A Study of Mortality Rates of the Velvet Crab during Holding and Transport

January 1985 (Re-printed January 2005)

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SR259

ISBN -

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ISBN -

Seafish Technology SR259

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Summary:

A joint study between the Industrial Development Unit of the SFIA and Hull University has been made of the conditions under which velvet crabs are held after capture and through the chain from quayside to delivery in the Spanish shellfish market.

The study included laboratory work to investigate the physiological changes which occur in velvet crabs as a result of variations in their essential parameters of temperatures, oxygen supply, aerial exposure and salinity. This laboratory work simulated conditions that a batch of velvet crabs might be subjected to on a typical journey.

From the outset it must be recognised that the velvet crab is far less robust than the common brown crab or green crab. It will very quickly become stressed in conditions which these other two species and many other crustacean can be safely shipped over a long journey. There are many undesirable practices which will considerably increase the mortality rates amongst velvets on arrival at the Spanish market. These include inadequate oxygen supply to the animals at the centre of a dense stowage, inability to control temperature to the ideal of 10°C, variations in salinity of the holding water but, above all, is the severe stress which can be caused to velvets by undue aerial exposure. This generally occurs onboard the vessel, at the quayside and in transit to the exporter. Surviving crabs which have been subjected to these forms of stress are almost certainly in a weakened condition for the onward shipment to Spain.

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1. Introduction

1.1. Origin and Funding

This report describes work undertaken by the University of Hull under contract to the Sea Fish Industry Authority between August 1984 and January 1985. It has been one of a number of projects aimed at removing constraints to the overall development of the fishery for the velvet swimming crab, Necora puber. Work to date has been by SFIA, MAFF and DAFS and has covered stock assessment, ecology, biology, processing, transport and marketing.

This work was funded by MAFF under commission A.1.2. (JAA 16).

1.2. The Problem

The velvet crab has proved difficult to transport alive from the main fishing areas of the West Coast and Islands of Scotland and the South West of England to the principal market which is Spain. The price obtained for this species is critically dependent on the animals arriving not only alive but in good enough condition to withstand further holding, handling and distribution. Further to this, in a market which is rapidly becoming much more competitive it is imperative to be able to consistently deliver a high quality product. Failure to do so will result in loses in both price and future opportunities.

The situation, therefore, was that at some point or points along the chain from fishermen to final sale the velvet crabs encountered unsuitable conditions which resulted in their death or devaluation. The problem was to identify those conditions and the physiological effects they induce in velvet crabs. Once this was done it was than necessary to examine any possible remedial action within the economic and logistic constraints which govern transport to Spain.

1.3. The Approach

The project was undertaken in distinct stages; close joint supervision of the researcher by the University and SFIA ensured that little time was lost in following up inappropriate leads.

Visits were made to some of the major exporters of *N. puber* and a literature search made in order to precisely define the extent and nature of the problems and what, if anything was being done to solve them.

Specimens of *N. puber* were examined in the laboratory in order to discover certain aspects of their physiology – gill structure, metabolites/waste products, 'normal' condition etc.

A lengthy examination was then made of the current procedures involved for first transport to the exporters' premises, grading and packing, vivier transport duration and conditions and the water quality changes which occur.

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Laboratory tests then reproduced the conditions discovered, exposed *N. puber* to them and monitored the changes the conditions appeared to produce in the crabs.

An examination was also made of an alternative method of holding which, though not immediately practicable, demonstrated the sorts of standards that should be aimed for.

2. The Current Practices

2.1. The Current Extent and Variability of Mortality

Mortality of velvet crab between consignment by the exporter and arrival in Spain is highly variable. Rates vary from occasional total loss to occasional 10-15% mortality. It was once reported privately by a Spanish driver that he expected to be paid on the basis of delivering 50-60% of his velvets in acceptable condition. Figures are, however, almost impossible to obtain and are often the source of much bad feeling between UK fishermen and exporters and between the exporters and the Spanish importers.

Visits were paid to the main UK exporters of velvet crabs, their experiences were discussed and an examination made of their current transport procedures. The exporters are listed in Appendix I.

There was general agreement that should the mortality rates of *N. puber* during holding and shipment be brought down then greater efforts would be made to develop lines of supply and seek markets. Generally, fishermen do not handle velvets and many are unaware of its market potential.

From discussions and observations it was clear that exporters use a variety of handling and transportation techniques in supplying live velvets to Spain. Seldom, if ever, does a load comprise velvet crabs only so the conditions operating in the vivier lorry tend to be those which experience has shown to be suitable for other species.

