CSIRO PUBLISHING

Marine & Freshwater Research

Volume 49, 1998

A journal for the publication of original contributions
in physical oceanography, marine chemistry,
marine and estuarine biology and limnology

www.publish.csiro.au/journals/mfr

All enquiries and manuscripts should be directed to
Marine and Freshwater Research
CSIRO PUBLISHING
PO Box 1139 (150 Oxford St)
Collingwood Telephone: 61 3 9662 7618
Vic. 3066 Facsimile: 61 3 9662 7611
Australia Email: ann.grant@publish.csiro.au

Published by **CSIRO** PUBLISHING
for CSIRO Australia and
the Australian Academy of Science

 Mar. Freshwater Res., 1998, **49**, 41–45

Effect of limb damage on the survival and burial time of discarded spanner crabs *Ranina ranina* (Linnaeus)

John M. Kirkwood[A] and Ian W. Brown

Southern Fisheries Centre, Queensland Department of Primary Industries, PO Box 76, Deception Bay, Qld 4508, Australia

[A]*To whom correspondence should be addressed. email: kirkwoj@dpi.qld.gov.au*

Abstract. Spanner crabs (*Ranina ranina*) often lose legs or segments of legs when being disentangled from fishing nets. Two field experiments investigated the effect of this on survival of discarded undersize crabs. To examine mortality directly attributable to limb damage, 100 crabs were each subjected to one of five treatments: no damage, or removal of one dactylus, three dactyli, one leg or one cheliped. Limb damage had a significant effect on survival, mean mortalities being, respectively, 5%, 20%, 25%, 55% and 90%. Thus, present fishing methods may lead to high mortality among discarded crabs.

To examine whether limb damage leads to increased exposure to predation, 40 crabs were released after each was subjected to one of the above treatments. There was no significant effect of limb damage on the time it took crabs to bury themselves. Crabs sank at a mean rate of 0.26 m s^{-1}, and on reaching the sea floor most crabs were motionless for up to 20 min before becoming active and immediately burying themselves; time to burial ranged from 6 s to 20 min, with 65% burying themselves within 68 s of reaching the sea floor.

Extra keywords: Brachyura, Decapoda, field experiment, mortality.

Introduction

Two objectives of implementing minimum legal size regulations in fisheries are to enable under-size individuals to attain sexual maturity before being subject to fishing mortality and to reduce total fishing mortality (Hill 1990). These objectives cannot be achieved if fishing leads to high mortality among animals discarded because they are smaller than the minimum legal size.

Spanner crabs (*Ranina ranina*) are the subject of an important fishery in southern Queensland and northern New South Wales, Australia. These large marine brachyurans are caught commercially in baited tangle nets placed on the sea floor. Crabs attracted to the bait entangle their legs in the mesh when they walk over the net. They are then hauled to the surface and disentangled by the crabbers. Crabs that exceed the legal minimum size (rostral carapace length (CL) >100 mm in Queensland, sub-orbital CL >93 mm in New South Wales) are retained for market, and smaller crabs are returned to the sea. The purpose of the present research was to follow the fate of these discarded crabs.

Disentangling *R. ranina* whose legs have become entangled in the mesh may be very time consuming. Crabbers use the following methods: *(i)* careful disentangling, *(ii)* breaking off entangled dactyli from one or more legs, *(iii)* seizing crabs by the carapace and quickly pulling them from the mesh, *(iv)* slamming the net frame against a solid surface so as to dislodge crabs by inertia or *(v)* scraping the net surface against a solid bar. Method *(i)* causes the least damage and is employed for crabs bound for market (mostly live export), whereas any of these methods may be employed to remove undersized crabs. Kennelly *et al*. (1990) found that crabs removed by method *(i)* rarely showed damage, those removed by method *(ii)* lost on average 3.95 dactyli, and those removed by method *(iii)* lost on average 2.9 dactyli and 0.8 limbs. The use of methods *(iv)* and *(v)* has now been largely discontinued by fishermen owing to the high level of physical damage they inflicted on crabs. As the *R. ranina* fishery is very labour intensive, crabbers are motivated to use the faster methods to remove discarded crabs (regardless of the level of injury inflicted) and may frequently return crabs to the sea with legs or segments of legs missing.

