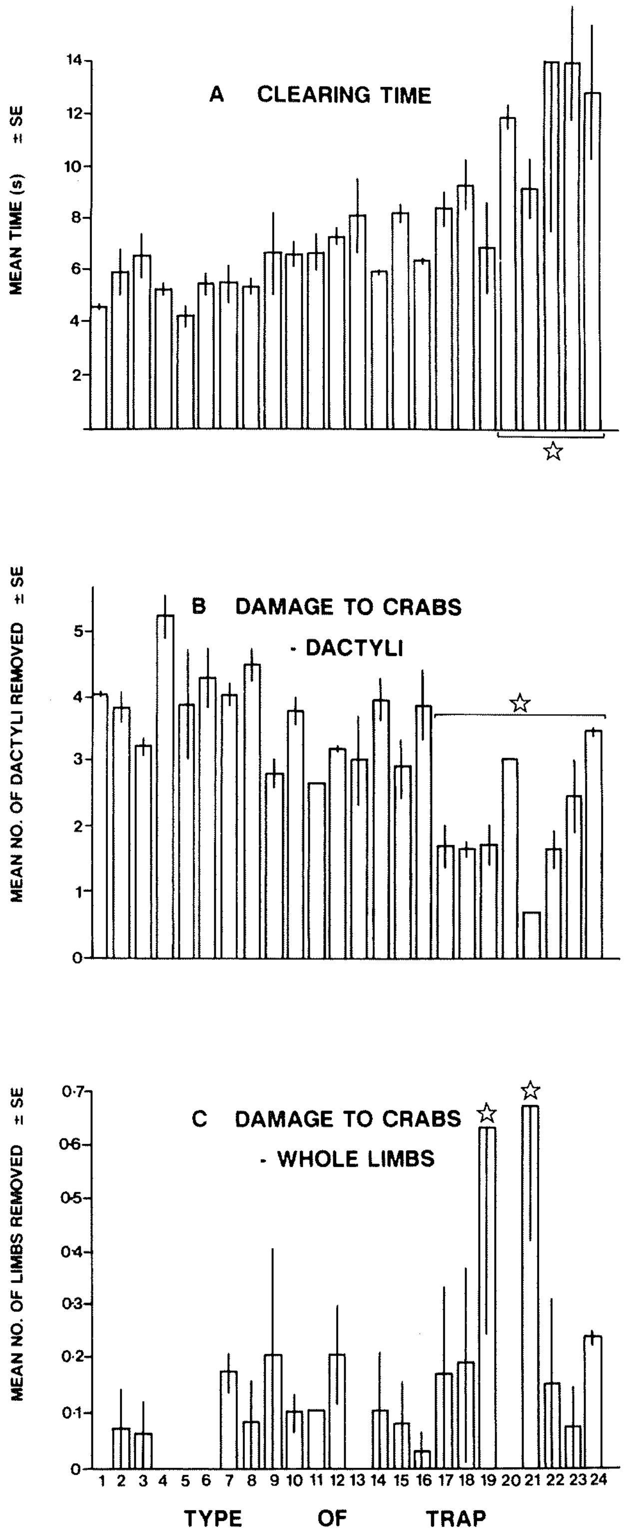

Fig. 6. *Ranina ranina.* (A) Time taken to remove crabs from 24 types of traps (n = 2). (B) Number of dactyli removed from crabs due to removal from 24 types of traps (n = 2). (C) Number of whole limbs removed from crabs due to removal from 24 types of traps (n = 2). See Table 1 for the identity of each trap

Table 3. *Ranina ranina.* Summaries of 4-factor analyses of variance to determine effects of different traps on the time required to clear crabs from traps and the damage done to crabs during clearing