It appears that mortality rates are very variable on a load to load basis. Higher rates tend to occur during the summer months and this is partly dependent on the amount of handling/storing prior to shipment. It is important to emphasise here that the final product should also be in good condition as well as being alive. Mutually satisfactory relationships between importers and exporters will depend on the consistent supply of good condition animals arriving in Spain.

2.2. Current Procedures for the Live Transport of *N. puber*

It is convenient to consider such procedures in relation to the complete marketing chain for velvet crabs as outlined in Fig. 1. Essentially the chain comprises a number of catchers (c) who catch, store and eventually ship live crabs to a major exporter. At the exporter's premises the animals may be stored for a variable length of time before being sorted, packed and loaded onto a vivier lorry which then proceeds to Spain. This system includes a number of alternative procedures at each stage, each of which will probably constitute some sort of stress to the crabs. Some stresses will be more severe than others and the result may be that the final load of animals in a vivier lorry comprises batches of animals with differing histories of handling/storage in the immediate past, and therefore, in differing condition. Unless more or less exactly the same procedures are followed on each occasion there is also the strong likelihood that the condition of the animals on a load to load basis will differ also.

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Because of their small size (compared with spider or brown crabs) and their very aggressive nature it is expedient and usual for velvet crabs to be densely packed, right-way up, in wooden orange crates with wired-down lids. Normally 9kg of animals are packed into each crate (75-100 animals) and crates are stacked in rows and tiers in vivier tanks supplied with vigorously aerated seawater, nominally at 9-10°C.

From observations made in Scotland, it seems to be common practice also for catchers to sort and pack velvets into orange crates for shipment to the exporter.

There are times when the animals have to be held for up to a week awaiting the on-shipment to or from the exporter's premises. Animals here may be held in floating or sunken cages or in holding tanks aggressive nature a week's duration under such conditions is considered maximal.

With reference to the marketing chain described in Fig. 1, the means by which the animals may reach the exporter are:-

By dry transport in crates by road/ferry

By vivier lorry

By vivier vessel

As such a journey may take many hours, choice (a) would necessitate animals being out of water during the packing/sorting process, during the whole of the journey and until dealt with at the exporter's premises. Whereas such a period of aerial exposure in humid conditions would be tolerated reasonably well by brown crabs, it is highly stressful for velvet crabs. The investigators had the opportunity to inspect such a delivery at an exporter's premises and saw the high mortality and generally poor conditions amongst the animals at reception. By contrast, consignments arising via the vivier system were in good conditions, lively and aggressive and mortalities were very low.

Exporters differ in the details of the reception of their consignments of crabs in relation to the times of shipping to Spain. Some exporters may hold animals for up to a week prior to shipment and whilst this gives the opportunity to select animals in good condition it also carries the risk that a high mortality may occur occasionally.

Shipment to the Continent is by vivier lorries usually owned by the Spanish importers. The journey time varies depending on the length of the journey within the UK. Appendix 2 shows some of the principal routes and relevant times.

Transporting conditions constitute another variable. Water filtration systems were seen on only some lorries and were of a simple type sufficient only for the removal of quite large particles. The need for filters at all is questionable given the timescale involved.

Most exporters declared that water temperature during transport was 9-10°C. However, the cooling system cooled the air used to aerate the water and were only started towards the end of packing. In the meantime water had been taken onto the lorry at the ambient sea temperature. In summer months this could reach as high as 14°C. Observations made during these investigations showed that water temperature hardly changed at all during journey time, hence that the cooling mechanism was inadequate.

Providing adequate aeration of the tanks during transit is another problem. Some methods of aerating the water may cause leaking and/or dilution by condensation if the wrong compressor is used. Some exporters have made, and continue to make, their own modifications to get around these problems. In the case of velvet crabs the problems are more acute. Brown crabs, spider crabs or lobsters are usually placed loose into tanks – they form a layer one animal deep and each animal is virtually assured of receiving adequately aerated water. Velvets, by contrast, are packed tightly into crates which may then be stacked up to 4 crates high – a very large volume of living animals per tank which will remove oxygen from the water almost as fast, or even faster, than oxygen can be supplied to it. Added to this is the obvious difficulty of ensuring that the inner core of each crate does not stagnate, become depleted of oxygen (hypoxic) and cause marked deterioration of product quality or death. It is very possible that animals dying in these situations hasten the deaths, or lower the quality of neighbouring animals creating a snowball effect.