In a laboratory experiment, Onizuka (1972) found that 70% of *R. ranina* that had lost an entire leg died, whereas undamaged controls suffered only 6.4% mortality over the same unspecified time period. A further laboratory experiment by Kennelly *et al.* (1990) found that 100% of *R. ranina* that had entire legs removed were dead after 8 days, and 62.5% of those that had one or more dactyli removed were dead after 50 days. The high rates of injury reported by Kennelly *et al.* (1990), and the high mortality of injured crabs in both studies, suggested that the majority of undersized crabs returned to the sea were likely to die within a few days. However, crabs which have survived the loss of one or more appendages do occur in commercial catches, and crabbers argue that results in the laboratory may not accurately reflect what happens in the natural habitat. Therefore, the present experiments were conducted in the ocean under conditions as close as practicable to natural conditions. Although Kennelly *et al*. (1990) did conduct a

10.1071/MF97110 1323-1650/98/010041$05.00

field experiment to validate their laboratory experiment, they did not provide details of what damage their experimental animals received, and their field experiment was terminated after 24 h when their cages lifted from the sand substratum and were lost.

In addition to the direct effects of stress or injury, post-discard mortality may also occur as the result of increased exposure to predation (Hill and Wassenberg 1990; Juanes and Smith 1995). *Ranina ranina* normally spends over 95% of the time buried in the substratum (Skinner and Hill 1987), which would presumably reduce its vulnerability to predators in the water column. Recently discarded crabs are subject to predation by loggerhead turtles (*Caretta caretta*) before they bury themselves in the substratum (Kirkwood and Brown, unpublished) and may also be vulnerable to other predators. As limb damage may reduce the ability of these crabs to bury themselves, it may expose them to a greater risk of predation. Therefore, a second experiment was performed to determine whether limb damage had any effect on the time it took discarded crabs to bury themselves.

Materials and methods

Discard mortality experiment

Five experimental cages were installed at 27˚01.6′S,153˚26.1′E, just off the north coast of Moreton Island, Queensland (Fig. 1). The depth varied from 7 to 8 m depending on tidal height. This site was selected because it had clean oceanic water, a suitable sand substratum for *R. ranina* (which naturally occurs there) and low current speeds, and it was sheltered from prevailing winds. Cages were constructed from galvanized steel mesh (mesh size 50 × 50 mm, 5 mm diameter wire) supported by a galvanized steel frame. This mesh size was small enough to retain all crabs with a rostral CL of >70 mm, and the wire diameter was sufficient to prevent entanglement of the dactyli. Each cage measured 2.4 × 2.4 × 0.7 m, had a hinged lid of 2.4 × 2.4 m, and weighed 150 kg. Cages were placed about 5 m apart and partially buried to a depth of 0.3 m by using a Venturi sand sucker operated by SCUBA diver and powered from the surface by a fire pump. This enabled crabs to bury completely without having to come into contact with the cage. The large size and weight of the cages ensured that they were not washed away. Cages were left in place for eight days prior to commencement of the experiment to allow the substratum to stabilize. The study site was marked by a yellow buoy, 2 m in diameter with a 3-m high tower topped by a yellow flashing light to reduce the likelihood of interference from vessels trawling or anchoring in the vicinity.

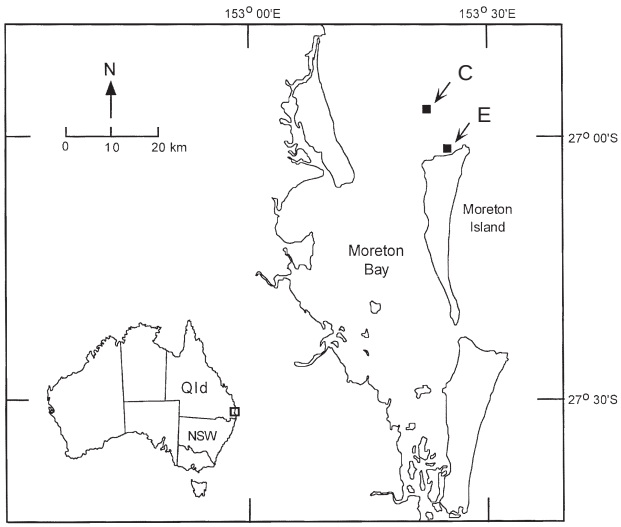

Fig. 1. Map showing (C) the site for collection of crabs and (E) the experimental site for release of crabs.

Crabs were collected by standard commercial fishing techniques on 9 April 1996 (Day 0) from depths of 20–30 m in the vicinity of 26˚57′S, 153˚23′E. Each crab was carefully disentangled from the net and inspected to ensure that it was undamaged. Crabs of 70–100 mm CL were retained for use. Crabs smaller than 70 mm CL are rarely collected on tangle nets and crabs larger than 100 mm CL are retained by crabbers so were not relevant to this study. Crabs were separated on the basis of sex, and collection was continued until at least 50 crabs of each sex had been collected.