Treatment	df	Time for clearing	Removal of dactyli	Removal of limbs
Mesh	2	••	••	••
Shape	1	•	ns	ns
Ply	1	ns	••	ns
Hanging	1	ns	••	•
M × S	2	••	ns	ns
M × P	2	ns	••	ns
M × H	2	••	ns	ns
S × P	1	ns	ns	ns
S × H	1	ns	ns	ns
P × H	1	ns	ns	ns
M × S × P	2	ns	ns	•
M × S × H	2	ns	ns	ns
M × P × H	2	ns	ns	ns
S × P × H	1	ns	ns	ns
M × S × P × H	2	•	ns	••
Residual	24			

effectively for these various sizes of both sexes. The only exception was for the CPUE of crabs of commercial value (Fig. 4). This size-class was caught better on a larger mesh-size only when there were very few crabs available for capture, whilst medium-sized male crabs were caught better with smaller mesh-sizes when there were few crabs available. This indicates significant variation between treatments for these size-classes and no consistent trend. The trap currently used by commercial fishermen in New South Wales (developed through trial and error over 6 to 12 mo of fishing) is that trap we found to be most successful, although 9- to 12-ply net tends to be used instead of 4-ply – heavier nets require less maintenance and replacement than lighter nets.

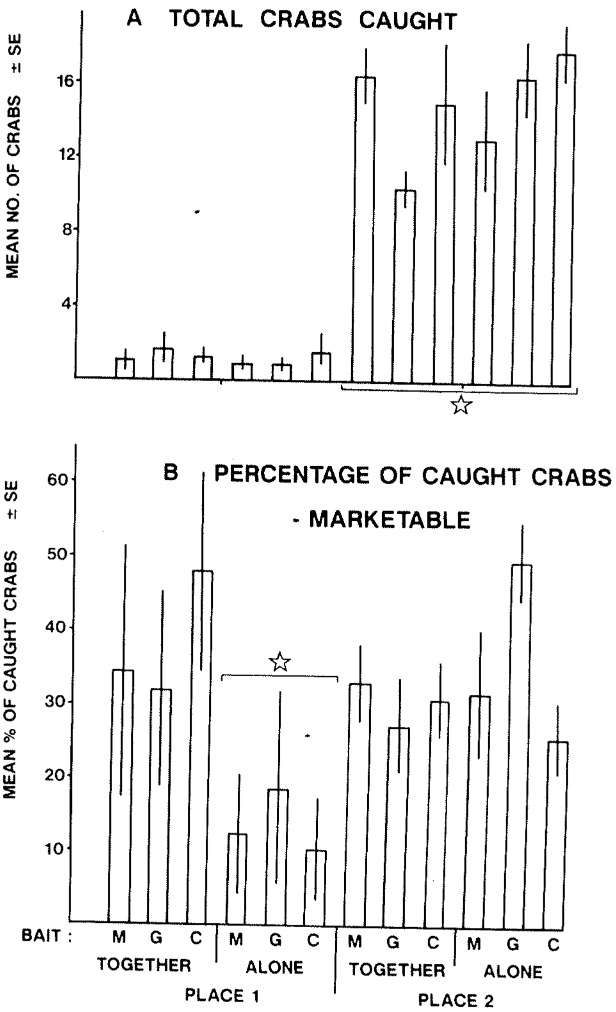

Fig. 7. *Ranina ranina.* Effects on CPUE of (A) total number of crabs and (B) percentage of retainable crabs caught on traps set in different places, 60 m apart and individually, and using 3 different types of bait (M = *Mugil cephalus*, G = *Girella tricuspidata*, C = *Cheilodactylus douglassii*) (n = 12)

Table 4. *Ranina ranina.* Summaries of 4-factor analyses of variance to determine effects on CPUE due to competition between traps set 60 m apart, different kinds of bait and in different places

Treatment	df	Total no. of crabs	% of retained crabs	% of females 80–89 mm	% of females 70–79 mm	% of males 110–119 mm	% of males 100–109 mm	% of males 90–99 mm
Place	1	••	ns	••	ns	ns	ns	ns
Competition	1	ns	ns	ns	ns	ns	ns	ns
Bait	2	ns	ns	ns	ns	ns	ns	ns
Sets	12	ns	ns	ns	•	••	ns	•
P × C	1	ns	••	ns	ns	ns	••	ns
P × B	2	ns	ns	ns	ns	ns	ns	ns
C × B	2	ns	ns	ns	ns	ns	ns	ns
P × C × B	2	•	ns	ns	ns	ns	ns	ns
B × S	24	ns	ns	•	•	••	ns	ns
Residual	46							

