LIVE SPANNER CRABS
Alternative handling methods

By Brian Paterson, Bruce Goodrick, Paul Exley and Ross Smith[1]

Abstract

The way that Spanner crabs (*Ranina ranina*) are treated on boats may explain why commercial operators have difficulty keeping these crabs alive in storage tanks on shore. We stored crabs on boats using three different methods, in baskets (the established industry practice), in cool air and in an aerated flow-through seawater tank. The condition of the crabs was assessed by taking haemolymph samples and measuring lactic acid and ion concentrations and then by recording the mortality of crab's from different treatments during subsequent storage in land-based tanks. If dehydration occurred, it was not reflected in the haemolymph ionic composition. On landing, the crabs held in baskets (25-28°C) had high levels of lactate in the haemolymph (about 40 mmol/L). Road transport prior to tanking saw no further lactate accumulate but many crabs died subsequently. Crabs stored in cool air (20°C) accumulated less lactate and lasted a few days longer before they too began to die. The crabs previously held on the boat in seawater (27-28°C) showed unexpectedly high mortality soon afterwards.

The counter-intuitive result from submerged crabs led us to the option of using cooled seawater sprays on the crabs. In the laboratory, the cool spray (19°C) improved the crab's ability to control haemolymph pH and delayed accumulation of lactate. We recommend that if spanner crabs are stored out of water then they should be kept cool (e.g. 20°C). Use of cooled seawater sprays may further improve physiological condition but this method is yet to be studied on catching boats. While these improvements are probably necessary, none of the parameters we measured adequately predicted onshore mortality. We suggest that the problem with long-term storage may be related to the fact that the claws are not immobilised and that submerged crabs may struggle and injure each other.

Keywords: Spanner crabs; *Ranina ranina*; Handling methods; Storage methods; Haemolymph; Lactic acid; Live transport; pH; Temperatures.

INTRODUCTION

Aquatic crabs and lobsters generally asphyxiate and desiccate when stored out of water. Carbon dioxide excretion and oxygen uptake is impaired and if the animal cannot satisfy its oxygen demand then lactic acid will accumulate in the haemolymph (Vermeer 1987; deFur *et al.* 1988; Uglow *et al.* 1986, Whiteley & Taylor 1992). One way to reduce this problem is to cool the animals down and reduce their metabolic rate (Whiteley *et al.* 1990). Dehydration is another potential problem (Tyler-Jones & Taylor 1986) and Taylor *et al.* (1987) found that dehydration increased the concentration of potassium and chloride in the haemolymph of the freshwater crayfish *Austropotamobius pallipes*. However, the literature is ambivalent about whether survival is improved by keeping the product damp or spraying water on it (Hunt *et al.* 1986; McLeese 1965; Simonson & Hochberg 1986; Vermeer 1987; Witham 1971). Presumably, some species are more susceptible than others and different circumstances may influence the rate of desiccation.

The Australian fishery for spanner crabs *Ranina ranina,* is one of the largest fishery for this species in the world, with a landed catch in 1994 of about 3000 t, of which most was caught in Queensland and the rest in New South Wales. Most of the crabs are now exported live to Taiwan but the crabs are still held out of water on boats, using practice that developed when the crabs were kept "alive" for cooking and freezing on shore. Spanner crabs handled this way, sometimes with an intervening period of transport by road, often die after a couple of days storage in seawater tanks. This means that they must be exported before the typical "purging" process used on other live products and also means that the crabs cannot be held over in tanks if the price is poor.

[1] Centre for Food Technology, Queensland Department of Primary Industries, 19 Hercules Street, Hamilton, Queensland, 4007, AUSTRALIA. Phone: +61 (07) 3406-8577 Fax: +61 (07) 3406-8677 Email: patersb@dpi.qld.gov.au

In order to establish a link between handling on the boat and later mortality, we kept spanner crabs at sea under a variety of conditions, then returned them to shore and stored them for several days in a recirculating seawater tank. At the same time, we examined the effects of an intervening period of road transport between landing the catch and actually placing it in a storage tank as well as the efficacy of using cool seawater sprays. Measurements of lactate and inorganic ion concentrations in the haemolymph of the crabs were made to shed some light on the stresses they were experiencing.