Crabs were transported to the study site 10 km away in perforated plastic boxes shaded by wet hessian bags and sprinkled with fresh seawater. These crabs were kept out of water for 1 to 2 h, depending upon when they were collected. Previous experience (Kirkwood, unpublished) showed that *R. ranina* that had been exposed to air for periods of up to 8 h survived in the laboratory for >90 days with no apparent adverse effect.

One hundred crabs were randomly assigned to one of five treatment groups (10 males and 10 females per treatment). The experimental treatments were no damage (0); one dactylus removed (D1), three dactyli removed (D3), one walking leg removed (L1) and one cheliped removed (C1). Each crab was numbered and coded with both a non-toxic permanent marker (‘Markal Paintstik’) and a label glued to its carapace. Four crabs (2 males and 2 females) were randomly selected from each of the five treatment groups to be placed in each experimental cage. Thus, each cage contained a total of 20 crabs, with all five treatments being equally represented in each cage. The initial density of crabs in each experimental cage was 3.47 crabs m^{-2}. Immediately prior to release into the cages, treatment crabs were damaged according to their randomly assigned code by removal of dactyli or whole appendages in a manner that mimicked the damage inflicted by methods *(ii)* or *(iii)* above. Crabs were then taken to the sea floor in a perforated plastic box and placed in cages by SCUBA divers.

Cages were initially inspected daily by SCUBA divers, but inspection intervals were gradually increased as the rate of mortality declined through the experiment. Each inspection involved a visual scan of the sand surface, after which two divers raked through the sand with their arms for 15–20 min per cage. All dead crabs were removed and their identities and dates of death recorded. The experiment was forcibly terminated on the night of 1 May 1996 (Day 22), when a trawler apparently collided with the marker buoy and dragged a trawl net through the experimental area. Cage 4 was lost, and both cage 5 and the buoy sustained damage and had sections of trawl net attached to them. Cages 1, 2, 3 and 5 were retrieved on 10 May 1996. Percentage mortality data at 21 days were analysed by a randomized complete-block-design analysis of variance (ANOVA), with cages being the blocks.

Burial time experiment

Experimental animals for this experiment were collected on 3 July 1996 from the same area and by the same procedures as for the previous experiment. Crabs of 70–100 mm CL were retained for use and were transported to a study site 600 m west of the previous experiment at 27˚01.5′S, 153˚25.8′E. The depth was 8 m.

Five crabs of the same sex were selected at a time, and each crab was randomly assigned to one of the five experimental treatments used in the previous experiment. Immediately after treatment, crabs were individually returned to the water, and their behaviour was observed by a SCUBA diver. The order of return to the water was pre-determined as follows:- male 0, male D1, male D3, male L1, male C1, female 0, female D1, female D3, female L1, female C1; this ensured that the diver knew to which treatment

group each crab belonged. This cycle was repeated four times, so that a total of 40 crabs were used (4 of each sex in each treatment). Release occurred on an ebb tide, between the hours of 1230 and 1500 on 3 July 1996.

During observation, the diver remained motionless on the sea floor at a distance of at least 5 m from the experimental animal. This distance was selected because previous experience (Kirkwood, unpublished) had demonstrated that stationary divers at a distance of >2 m had no observable effect on the behaviour of *R. ranina*. The exact time when each crab was released (t_1) was recorded on board the vessel, and (when possible) by the diver. The diver also recorded the time at which the crab first reached the sea floor (t_2), and the time when it had completely buried itself (t_3). Sinking time was calculated by subtracting t_1 from t_2, and burial time was calculated by subtracting t_2 from t_3. Burial time usually included a period when a crab remained motionless on the sea floor. Data were $\log_{10}$ transformed to reduce a strong positive skew, prior to ANOVA.

Results

Discard mortality experiment

There was no significant interaction between sex and treatment and no significant difference between the mortalities of each sex, but there was a highly significant difference between the mortalities experienced by spanner crabs subject to different treatments (Table 1*a*). Post-hoc comparison (Fisher's LSD) revealed that mortality was significantly higher amongst crabs in C1 than crabs in all other treatment groups (Table 1*b*). Crabs in L1 had significantly higher mortality than those in D1, D3 or 0, but there were no significant differences among these last three groups.