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

A greater number of dactyli were generally removed from crabs caught on 25 mm and 85 mm meshes, but these mesh-sizes led to less removal of whole limbs. In the only study of the effects of limb-damage on the survivorship of *Ranina ranina*, Onizuka (1972) found that 90 % of crabs survived with dactyli removed from 4 limbs, whilst only 30 % of crabs survived with 1 whole limb removed. These results suggest that smaller mesh-sizes will minimize mortality due to removal from traps. It also took significantly longer to remove crabs from the larger mesh-size than smaller meshes, indicating that smaller mesh-sizes are optimal with respect to clearing-time.

Since no bait caught more crabs than any other, future sampling will use whatever bait is available. We are also now confident that traps set 60 m apart fish as effectively as individual traps set much further apart. Thus, traps set 60 m apart do not compete with one another for the same crabs and so can be considered as true independent replicates. Indeed, the only effect of using a 60 m distance between traps on a set compared to setting traps individually was to enhance the capture of large, male crabs when the relative number of crabs appeared low.

Thomas (1953), Sinoda & Kobayasi (1969) and Miller (1983) point out the need for examinations of the reliability of methods which estimate the relative abundances of organisms using baited traps. In this study, a methodology involving manipulative field experiments was shown to achieve this by testing discrete hypotheses concerning the various methods available to catch and sample *Ranina ranina*.

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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

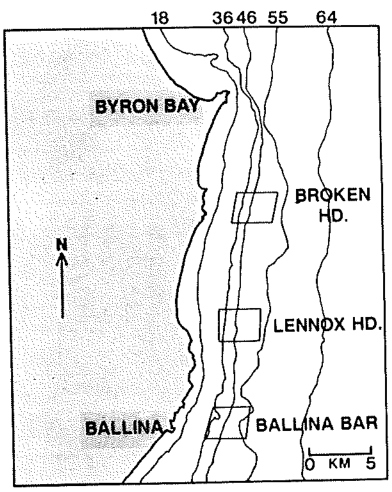

Fig. 1. Locations of study sites. Depth contours are in metres

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.

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.

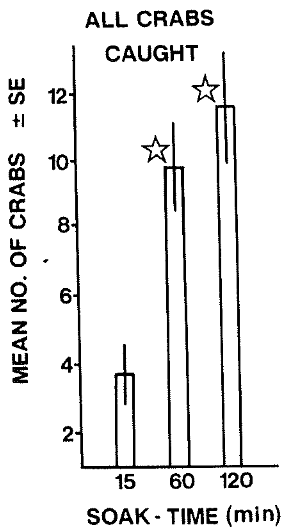

Fig. 2. *Ranina ranina*. Effect on CPUE of numbers due to different soak-times ($n = 20$). In this and subsequent figures, ☆ indicates a significant difference among means (Ryan's test, $p < 0.05$)

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).

