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EXECUTIVE SUMMARY

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We present incidental mortality estimates for paua harvesting in PAU 7 (Marlborough). Mortality of undersize paua during removal from the reef and their subsequent return was estimated in two experiments and by examining commercial paua catches. The proportional mortalities of paua from these observations were then scaled to estimate total incidental fishing mortality in the fishery. The estimates indicated that incidental mortality from these sources was very low (about 3 paua per 1000 harvested).

1. INTRODUCTION

Stock assessments developed for paua have so far assumed that there is no mortality associated with capture of undersized animals. Undersized paua may die from wounds caused by removal, desiccation, or osmotic and temperature stress at the surface, or indirectly from being returned to unsuitable habitat or being lost to predators or bacterial infection. Because paua, along with other species of abalone, lack an effective clotting mechanism in their blood plasma, haemorrhaging may be fatal (George & Ferguson 1950, Hill & Welsh 1966, Pirker 1992, Taylor et al. 1994). If such incidental mortality is non-trivial, then an estimate of this loss should be incorporated into the assessments and fishing practices changed to minimise mortality (Tegner et al. 1989, Shepherd & Breen 1992).

In 2000–01, reported commercial landings for all paua fishstocks combined totalled 1146 t. As the exploitation rate in these fisheries increases, paua just smaller than the minimum legal size (MLS) are more likely to be removed from the reef, measured, and returned. This particularly applies to the case in PAU 7 where, in 2000–01, 69% of the landed catch was within 10 mm of the MLS of 125 mm (Breen et al. 2001).

2. METHODS

The assessment of incidental fishing mortality from fishing tools was done in three parts: laboratory experiments to examine long-term mortality caused by wounding, field observations to assess the proportion of paua in each of seven damage categories and four handling categories, and a field experiment to assess the short-term survival of damaged paua in the wild.

2.1 Long-term mortality

One hundred and fifty paua (76 females and 74 males) were allocated to treatments as shown in Table 1. They ranged in size from 100 to 154 mm with a mean of just under 134 mm.

The experiment was conducted in the NIWA aquarium facility at Greta Point using the following range of damage categories.

- Light foot cut (FC1) – shallow cut to the foot about 2–3 mm deep and 5 mm long.
- Deep foot cut (FC2) – deep cut to the foot about 10 mm deep and 20 mm long.
- Mantle abrasion (MA) – removal of about 150–200 mm^2 of the black epithelial tissue from the mantle edge.
- Foot abrasion (FA) – as for mantle abrasion, but in the centre of the foot.
- Mantle cut (MC) – a 5–10 mm long cut to the mantle edge.
- Shell damage (SD) –about 100 mm^2 broken off the shell edge
- Control – no damage

For each of the seven damage categories, at least 10 replicate 4 litre plastic tanks each containing two paua, were set up. Paua were fed, *ad libitum*, a diet of the large brown alga *Lessonia variegata*. The tanks were supplied with unfiltered seawater at a rate of about 3 litres per minute and were cleaned twice per week. All paua were checked daily for mortality by touching them to see whether they were clamped to the container, and were fed every 2 or 3 days. The injuries were inflicted on the paua using a diver's knife and were intended to mimic as closely as possible those likely to be seen during commercial operations using this type of tool. It should be noted that the tool generally used by divers in PAU 7 is a custom-made stainless steel knife with a rounded tip and no sharp edges. The design makes cutting the paua less likely, although abrasions and shell damage may occur. The deep and shallow cuts were made at a low angle cutting diagonally across the foot rather than vertically. Data from this experiment were used to estimate proportional mortality for each damage category.

Although aquarium experiments may underestimate mortality (there are no predators and food was unlimited), countervailing assumptions about water quality, disease, and so on may reduce survival in the laboratory compared to the field. We estimated mortality in the laboratory because our inability to find all paua released after several months at liberty would have made the cause of mortality unknowable, thereby confounding analysis.

The experiment was run for 70 days. In similar experiments in the New South Wales abalone fishery, all mortality in experiments lasting up to 42 days occurred within the first 14 days (N.L. Andrew, unpublished data).

2.2 Field observations

Direct observation of divers while fishing would cause them to modify their normal behaviour. In addition to this, the common practice in paua harvesting in PAU 7 is for the divers to discard sub-legal sized paua without bringing them back to the boat to be measured. It was, therefore, not possible to examine catches for damage without substantially altering the current harvesting methods.