Most of the mortality observed in this experiment occurred within the first few days, and no mortality occurred in any of the five cages from Day 13 until the experiment was terminated on Day 21 (Fig. 2). There were no further mortalities in the four cages retrieved on 10 May 1996, 31 days after the experiment commenced.

Table 1. ***(a)*** **Randomized complete-blocks ANOVA on the effects of treatment and sex on the mortality of spanner crabs 21 days after release:** ***(b) post hoc*** **comparison (Fisher's protected LSD) of mean mortalities under different treatments 21 days after release**

Treatments grouped by the same letter were not significantly different at $P = 0.05$

(a)

Source	df	SS	MS	*F*	*P*
Blocks (Cages)	4	4200	1050.00	1.465	0.2331
Treatment	4	45700	11425.00	15.942	< 0.0001
Sex	1	50	50.00	0.070	0.7932
Treatment × Sex	4	700	175.00	0.244	0.9113
Error	36	25800	716.67		

(b)

Treatment	Mortality (%)		Group
	Mean	s.e.	
Control	5.00	5.00	a
1 Dactylus	20.00	8.16	a
3 Dactyli	25.00	8.33	a
1 Pereiopod	55.00	11.67	b
1 Cheliped	90.00	6.67	c

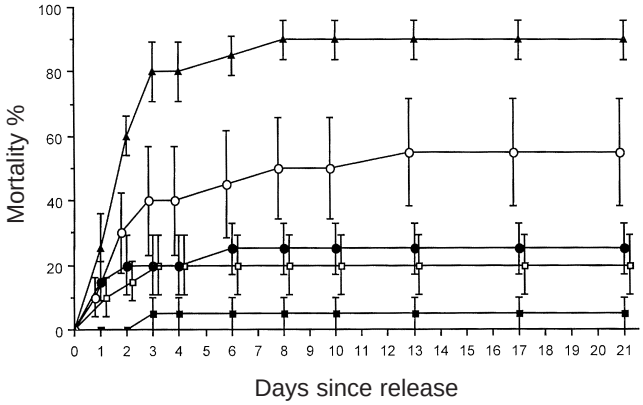

Fig. 2. Percentage mortality (mean ± s.e.) of *Ranina ranina* over 21 days following application of five different treatments: (■) control, (□) 1 dactylus removed, (●) 3 dactyli removed, (○) 1 pereiopod removed, and (▲) 1 cheliped removed.

Burial time experiment

Crabs took an average of 31.2 s to reach the sea floor, giving a mean sinking rate of 0.26 m s^{-1} (s.d. 0.03 m s^{-1}). Limb damage had no significant effect on the time it took crabs to bury themselves once they had reached the substratum (F = 0.306, df = 4,35, P = 0.983). Most crabs landed on the sea floor on their backs, and all but one of them remained motionless for a period ranging between 4 s and 20 min. The one exception (a female in L1) commenced burying as soon as it reached the sea floor, and was buried within 6 s. After a period of inactivity, each of the remaining 39 crabs became active and either immediately buried themselves (31 crabs) or swam for between 0.5 and 4 m before burying themselves (8 crabs). Overall time from reaching the sea floor to burial for these 39 crabs ranged from 10 s to 20 min. 65% of crabs had buried themselves within 68 s, but the remaining 35% took between 2 and 20 min.

Further observation of released crabs showed that resumption of activity by inert crabs could be triggered by a diver approaching to within 1 m, and all crabs touched by a diver responded by immediately becoming active and burying.

Discussion

It is clear that limb damage leads to increased mortality in discarded undersized *R. ranina*, but it is difficult to determine the extent to which this damage frustrates the aims of minimum size legislation. This is because it is not possible to reliably assess the overall extent of limb damage

inflicted on discarded *R. ranina*. Although Kennelly *et al.* (1990) estimated the amount of damage inflicted by different methods of removal, estimation of how often each method is employed by commercial crabbers is problematic because it is likely that crabbers modify their behaviour in the presence of an observer. Whenever an observer was on board a crabbing vessel, all crabbers removed undersized crabs either by careful disentanglement or by breaking one or a few dactyli, whereas anecdotal evidence suggests that many crabbers employ more damaging methods to remove crabs from their nets. However, it is certain that many crabs are returned to the sea with appendages damaged or removed. Even with very careful disentanglement, some loss of appendages occurs. The present work suggests that over half of the crabs returned to the sea after suffering the loss of an entire appendage are likely to die within a few days.