METHODS AND MATERIALS

Effect of storage method on haemolymph lactic acid and ion concentration

- *On the boat*

Crabs were harvested off the coast of Bundaberg in southern Queensland in a commercial crab boat. Crabs taken from the net were distributed randomly amongst three experimental treatments. Sixty crabs were stored in each treatment. Each treatment could be accommodated in two of the plastic baskets normally used in the fishery for keeping crabs.

One treatment involved storing crabs in water and the other two treatments involved crabs stored out of water. The wet treatment (WET) used a 180 L tank which seawater entered from the vessel's deck hose. The water in the tank was aerated using a battery powered air pump and an array of air stones tied to a grid on the tank bottom. The tank had baffles to prevent surging. The two dry treatments were crabs stored in plastic baskets and covered with a damp towel (DRY) which is similar to the methods currently using in this fishery and a second treatment (DRY/COLD) where crabs were placed in insulated boxes and a polystyrene sheet placed over them along with 1 kg of frozen gel-ice.

The required number of crabs for each treatment were gathered over 19 shots (a shot involves harvesting a long line with 10 tangle nets (each 1 m^2) attached). Within each treatment the crabs were held in air for varying periods depending on the time of day that they were caught. The crabs from each net were distributed between the treatments in such a way that time spent out of water was independent of treatment.

After all crabs required for these three treatments were captured, the remaining crabs harvested were kept as surplus in baskets, covered with a wet piece of polyurethane foam and 1 kg of frozen gel ice, (the method used by this particular fisher) and returned to shore for the road transport experiment.

- *Sorting on shore*

The crabs from the storage experiment were unloaded from the boat and crabs that were not in baskets at this stage (WET and DRY/COLD) were each transferred to a pair of baskets. The crabs caught after those used in the storage experiment were then randomly distributed amongst 6 baskets (i.e. 30 crabs/basket). These crabs were destined for the road transport experiment.

At this stage, 1 mL samples of haemolymph were taken from four crabs chosen at random from each basket of crabs from the storage experiment and from two baskets of surplus crabs. Each sample was injected into a 1 mL microcentrifuge tube and a 0.4 mL sub-sample was immediately mixed into an equal volume of 0.6 mol/L perchloric acid in a second 1 mL microcentrifuge tube. Both vials (whole haemolymph and perchlorate extraction) were then frozen in dry ice and returned to the laboratory in Brisbane for further extraction and analysis.

After completing sorting and haemolymph sampling, the crabs from the storage experiment (WET, DRY and DRY/COLD) were placed in a recirculating seawater aquarium (18.9°C). At this stage these crabs had been in air for between 7 and 13 h. This aquarium was cooled to 17.7°C overnight.

Effect of road transport on haemolymph lactic acid and ion concentration

At the same time, two baskets of the randomly sorted, surplus crabs (the baskets from which crabs had haemolymph samples taken) were also placed in the aquarium. These crabs were the controls for the road experiment (CONTROL) and had been in air for between 4 and 7 h. A further two baskets of the surplus crabs were placed on the floor beside the aquarium and surrounded with cardboard. These were the blanks for the truck experiment (AIR). The remaining two baskets of crabs (ROAD/AIR) were tied onto the back tray of a four-wheel drive vehicle, covered with a tarpaulin and driven to and from the Town of 1770. This is the same road normally used when trucking crabs from the Town of 1770 to Bundaberg (124 km) and thence to Brisbane (a further 368 km south). On arriving back at the recirculating seawater aquarium, about 6 h later, haemolymph samples were taken from 8 crabs in each of the AIR and ROAD/AIR treatments. These samples were partitioned into whole haemolymph and perchlorate extracted haemolymph as before. and the remaining crabs from both of these treatments (which at this stage had been out of water for between 10.5 to 13.5 h) were then placed in the aquarium beside the CONTROLS.

Recording survival of crabs during subsequent storage

The number of dead crabs in each treatment in both experiments was counted twice on the following day (morning and afternoon) and then again twice daily for the following four days.

Effectiveness of cooled seawater sprays

Live spanner crabs were purchased from a commercial supplier (Mooloolaba Fisheries, Mooloolaba, Southern Queensland) and stored in a recirculating sea-water holding tank (temperature 19°C) at our Hamilton laboratory. The experiment began 4 days after the crabs arrived.