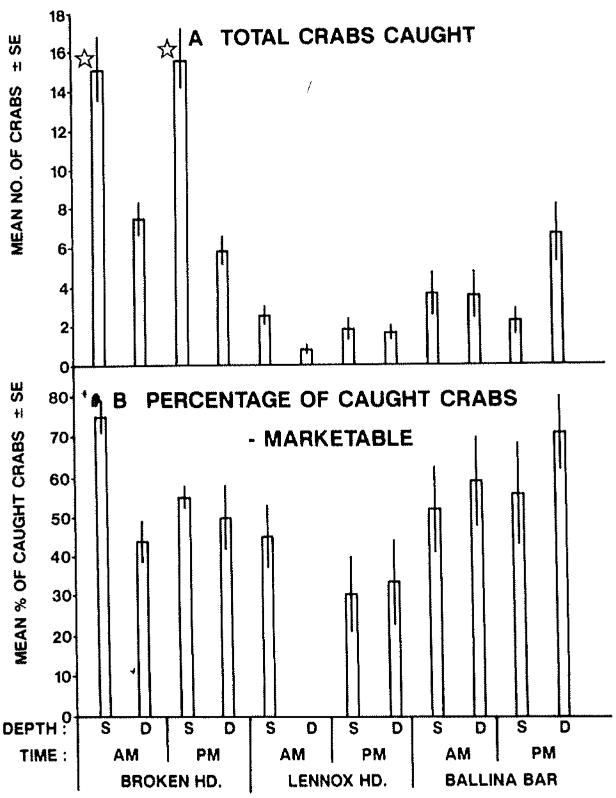

Fig. 3. *Ranina ranina.* Effects on CPUE of (A) total numbers of crabs and (B) percentage of retainable crabs, due to depth, time of day and in different locations ($n = 15$)

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

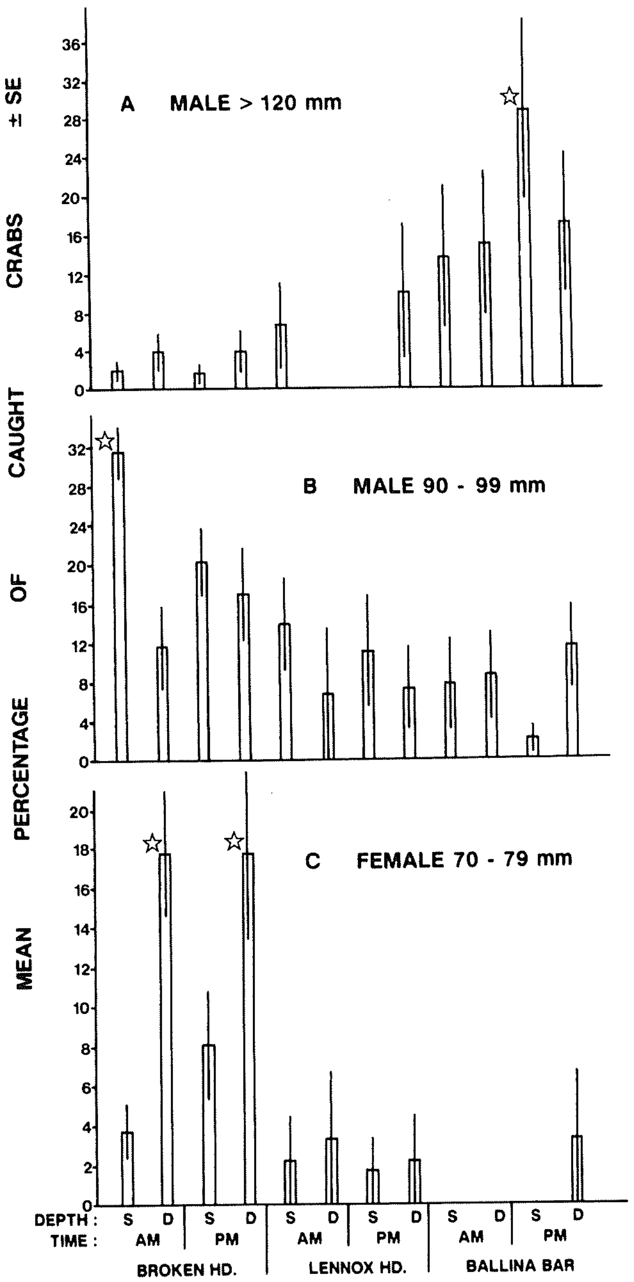

Fig. 4. *Ranina ranina.* Effects on CPUE of (A) percentage of male crabs ⩾ 120 mm, (B) percentage of male crabs 90–99 mm and (C) percentage of female crabs 70–79 mm due to depth, time of day and in different locations (n = 15)

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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