Similar results were reported by Onizuka (1972) and Kennelly *et al.* (1990), although direct comparisons are limited by differences in experimental treatments. There was no significant difference in the mortality of undamaged crabs in the three studies ($\chi^2 = 0.55$, df = 2, $P > 0.5$), but the mortality of crabs that had sustained similar damage was lower in both the present field experiment and Onizuka's (1972) study than in the laboratory experiment of Kennelly *et al*. (1990) (Table 2). The higher mortalities observed by Kennelly *et al*. (1990) may have been caused by conditions in the laboratory, including the potential effects of intraspecific aggression; the initial density of crabs in that experiment was 30.30 individuals m^{-2}, compared with 3.47 crabs m^{-2} in the present study. Injury to decapods is known to increase their vulnerability to attack from conspecifics (Juanes and Smith 1995). *R. ranina* maintained under crowded conditions (12–16 individuals m^{-2}) frequently displayed intraspecific aggression to such an extent that injured conspecifics were attacked, further damaged and eventually killed (Kirkwood, unpublished).

Two methods have been employed in attempts to reduce the level of injury to discards: *(1)* informing commercial crabbers of the effects of limb damage on post-discard survival, and *(2)* employing alternative, less damaging, crabbing methods. The first method has met with some success, but many crabbers still use more damaging methods of removal, and the extent of these activities is difficult to monitor. Several alternative methods of fishing for *R. ranina* have been tested by Sumpton *et al.* (1993) and by the present authors (unpublished), but these have proven ineffective in comparison with present methods.

A third option would be to remove the current minimum size limitation. At present, total fishing mortality is the sum of the number of crabs taken to fill the annual Total Approved Catch (TAC, in tonnes) and the unknown number of crabs that die after being discarded. If all crabs that are caught are retained, then fishing mortality would be limited by the prevailing catch quota. In this case, the total number of crabs required to fill the TAC would exceed the number required under the current minimum size limitation (Table 3). For the legal minimum size legislation to reduce the number of crabs killed by fishing, the number of crabs retained for market (R) and the proportion (y) of discarded crabs (D) which subsequently die must be less than the estimated catch if all crabs were retained (C); i.e.

$$R + yD < C. \quad (1)$$

For the 1996 TAC of 2670 t for the State of Queensland, $C = 7\,034\,035$. Substituting data calculated in Table 3 into Eqn 1, $5\,627\,177 + y3\,854\,965 < 7\,034\,035$. Hence, $y < 0.365$.

Hence, if >36.5% of discarded crabs die as a result of fishing, the current minimum size legislation actually acts to increase fishing mortality.

While buried, *R. ranina* can stop its heart for periods of up to 20 min, relying on its *cor frontale* to circulate haemolymph to its brain, eyestalks and antennae (N. Gribble, personal communication). While conserving energy, this behaviour would also render *R. ranina* less

Table 2. Comparison of mortalities (mean %, numbers of individuals in parentheses) of damaged *Ranina ranina* recorded in three studies

Damage	Onizuka (1972)	Kennelly *et al.* (1990)	Present study
Nil	6.4 (94)	12.5 (16)	5 (20)
1 Dactylus	7.7 (13)	62.5 (16)	20 (20)
3 Dactyli	–	–	25 (20)
4 Dactyli	9.3 (54)	62.5 (16)	–
8 Dactyli	20.0 (15)	–	–
1 Pereiopod	70.0 (10)	–	55 (20)
2 Pereiopods	–	100.0 (16)	–
1 Cheliped	–	–	90 (20)

Table 3. Comparison of estimated numbers of *Ranina ranina* caught in the State of Queensland under the minimum size limitation of 100 mm CL with estimated numbers that would have been caught if that limitation had not existed

Mean weights and percent discards based on unpublished length–frequency data and length–weight relationships (Brown 1986)

	Current size restriction	No size restriction
Mean wt of retained crabs (g)	474.48	379.58
Total Approved Catch (t)	2670	2670
Crabs needed to make up TAC	5 627 177	7 034 035
Discarded (%)	40.66	0
Discarded (no. individuals)	3 854 965	0

easily detectable to predators such as rays and hammerhead sharks which detect the electrical impulses of buried prey (Kalmijn 1971, 1978). Thus, this dormant state may be a mechanism for predator avoidance.