A group of 40 crabs (430.4±134.2 g, range 332-1088 g) were taken from the tank using a scoop net and placed in plastic tubs, 10 crabs per tub. Two tubs of crabs were placed under the spray (Spray) and two tubs (No spray) were placed floating on the top of the water, covered and held in position by the lid of the tank (temperature 19°C, and >90% humidity). The remaining crabs in the tank were used as controls. For the spray treatment, water from the holding tank was sprayed over the crabs using a submersible pump connected to a manifold fitted with garden micro-irrigation sprays. The excess flow from the pump was released back into the tank using a tap and bypass.

After 3 h, haemolymph samples were taken from 8 crabs in each treatment (No spray and Spray) and from 4 submerged crabs. This process was repeated again 12 h after the start of the experiment.

Samples of haemolymph (about 0.8 mL) were taken from the crabs using an ice-cold glass Hamilton syringe and 22 gauge hypodermic needle. A hole was carefully punched through the carapace above the pericardium to allow easy penetration of the sampling needle.

The pH of each haemolymph sample was determined anaerobically using a Radiometer G299A microcapillary electrode connected to a Radiometer BMS3 Mk2 thermostated to the experimental temperature (19°C) and calibrated using precision buffers. After measuring the pH, a 400 mL sample of the haemolymph was mixed with an equal volume of ice-cold perchloric acid (0.6 mmol/L) in a labelled vial and the precipitated haemolymph was stored in a freezer (-29°C) until completing the experiment and the extraction was continued determination of lactic acid concentration (Boehringer-Mannheim cat. 139084).

Measuring haemolymph lactate and ion concentration

The frozen partially-extracted haemolymph samples were thawed and the supernatant was removed by centrifuge and then neutralised with 3 mol/L KOH in order to remove the resulting precipitate. The extracts were frozen prior to determination of L-Lactic acid using a commercially available kit (Boehringer-Mannheim cat no: 139 084) and a UV-visible spectrophotometer at a wavelength of 340 nm. Appropriate dilutions of the raw extract, or modifications to the total reagent volume, were made to bring the sample values within the standard curve.

The concentrations of sodium (Na^+), magnesium (Mg^{2+}), potassium (K^+) and calcium (Ca^{2+}) were measured in whole haemolymph by inductively-coupled plasma mass spectrometry (ICP-MS). The coagulated sample (200 to 400 mg) was digested in 2.5 mL of nitric acid in low pressure teflon bombs, placed in a microwave oven for 40 min at 280 watts. Each digested sample was then diluted to 50 mL with distilled water and analysed by ICP-MS, with standards.

RESULTS

Haemolymph lactic acid and ion concentration at the factory

- *Storage method*

Table 1 shows the effect of different treatments on the lactic acid concentration in the haemolymph of spanner crabs.

Table 1: Effect of different treatments on the boat on mean concentrations (±SC) of lactic acid (mmol/L) and ion concentrations (mmol/kg) in the haemolymph of spanner crabs *Ranina ranina* arriving at a factory. Eight crabs sampled per treatment *ns* indicates no significant difference between treatments. In each column, means assigned different letters are significantly different

	Temp (°C)	Time in air (h)	Lactic acid	Na	Mg	Ca^{ns}	K^{ns}
WET	27-28	4-5	22.5±5.38*a*	441±8.1*a*	45±0.0*a*	16.2±1.20	12.5±1.45
DRY	25-28	7-13	39.6±14.70*b*	479±21.2*b*	43±2.0*b*	16.1±2.77	13.9±2.11
DRY/COLD	19-21	7-13	23.4±11.84*a*	461±24.4*a*	45±2.1*a*	14.6±2.27	12.1±0.90

Table 2: Effect of road transport on mean concentrations (±SD) of lactic acid (mmol/L) and ion concentrations (mmol/kg) in the haemolymph of spanner crabs *Ranina ranina* arriving at a factory. Eight crabs sampled per treatment. *ns* indicates no significant difference between treatments. In each column, means assigned different letters are significantly different

	Time in air (h)	Lactic acid^{ns}	Na	Mg	Ca^{ns}	K^{ns}
CONTROL	4-7	27.1±8.75	483±20.6*ab*	42±1.8*a*	14.2±2.65	13.4±0.85
AIR	10-13	35.1±11.41	498±46.4*a*	47±2.9*b*	17.2±2.61	12.5±0.76
ROAD/AIR	10-13	38.5±11.07	451±25.9*b*	44±2.7*ab*	15.3±2.87	12.3±1.85

The lowest concentrations were seen in the live well (WET) and when crabs were stored at low temperature (DRY/COLD). The highest concentration was seen in crabs stored in air on deck (DRY). The highest Na^+ and lowest Mg^{2+} concentrations were also seen in this treatment. Treatment on the boat had no significant effect on haemolymph Ca^{2+} and K^+ concentration.