Damage done to paua harvested by divers in PAU 7 was estimated by observing the landed catches from 28 diver-days in a paua factory in Blenheim. A sub-sample of a diver's landed catch (usually one bin) was examined and the number of paua in the different damage categories was recorded. Catches from a further 3 diver-days were observed in the field, giving a total of 31 diver-days.

It was assumed that the observed proportions of damaged paua landed at the shed were similar to the damage inflicted on the sub-legal paua returned to the reef. These observations were augmented by interviewing divers to get information regarding the type of tool used, the proportion of the catch retained, their diving experience, and the way the paua were handled.

The observed damage to the landed catch was scaled by the proportion of the total landed catch examined to give the proportion of damaged paua in each damage category. These proportions were then applied to the number of under-sized paua returned to the sea estimated from the results of diver interviews.

The damage categories used were the same as in the laboratory experiment (see Section 2.1), and the handling categories were as follows.

a) *Returned immediately by the diver.* The paua was removed from the reef, measured underwater, then returned immediately to the reef without being brought back to the boat for measuring.

b) *Replaced by the diver.* The paua was removed from the reef and taken back to the boat to be measured, then replaced on the reef by the diver.

c) *Thrown on to reef.* As for (b), but the undersized paua are thrown back on to reef from the boat.

d) *Thrown on to sand.* As for (c), but the undersized paua are thrown back on to sand from the boat.

2.3 Field experiment

The damage categories used in this experiment were the same as in Section 2.1. The categories used differed slightly, however, as in order to treat the paua, it was necessary to take them back to the boat. The time the paua were out of the water was kept to a minimum, generally less than 5 minutes. The handling category 'returned immediately by the diver' was not therefore tested. Because all paua which were thrown from the boat landed on their shell, they were placed on the sand on their shells and not thrown on to sand. This allowed the divers to more easily monitor their survival.

The field experiment was conducted at Palmer Head on the Wellington south coast over 2 days. Paua were collected by divers and taken to the boat where they were treated and then either returned to the reef or sand by the divers, or thrown on to reef. Ten paua were allocated to each of the seven damage categories and three handling categories. The returned paua were observed continuously by divers for the first 5 minutes, then checked again after 30 and 60 minutes. Any deaths were recorded along with whether the paua were actively attempting to right themselves, and the numbers and behaviour of any predators.

2.4 Microbiology

Two paua from the deep foot cut (FC2) treatment were checked for abnormal bacterial infections after they had died. The area around the wound was swabbed with a sterile swab and 10^{-4} and 10^{-6} dilutions were made on the deep tissue after surface sterilising. Dilutions of 10^{-4}, 10^{-6}, and 10^{-8} of the swab material were plated on marine agar.

The bacterial growth from the wound site was compared to that found from foot swabs taken from the same animal away from the wound site.

While dissecting the paua it was noticed that there was a severe brown discoloration of the apex of the gonad and gut. Histological sections were taken along with photographs, and a fungus was isolated.

2.5 Statistical methods

Exact 95% confidence intervals are given for proportions, determined from the *F*-distribution, i.e., for a proportion π, where $\pi = r/n$, and r = the observed number out of the total, n, then the 95% confidence interval is determined by:

$$\pi_{0.025} = \frac{r}{r + (n - r + 1)\,F_{0.025,2n-2r+2,2r}}$$

$$\pi_{0.975} = \frac{r+1}{r + 1 + (n - r)\,F^{-1}_{1-0.975,2r+2,2n-2r}}$$

Regression and ANOVA analyses were performed in S-Plus (MathSoft 1997) using standard methods (Cochran 1977).

3. RESULTS

3.1 Long-term mortality

The number of paua allocated to each treatment and the proportion dying within 70 days are shown in Table 1.

paua discarded annually (Table 9). Because the only paua which died in the short-term were from the deep foot cut group (FC2) and no paua in the observed commercial catch had deep foot cuts, there was no short-term mortality.

Long-term mortality estimates were calculated from the proportion of paua dying in the lab experiment and the observed proportions of paua in each of the damage categories from the field observations multiplied by the number of paua discarded annually (Table 10).

Table 10: Estimates of the long-term mortality for the PAU 7 commercial catch with their associated lower and upper 95% confidence intervals.

Damage category	Prop$^{n.}$ dead (Table 1)	Prop$^{n.}$ observed (Table 4)	N dead	Lower 95% ci	Upper 95% ci
FC1	0.05	0.001	12.6	12.0	13.2
FC2	0.40	0.000	0		
MC	0.00	0.001	0		
FA	0.05	0.166	2100.2	1997.4	2202.9
MA	0.00	0.139	0		
SD	0.00	0.011	0		
Total mortality			2113	1839	2387

The total incidental mortality and the incidental mortality rate for the commercial catch in PAU 7 are shown in Table 11.