On the basis of the work of Kennelly *et al.* (1990), Juanes and Smith (1995) report that *R. ranina* is the only decapod crustacean known which does not undergo autotomy in response to predator attack. However, recently moulted soft-shelled *R. ranina* crabs undergo autotomy when attacked by conspecifics or handled by people (Kirkwood, unpublished). This is presumed to be a mechanism for predator avoidance (Robinson *et al.* 1970), but it has several adverse consequences in the longer term, such as reductions in growth rate, competitive ability, foraging efficiency and mating success, and an increase in vulnerability to attack (Juanes and Smith 1995). As *R. ranina* can apparently reduce detection by predators through entering a dormant state, the selection pressure for it to undergo autotomy may be exceeded by the selection pressures of those adverse effects. This situation may be reversed when crabs are particularly vulnerable to attack after moulting. An alternative explanation offered by Kennelly *et al.* (1990) is that the lack of autotomy in *R. ranina* may reduce the risk of losing an appendage during the stresses of digging through the sand.

Virtually all crabs released as part of the present study of burial time remained immobile upon reaching the substratum for periods ranging from a few seconds to 20 min. This immobility may be due to their stopping their heartbeat as a predator avoidance mechanism triggered by the stress of capture and handling. The fact that there was no relationship between this behaviour and the degree of damage suffered by the crabs suggests that it was not due to stress caused by injury. Thus, any discarded crab is likely to be subject to an increased risk of predation, but the level of this increased exposure is usually slight.

Acknowledgments

We thank Brett Davidson, skipper of the RV *Warrego*, for his assistance with the field experiments. We also thank Adam Butcher, Darren Cameron, Ian Halliday, Simon Hoyle, Stuart Jackson, Kath Kelly, Jason McGilvray, Michael O'Neill, Brian Pascoe, Claire Peterken, Petra Ringeltaube, John Sutherland and particularly Matthew Seese for their assistance with diving operations. We are grateful to Warren Delaney of the Queensland Museum for loan of the pump and Venturi sand sucker, and to the Queensland Department of Transport, Harbours and Marine Division, for provision of the Special Mark buoy. This research was funded by the Fisheries Research and Development Corporation (Grant 95/022).

References

Brown, I. W. (1986). Population biology of the spanner crab (*Ranina ranina*) in south-east Queensland. Unpublished report, Queensland Department of Primary Industries, Brisbane. 106 pp.

Hill, B. J. (1990). Minimum legal sizes and their use in management of Australian fisheries. In 'Legal Sizes and their Use in Fisheries Management'. (Ed. D. A. Hancock.) Bureau of Rural Resources Proceedings No. 13. pp. 9–18. (Australian Government Publishing Service: Canberra.)

Hill, B. J., and Wassenberg, T. J. (1990). Fate of discards from prawn trawlers in Torres Strait. *Australian Journal of Marine and Freshwater Research* **41**, 53–64.

Juanes, F., and Smith, L. D. (1995). The ecological consequences of limb damage and loss in decapod crustaceans: a review and prospectus. *Journal of Experimental Marine Biology and Ecology* **193**, 197–223.

Kalmijn, A. J. (1971). The electric sense of sharks and rays. *Journal of Experimental Biology* **55**, 371–84.

Kalmijn, A. J. (1978). Electric and magnetic sensory world of sharks, skates and rays. In 'Sensory Biology of Sharks Skates and Rays'. (Eds E. S. Hodgson and R. F. Mathewson.) pp. 507–28. (US Department of the Navy, Office of Naval Research: Arlington.)

Kennelly, S. J., Watkins, D., and Craig, J. R. (1990). Mortality of discarded spanner crabs *Ranina ranina* (Linnaeus) in a tangle-net fishery – laboratory and field experiments. *Journal of Experimental Marine Biology and Ecology* **140**, 39–48.

Onizuka, E. W. (1972). Management and development investigations of the kona crab, *Ranina ranina* (Linnaeus) Final Report. (Division of Fish and Game, Department of Land and Natural Resources: Honolulu.) 28 pp.

Robinson, M. H., Abele, A. G., and Robinson, B. (1970). Attack autotomy: a defence against predators. *Science* **169**, 300–1.

Skinner, D. G., and Hill, B. J. (1986). Catch rate and emergence of male and female spanner crabs (*Ranina ranina*) in Australia. *Marine Biology* **91**, 461–5.

Skinner, D. G., and Hill, B. J. (1987). Feeding and reproductive behaviour and their effect on catchability of the spanner crab *Ranina ranina. Marine Biology* **93**, 211–18.

Sumpton, W. D., Brown, I. W., and Kennelly, S. J. (1993). Fishing gears that minimise damage incurred by discarded spanner crabs (*Ranina ranina*): laboratory and field experiments. *Fisheries Research* **22**, 11–27.

Manuscript received 27 June 1997; revised and accepted 5 December 1997