- *Road transport*

Unexpectedly, driving crabs to the Town of 1770 and back to the factory had no significant effect on the haemolymph lactic acid concentration of spanner crabs (Table 2). However, significant differences where seen in haemolymph Na^+ and Mg^{2+} concentration. Haemolymph Na^+ concentration of crabs after the road trip (ROAD/AIR) was significantly lower than that of crabs that remain undisturbed beside the storage tank (AIR). Haemolymph Mg^{2+} concentration increased significantly during the period in crabs that were not transported (AIR), although there was no significant difference between the concentrations of the air and ROAD/AIR crabs in Table 2. This reversed the trend seen above when Mg^{2+} concentration fell in the DRY treatment on the boat.

Survival at the factory

- *Storage method*

Crabs were stored on the boat using different treatments (60 crabs/treatment) and delivered to a recirculating seawater storage tank on shore, where their mortality was followed for several days (Figure 1). Crabs from the DRY/COLD treatment on the boat showed the best results. Mortality was quite low in this treatment for the first 3 days but afterwards, mortality rate increased. About half of the crabs in the other treatments had died after 5 days of storage.

- *Road transport*

These crabs had only been in air (primarily on the boat) from 4 to 7 h when the first group was placed without delay in the storage tank (CONTROL on Figure 2). Mortality in this group was negligible during the first day but thereafter increased dramatically. Initially, mortality rate was highest in crabs that had been transported by truck for 6 h between being landed and being placed in the holding tank (ROAD/AIR). Crabs that spent this period undisturbed in air (AIR) showed a cumulative mortality profile that was not significantly different from that of the crabs that were placed in the tank without the 6 h delay.

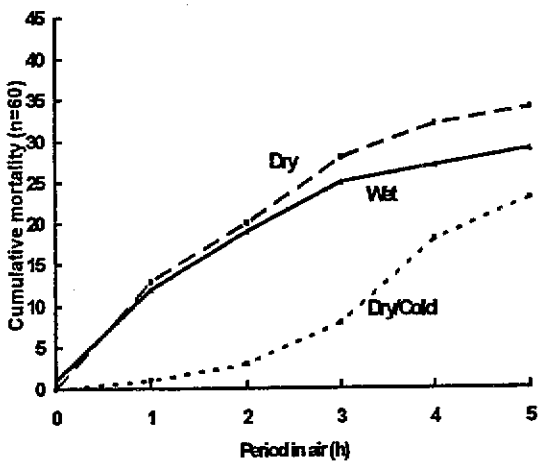

Figure 1: Effect of on-board handling method on the subsequent survival of spanner crabs in a seawater storage tank.

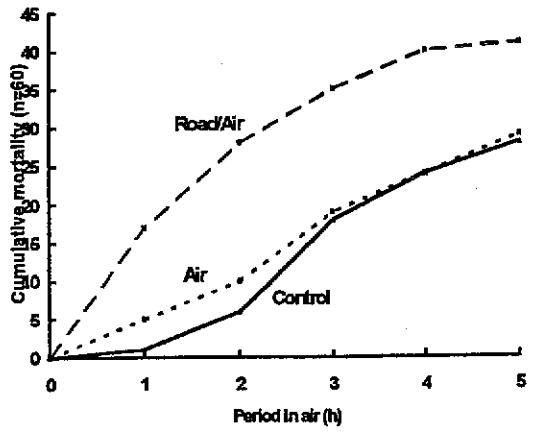

Figure 2: Effect of road transport on the subsequent survival of spanner crabs in a seawater storage tank.

Effectiveness of seawater sprays

- *Haemolymph pH*

The crabs in the No spray treatment were more acidotic (pH fell lower) than the crabs in the spray (Figure 3). Haemolymph pH of crabs resting in the aquarium at 19°C was 7.77±0.05 (mean±SD, n=8).