Table 11: Estimates of the total incidental mortality for the PAU 7 commercial catch. (* - calculated as total incidental mortality / N paua landed annually * 1000).

Mortality source	N	Lower 95% ci	Upper 95% ci
Short-term mortality	0		
Long-term mortality	2 113		
Total incidental mortality	2 113	1839	2387
Death rate per 1000 paua landed *	3.04	2.6	3.4

3.5 Recreational fisheries

The total catch from recreational paua fishing in PAU 7 is estimated at between 2 and 7 t (Teirney et al. 1997, Bradford 1998). Observing these catches was again difficult for the same reasons outlined earlier but, assuming that the amount of damage caused to paua is at least the same as that in the commercial sector and that the proportion of the catch returned is the same, then an incidental mortality rate of 3 per 1000 paua landed would represent the lower limit. Seven tonnes of paua translates to about 26 000 paua giving an additional 80 paua dying incidentally.

3.6 Maori customary fisheries

Although there is an important customary use of paua by Maori, there are currently no estimates of catch available.

4. DISCUSSION

Given the injuries inflicted on the FC2 treatment paua, their relatively low mortality rate in the laboratory experiment was surprising. Although paua are regarded as having no effective clotting mechanism in their blood, it is clear that they are able to suppress blood loss, presumably by muscular contraction of the tissue surrounding the wound site. Following wound closure, a series of cellular events occurs leading to the removal of damaged tissue and the formation of new muscle tissue and vascularisation (Taylor 1993).

In addition to the loss of undersize paua, damage to legal-sized animals may also affect the worth of the harvest. Taylor et al. (1994) reported that 51% of the tissue weight of a paua (less the shell) is blood; loss of significant volumes of blood may increase the numbers of paua per landed tonne. Pirker (1992) reported that as much as 54% of paua removed from the substratum in PAU 3 may be undersized. Of these paua, he estimated up to 13% were probably damaged in some way, and up to 80% of these may have fallen victim to predation by fish or starfish following their return to the reef. Taylor et al. (1994) reported that 14% of paua removed from a reef by commercial divers were undersized and were returned to the reef, but provided no details of the method used to make this estimate or where it was made.

The lack of short-term mortality in the field experiment was also surprising in that, although there were plenty of predators present, only two paua were lost within an hour, both from the deep foot cut treatment. Although none of the paua placed on sand died within an hour, it is doubtful that they would survive the attentions of starfish and whelks before being able to move on to reef.

Our estimates of incidental mortality associated with fishing in PAU 7 may be unrealistically low, as they rely upon several assumptions that are difficult to test. Handling by the sub-sample of fishers interviewed, for example, may not be representative of the handling behaviour of fishers in PAU 7. It is also possible that handling behaviour was misreported. In interviews, fishers may not report behaviour they know to be destructive, such as returning undersized fish to sand. Anecdotal evidence suggests that this is true in this instance. The assessment of damage in sheds may also be confounded if fishers do not land paua which are badly damaged and likely to be rejected for processing. Similarly, several sources of mortality were not included in this study, the most important of which was the behaviour of 'deckies' who sort the catch as it is returned by divers. If the catch is handled poorly, for example, violent twisting of paua while separating one from another, then additional mortality may be introduced. As knowledge of these sources of mortality become better understood, they can be included in estimates of total incidental mortality.

The estimated total incidental mortality of 2113 paua in the PAU 7 fishery represents a loss of about 500 kg of paua meat, assuming a shucked paua weighs about 250g. The estimates presented in this report are probably at the lower limit of the true situation. Estimates greater than this amount will be reliant on assumptions made about the behaviour of divers and sorters/handlers on boats.

These caveats aside, the incidental mortality rate in PAU 7 appears to be very low, and there is clear evidence that education within the industry has improved the handling behaviour of divers. If the divers continue to use the recently developed purpose-built knife and return sub-legal paua to the reef as soon as possible, then there appears to be little problem with incidental mortality.

While examining the landed catches from PAU 7 in the paua factory, a catch of about 200 kg was landed from Kaikoura (PAU 3) which had been harvested using hooks, which are still widely used in that area. Of that catch, about 2.5 kg of shucked meat was rejected due to gross damage caused by the hooks and many more had shallow foot cuts, mantle damage, and shell damage. Assuming that damage to the returned paua is in the same proportion as that observed in the landed catch, then this represents an incidental mortality rate of at least 10%, which is likely to have a substantial negative effect on both the paua population and on the value of the fishery.

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