Other aspects of procedures which may contribute to deterioration of quality centre around occasions when the animals are being sorted handled and packed. Any time spent out of water for a crustacean is a major stress as their ability to take up sufficient oxygen is impaired and there is the possibility that the animal will quickly lose body water. Temperature can govern the severity of the stress and, generally, the stress is higher at higher temperatures. Precautions to minimise periods of aerial exposure and to keep animals moist and cool whenever such exposure is inevitable would be sensible, particularly in summer months when air temperatures are high. Any reduction in the stress level at this stage will aid the animal to survive the final stresses incurred during subsequent handling/sorting/transporting procedures.

Other possible stresses mentioned; but not studied here; include those of noise and vibration during transport. Current work being carried out by Dr. Regnault in France [1]has shown that the normal background noise in a marine laboratory substantially elevated metabolic rates of shrimps, compared with animals kept in soundproofed rooms.

[1] Personal communication

3. Stress in Necora puber

The major factors which were concentrated upon in the experiments carried out in this study were the effects of impaired oxygen uptake and the modifying effect of temperature.

Observations indicated that major stresses to velvet crabs include the physical ones of handling and packing but above and beyond these is the stress of being exposed to air. However, at the sorting/packing stages the animals in obviously poor condition are removed. Experience has shown that healthy animals packed at this stage are likely to arrive in good condition. Those that don't are likely to have had considerable aerial exposure before shipping and/or periods of hypoxia during shipment.

N. puber, like any other crustacean is covered by a hard, impermeable shell and, like any other living creature, it has to exchange material between its body and its environment. In the current context the key materials exchanged are the respiratory gases – oxygen which is taken up from the water and carbon dioxide which is given up to the water. The sites for these exchanges are the gills which function most efficiently when they are covered with water. When not covered with water, or when in water less than half-saturated with oxygen, then effectively the animal has to breathe without an external source of oxygen. This is called anaerobic respiration and, when it occurs, a substance called lactate begins to accumulate in the blood. Lactate is a toxic substance which, if high concentrations persist, will ultimately kill the animal and meantime's will adversely affect its condition as a commercial product.

Furthermore, crabs are cold-blooded creatures whose metabolic rates are determined largely by external temperatures. Within limits the higher the temperature the higher the metabolic rate and the more rapidly will the animals become distressed by an inadequate oxygen supply.

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4. The Experiments of Aerial Exposure

4.1. The Effects of Aerial Exposure

Inevitably times occur when velvet crabs will be exposed to the air. Usually such times are after catching, on the journey between catcher and exporter and immediately before and after sorting and packing. Despite common-sense precautions to keep animals at such times in moist and cool conditions, any period of aerial exposure must be regarded as a stress which jeopardises the life or condition of a crab.

The laboratory studies described below were made to gain some appreciation of the magnitude of such stresses and to determine how *N. puber* compared with other, commonly marketed crab species in its responses to aerial exposure.

4.2. Mortality in Humid Conditions

The data summarised in Table 1 shows clearly that *N. puber* is much less tolerant of aerial exposure than either the brown or green crabs. Indeed, at the end of 24 hours many of the latter two species were still quite active whereas none of the surviving velvets were. This point is important because limb movement is one of the criteria used to sort live from dead animals prior to packing for shipment to final market. Although still able to move their limbs, it is doubtful if any of the surviving velvets from the above experiment would have been in good ‘condition’ at their final destination if they were packed in such a condition – most would almost certainly have died.

4.3. Blood Glucose and Lactate Levels

Periods lasting some hours when velvet crabs are out of water may not be unusual during the shipment of this species. A laboratory simulation of this on groups of crabs was carried out. The animals, 5 in each group, were bled at the start and end of a 4 hour period during which the animals were maintained at a relative humidity (r.h.) of 80% and a temperature of 16°C. The animals were bled again after some hours in fully oxygenated seawater. A control group of animals was kept in fully aerated seawater and bled at the same times as the experimental groups.

The data obtained are given in Table 2 and show that a very substantial rise in blood lactate occurred during the exposure period and that this was not fully removed during the following 6 hours in fully-oxygenated conditions. Likewise, a pronounced rise in blood glucose (hyperglycaemia) occurred during the exposure period and this also was still evident after a 6 hour recovery period. The control animals showed no substantial changes which removed the handling/bleeding procedures as causes of the observed changes in the experimental groups.

Lactate accumulation is ultimately lethal to the animals and furthermore is evidence to suggest that the species is poorly adapted to respire anaerobically; also hyperglycaemia is widely recognised as a general response to stress in crabs. Thus the two sets of data taken together give a strong indication that even a few hours of aerial exposure in moist conditions constitute a considerable stress for *N. puber*.