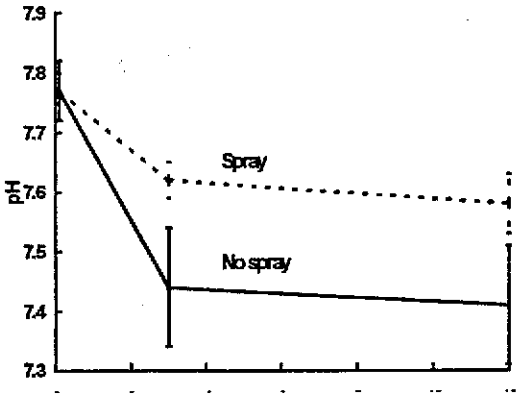

Figure 3: Effects of spraying seawater on the mean pH (±SD) in the haemolymph of spanner crabs stored out of water. Each point represents 8 crabs.

When crabs were stored in humid air or a seawater spray at that temperature the haemolymph pH fell significantly in both treatments during the first 3 h but thereafter did not change significantly (Figure 3). The haemolymph pH of 8 crabs stored for 3 h in the spray treatment was 7.62±0.03, significantly higher than 8 crabs in the air treatment, 7.44±0.10.

- *Haemolymph lactic acid concentration*

Lactic acid accumulated more rapidly in the No spray treatment, particularly in the first 3 h of the experiment (Figure 3). The concentration of lactic acid in the haemolymph of submerged crabs was 0.08±0.03 mmol/L, rising rapidly to 2.84±1.36 mmol/L after 3 h. Lactic acid accumulated more slowly in the sprayed crabs (0.48±0.20 mmol/L after 3 h) but because the data shows heterogeneity of variances it is necessary to transform the raw data using log transformation and the log means were then compared using an LSD (t) pairwise comparison (Table 3). This showed that the rise in lactate concentration in the haemolymph was significantly slower in the sprayed crabs, though it was apparently only delayed since lactate concentration rose later in the experiment.

DISCUSSION

You would expect that storing the crabs in water would be considerably better than any kind of storage out of water. This proved not to be the case. The best survival in this experiment was found when crabs were stored in cold air rather than stored in a tank of continually refreshed sea-water. However, before we go looking for spanner crabs on beaches it is worthwhile acknowledging that crowding unrestrained crabs in a "live well" is probably not a good idea.

Storage on boats

The crabs struggle actively when lifted from the water and continue to scramble about for a short period when placed in the baskets (which accomodate about 30 kg of crabs). After this, the crabs become relatively quiescent. Judging by the lactic acid levels in the haemolymph that immobility is not surprising.

When haemolymph samples were taken from the crabs on arrival at the factory and analysed, they had very high concentrations of lactic acid in the haemolymph. Anything done to the crabs after that had a relatively small impact on the amount of lactic acid in the haemolymph. The lowest values on "arrival" (about 20 mmol/L), were seen in crabs sampled from the WET and DRY/COLD treatments. Much of this lactate may have accumulated in the "cold" crabs while they were being weighed and sorted into baskets, loaded onto a truck and driven next door at ambient temperature. Similarly, the WET tank was drained to reduce weight prior to the vessel returning to shore.

The lactate concentration was higher in the crabs that remained in the baskets at ambient temperature. These are extraordinarily high values, and evidence that there is probably something seriously wrong with the way that this crab is routinely handled. European and Norway lobsters *Homarus gammarus* and *Nephrops norvegicus* only accumulate about 8 to 10 mmol/L of lactic acid in their haemolymph during post-harvest handling (Spicer *et al.* 1990; Whiteley & Taylor 1992).

Table 3. Comparison of mean lactate concentration (mmol/L) in the blood of crabs in the spray and no spray treatments after log transformation. Log means sharing the same letter are not significantly different at 1%

	Submerged	Treatment			
		Spray		No spray	
		3 h	12 h	3 h	12 h
Log means	-1.164*a*	-0.3649*b*	0.4594*c*	0.3907*c*	0.6585*c*
Back transformed means	0.076	0.432	2.880	2.459	4.555

To some extent, the extraordinarily high lactic acid concentrations in spanner crabs may reflect a complete failure in respiratory gas exchange during long periods out of water. Lowery and Tate (1986) associated levels of lactate at around 40 mmol/L with "morbidity" when blue crabs *Callinectes sapidus* were deprived of oxygen underwater. Crabs that sustain moderate levels oxygen uptake in air, such as *C. sapidus* and *S. serrata* show only a small rise in lactate concentration or no change at all (deFur *et al.* 1988; Varley & Greenaway 1992).

