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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.

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 disentanglement 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 at least

60 min. In New South Wales, individual fishermen are permitted to use 20 or 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 seized 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 $64 \times 41 \times 39$ 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 $122 \times 61 \times 61$-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 $\times$ 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 five 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 $22.5 \pm 2.5\,^{\circ}C$ 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 debris 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-tags 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 described 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.

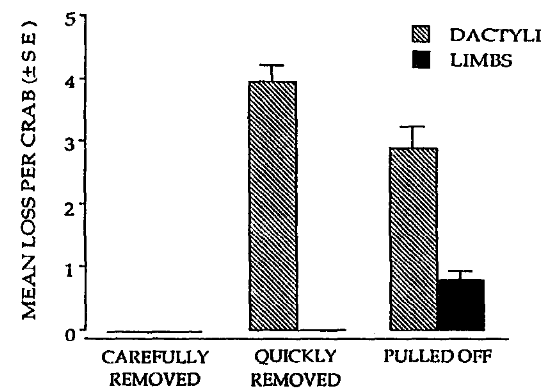

Fig. 1. Loss of dactyli and whole limbs of *R. ranina* due to removal from commercial tangle-traps using three methods of disentanglement (n = 20 for each method).

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 statistically 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.,

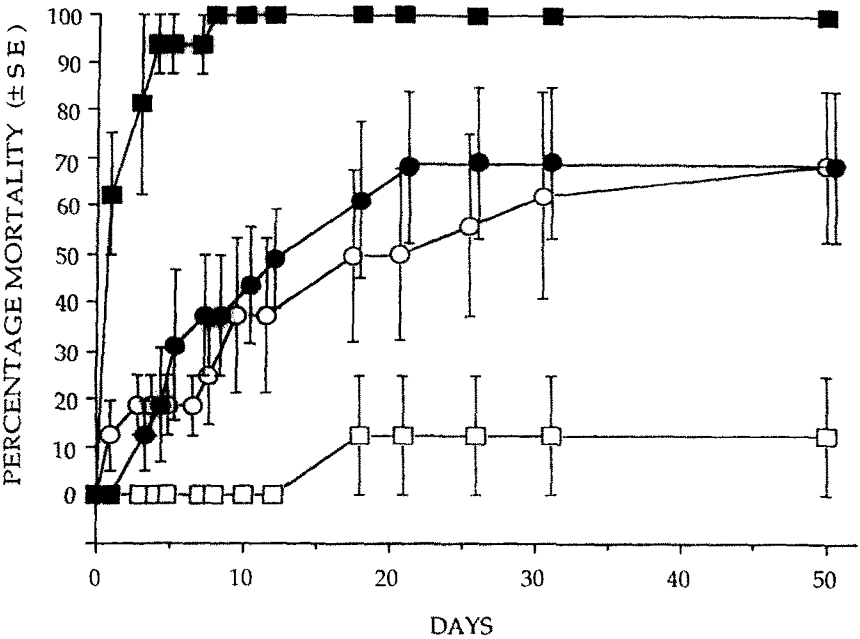

Fig. 2. Mortality of *R. ranina* in aquaria due to various levels of limb damage (n = 16 for each treatment). Treatments are: crabs with two limbs removed (■), four dactyli removed (●), one dactylus removed (○), undamaged crabs (□).

greater mortality for crabs with two limbs removed than that for crabs with one or 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 ($F = 9.21$, $P < 0.01$).

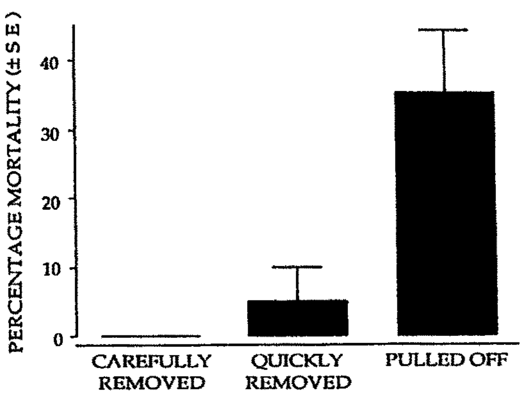

Fig. 3. Mortality during a 24-h period of *R. ranina* in field enclosures following removal from tangle-traps using three methods of disentanglement (n = 20 for each treatment).

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.; Kennelly & 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 lost 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 $\approx 60\%$ 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.

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