Surprisingly, the haemolymph showed no changes in ionic concentration that were consistent with dehydration. Perhaps the ions were redistributing within the crab's body compartments rather than concentrating in the haemolymph. The concentrations of some ions changed as a function of the time they spent out of water and significant differences were demonstrated between handling treatments. Transporting the crabs by truck reduced the sodium concentration relative to crabs left undisturbed in air for the same period (Table 2). There was also an non-significant decrease in the haemolymph sodium concentration of dehydrated crayfish *A. pallipes*, apparently as this ion entered the muscles (Taylor *et al.* 1987).

Rising calcium concentration often, but not always, accompanies acidosis in crustacean haemolymph (Taylor & Innes 1988; Varley & Greenaway 1992). However, haemolymph calcium concentration was similar in all treatments. Either it does not change or it has already risen and plateaud very soon after capture.

Road transport

In this study, the factory was located near the dock and it was only necessary to load the crabs onto a truck and drive next door. However, spanner crabs are sometimes driven long distances after landing, a practise which lengthens the delay before they are submerged.

We have not attempted to simulate an actual truck loaded with crabs, but rather we wished to demonstrate that transporting crabs by road was capable of killing them. We admit that the stress experienced by these crabs went beyond that you would expect from crabs carried over the same road in a heavily laden truck. The stress experienced by commercial shipments of crabs would presumably lie somewhere within the range of mortality described here. The objective of improving the survival of the crabs would be to bring the mortality closer to that expected if you just held the crabs in air for the same period.

The crabs were still alive when placed in the holding tank in Bundaberg. This emphasises the extraordinary ability of this crab to take punishment of this magnitude without giving any warning signs to the people handling them. However, the crabs became very weak and lethargic soon after they were submerged and the mortality rate the next day speaks for itself. We suspect that the crabs asphyxiated when returned to the water as a similar phenomenon has been reported from work on mud crabs (Varley & Greenaway 1992).

Contrary to our expectations, even a "worst case" attempt at road transport like that conducted here did not cause a significant increase in the haemolymph lactic acid concentration in spanner crabs above that you would expect from leaving them in air for the same time. Disturbance increases the haemolymph lactic acid concentration of *H. gammarus*, apparently by increasing locomotor activity and metabolic rate (Taylor & Whiteley 1989; Whiteley *et al.* 1990) however, disturbance may not increase the activity and the haemolymph lactic acid concentration of a crab that has already fatigued (Burke 1979).

- *Mortality during storage on shore*

Spanner crabs are usually packed for export about 12 h after arriving at the factory. They accumulate such high levels of lactic acid in their haemolymph during routine post-harvest handling that it will probably take them several hours to recover (Bridges & Brand 1980) and this time may not be much less than the "recovery" period that the crabs currently receive before they are exported (Paterson *et al.* in prep.).

The crabs need to be exported promptly because a large proportion tend to die if they are left in storage tanks for several days to "purge." As shown in this study, regardless of the method used to store spanner crabs on the boat, a large percentage of the catch still succumbs within 5 days of capture. All that keeping the crabs cold on the boat did was to delay the onset of mortality by 3 days.

The high mortality in the live well treatment was unexpected. It suggests that low temperature per se rather than submersion in water has a beneficial effect on the crabs. Certainly, the lactic acid content of the haemolymph was not a good indicator of subsequent survival results. Aquatic crustaceans survive better out of water anyway if they are cooled down (deFur *et al.* 1988) but there may be a further benefit here from reducing activity and physical injury. Spanner crabs are not "banded" or "tied" after harvest.

The crabs are not as dangerous to people as mud crabs (*Scylla serrata*) but when you try to pick a spanner crab out of a basket, you very often get that crab and several others attached! This cannot be good. When the crabs are crowded, they will injure each other regardless of whether or not they are underwater. Perhaps with spanner crabs, the cooled crabs were less

active in storage and less likely to injure each other, and thus promote fewer opportunities for bacterial infections to take hold.

Effectiveness of cooled seawater sprays

Storing in spanner crabs in air at low temperature alleviates the physiological effects of emersion. The amount of lactic acid that accumulates when spanner crabs are stored in air at 19°C is similar to that seen in other commercial species (deFur & McMahon 1984; deFur *et al.* 1988; Spicer *et al.* 1990; Johnson & Uglow 1985) though as we have seen emersion at higher temperatures leads to a more dramatic accumulation of lactate.

Spraying cold seawater over spanner crabs stored in air alleviates to a certain extent the physiological symptoms of asphyxiation, particularly during the first few hours in air when the greatest change in haemolymph pH occurs. The spray allows the crabs to regulate the pH of their haemolymph at a higher level than would otherwise be possible, even to the extent of reducing the rate of lactic acid accumulation in the haemolymph. Given the clear benefit of storing spanner crabs in a spray system, it is interesting that Varley and Greenaway (1992) found elevated total CO_2 concentration and CO_2 tension in the haemolymph of mud crabs *Scylla serrata* stored in a spray system at a fish market. The crabs were apparently using their normal mechanism for buffering acidosis in the absence of contact with water.

The low lactic acid concentration in spanner crabs stored in the spray was not what we expected to happen. Small amounts of water entering the gill chamber may act as an important sink for carbon dioxide excretion during the acidosis at the beginning of emersion but it should not favour oxygen uptake, (deFur *et al.* 1983). However we have only measured haemolymph lactate concentration, we cannot say emphatically the the different lactate levels point to different rates of anaerobic metabolism in the tissues. Perhaps the crabs in the spray treatment retain the lactate in their tissues for longer, so that it passes into the haemolymph at a slower rate. Obviously, this storage technique needs to be studied in greater detail, particularly given the ambivalent reports of spraying or dampening in the literature.

If the lower haemolymph lactate level reflects differences in lactate production and removal then there are several possible factors involved. We can probably rule out extra activity raising the lactate level. If anything, casual observations indicate the the crabs under the spray were more lively. If the two groups of crabs have a similar demand for oxygen, then perhaps the wetting effect of the spray may enhance gas exchange at the gill. But this could just as reasonably retard oxygen uptake, by keeping the gill water-logged and reducing the surface area available to exploit atmospheric oxygen (deFur *et al.* 1988). If oxygen demand at the tissues is equal and the efficiency of the gill uneffected, then perhaps the haemolymph of the crabs in the spray treatment is better able to deliver oxygen to the tissues because the higher pH favours oxygen transport to the tissues (Burnett 1992).

CONCLUSIONS

Spanner crabs can build up extraordinarily high concentrations of lactic acid during routine handling and storage in air after harvest. Cooling the spanner crabs down on the boat reduces this physiological stress and improves the survival of the crabs during the first few days of storage, but the crabs still begin to die after this. Using a cooled sea-water spray appears to further alleviate the physiological stress of storing the crabs in air. However, while these handling improvements are probably necessary, other factors not related to the parameters measured in this study are still preventing the harvested crabs from being purged and stored on shore for long periods. The fact that unrestrained crabs are crowded together in tanks may provide part of the explanation.

ACKNOWLEDGEMENTS

Stephen Nottingham (CFT) provided statistical advice and support to this research. The ICP-MS determinations were conducted by Hugh MaWhinney, Paul Heilscher and Elliot McElroy at the Animal Research Institute (QDPI). Thanks also to John Short (FISHMAC, Bundaberg) and his skipper Wayne Linklater. Bruce Trewavas (Satellite Seafoods, Bundaberg) kindly provided access to his crab holding tanks. This research was supported by the Fisheries Research and Development Corporation (Project 92/71).

REFERENCES

Bridges, C.R. and Brand, A.R. 1980, 'The effect of hypoxia on oxygen consumption and blood lactate levels on some marine Crustacea', *Comp. Biochem. Physiol.* 65A:399-409.

Burke, E.M. 1979, 'Aerobic and anaerobic metabolism during activity and hypoxia in two species of intertidal crabs', *Biol. Bull.* 156:157-168.

Burnett, L.E. 1992, 'Integrated function of the respiratory pigment hemocyanin in crabs', *Am. Zoo.* 32:438- 446.

deFur, P.L. McMahon, B.R. and Booth, C.E. 1983, 'Analysis of hemolymph oxygen levels and acid-base status during emersion '*in situ*' in the red rock crab, *Cancer productus', Bio. Bull.* 165:582-590.

deFur, P.L. and McMahon, B.R. 1984, 'Physiological compensation to short-term air exposure in red rock crabs, *Cancer productus* Randall, from littoral and sublittoral habitats. II. Acid-base balance', *Physiol. Zoo.* 57:151-160.

deFur, P.L. Pease, A. Siebelink, A. and Elfers, S. 1988, 'Respiratory responses of blue crabs, Callinectes *sapidus* to emersion', *Compar. Biochem. Physiol.* 89A:97-101.

Hunt, J.H. Lyons, W.G. and Kennedy, F.S. 1986, 'Effects of exposure and confinement on spiny lobsters, *Panulirus argus*, used as attractants in the Florida trap fishery', *Fish. Bull.* 84:69-76.

Johnson, I. and Uglow, R.F. 1985, 'Some effects of aerial exposure on the respiratory physiology and blood chemistry of *Carcinus maenus* L. and *Liocarcinus Puber* L.', *J. Exper. Marine Bio. Ecol.*, 94:151-165.

Lowery, T.A. and Tate, L.G. 1986, 'Effect of hypoxia on hemolymph lactate and behaviour of the blue crab *Callinectes sapidus* Rathburn in the laboratory and field', *Comp. Biochem. Physiol.* 85A:689-692.

McLeese, D.W. 1965, 'Survival of lobsters, *Homarus americanus*, out of water', *J. Fish. Res. Bd Can.* 22:385-394.

Simonson, J.L. and Hochberg, R.J. 1986, 'Effects of air exposure and claw breaks on survival of stone crabs *Menippe mercenaria*', *Trans. Am. Fish. Soc.* 115:471-477.

Spicer, J.I., Hill, A.D., Taylor, A.C. and Strang, R.H.C. 1990, 'Effect of aerial exposure on concentrations of selected metabolites in blood of the norway lobster *Nephrops norvegicus* (Crustacea Nephropidae)', *Mar. Biol.* 105:129-135.

Taylor, E.W., Tyler-Jones, R. and Wheatly, M.G. 1987, 'The effects of aerial exposure on the distribution of body water and ions in the freshwater crayfish *Austropotamobius pallipes* (Lereboullet)', *J. Exper. Biol.* 128:307-322.

Taylor, E.W. and Innes, A.J. 1988, 'A functional analysis of the shift from gill- to lung-breathing during the evolution of land crabs (Crustacea, Decapoda)', *Biol. J. Linnean Soc.* 34:229-247.

Taylor, E.W. and Whiteley, N.M. 1989, 'Oxygen transport and acid-base balance in the hemolymph of the lobster *Homarus gammarus* during aerial exposure and resubmersion', *J. Exp. Biol.* 144:417-436.

Tyler-Jones, R. and Taylor, E.W. 1986, 'Urine flow and the role of the antennal glands in water balance during aerial exposure in the crayfish, *Austropotamobius pallipes* (Lereboullet)', *J. Comp. Physiol.* 156B:529-535.

Uglow, R.F., Hosie, D.A., Johnson, I.T. and MacMullen, P.H. 1986, 'Live handling and transport of crustacean shellfish: an investigation of mortalities', *Sea Fish Industry Authority Technical Report* 280.

Varley, D.G. and Greenaway, P. 1992, 'The effect of emersion on haemolymph acid-base balance and oxygen levels in *Scylla serrata* Forskal (Brachyura: Portunidae)', *J. Exper. Marine Biol. Ecol.* 163:1-12.

Vermeer, G.K. 1987, 'Effects of air exposure on desiccation rate, hemolymph chemistry, and escape behaviour of the spiny lobster, *Panulirus argus', Fish. Bull.* 85:45-51.

Whiteley, N.M., Al-Wassia, A.H. and Taylor, E.W. 1990, 'The effect of temperature, aerial exposure and disturbance on oxygen consumption in the lobster *Homarus gammarus* L.', *Mar. Behav. Physiol.* 17:213-222.

Whiteley, N.M. and Taylor, E.W. 1992, 'Oxygen and acid-base disturbances in the hemolymph of the lobster *Homarus gammarus* during commercial transport and storage', *J. Crust. Biol.* 12:19-30.

Witham, R. 1971, 'Live shipping of Florida's spiny lobster', *Quart. J. Florida Acad. Sci.* 33:211-220.