Noteworthy also is the persistence of the stress effects for several hours after the return of the animals to fully aerated seawater. This may have serious implications as there are probably many occasions when animals are packed, sent to exporter, sorted and repacked and then shipped – all within the space of a few hours. Presumably the stress effects of the two handling/exposure periods are cumulative in such cases.

Unpublished data on blood lactate and glucose levels following aerial exposure of the green crab, the brown crab and the velvet crab have generously been provided by Mr. I. T. Johnston at Hull University. These data are given in Tables 3a and 3b and show how little affected the green crab appears to be after 24 hours in moist conditions. On the other hand, the velvet crab shows very high levels of lactate and glucose and many animals of this species died during the exposure period – the data given all refer to two surviving animals. The brown crab held an intermediate position between the other two species.

These results give further evidence of how species differ in their response to a particular stress and reaffirm the sensitivity of velvet crabs to aerial exposure. Both of the surviving animals in the present experiment were in a very poor condition after 24 hours' exposure.

4.4. Heart and Scaphognathite[2] Activity

For reasons given earlier, the activities of the hearts and scaphognathites may provide some indication of metabolic stresses imposed upon crabs. Groups of 5 crabs were monitored for their organ rates immediately before being subjected to a 4 hour period of aerial exposure (at r.h. = 80%; temp. = 12°C). Rates were taken again some 10, 30 and 60 minutes following return of the animals to fully aerated seawater (12°C). The data obtained are shown in Figs. 2 & 3 and show that each organ increased in beat frequency (compared with original values) when the animals were <u>returned</u> to water. Although the ventilation rates had returned to approximately original values after 1 hour, heart rates were still almost double the original values after this time.

4.5. Handling/Transport Simulation

On the basis of the foregoing experiments and on a series of observations made at an exporter's premises and during shipment in a vivier lorry from Scotland to Spain, the following simulations were made:-

A group of 6 animals were bled and then given one hour of aerial exposure (r.h. = 80%; temp. = 12°C). This simulates crated animals awaiting sorting and packing at the exporter's premises.

The animals were tipped onto a bench top and handled for 3 minutes. This simulates the handling/sorting/packing procedure.

[2] The scaphognathites are those appendages which, by their beating motion, drive water over the gills. The scaphognathite rate is often called the 'ventilation rate'.

The animals were given a further 30 minutes of aerial exposure under the same conditions as (a) above. This simulates the waiting period whilst sufficient crates build up before loading onto the vivier lorry. The animals were bled again at this point.

The animals were maintained for 12 hours (12°C) in fully-aerated seawater and then a further 4 hours in hypoxic conditions (40% oxygen saturation). This simulates the conditions on the vivier lorry. The animals were bled a third time at this point.

The blood samples were assayed for glucose and lactate and the findings are given in Table 4. They show clearly that the combination of aerial exposure and handling stress is quite severe and produces an expected elevation of glucose and lactate levels. It may be expected tat the subsequent 12 hours of fully-oxygenated conditions would allow the animals to recover somewhat but, after 4 hours hypoxia, values were still substantially higher than originally, indicating the animals were stressed. If anything this simulation was much too mild as it is not to be expected that oxygen conditions are maintained fully saturated for 12 hours on the vivier lorry. Additionally, the animals would have had to contend with the stresses of noise, vibration and dense packing in a real situation.

4.6. Conditions during Transport

Velvet crabs are usually packed, in an upright position, tightly into wooden fruit crates – orange boxes, some 40 x 20 x 26cm. Each crate is packed with approximately 9kg of animals which, depending on size, corresponds to 75-100 animals.

Through the generosity of Mr. R. George it was possible to intercept crates of crabs some 24 hours into the journey from Scotland to Spain. Unpacking these crates on one occasion revealed 41 dead animals confined almost exclusively to the central 'core' of each crate. As this finding suggests the central animals may not be receiving adequate oxygen; a series of simulations of crate storage conditions was made.

4.7. Oxygenation in the Centre of Crates and in Tank Water

Figure 4 illustrates a typical set of data obtained on the oxygen saturation characteristics of the tank water and of the water in the centre of a crate full of animals. The tank volume was 60 litres at a temperature of 16°C. In this instance the water in the crate assumed very low values within 24 hours reaching the critical 50% saturation in less than 20 minutes. Even the external water in this case dropped to a stable value at around 50% saturation despite vigorous aeration. In other simulations with very vigorous aeration, values did not always drop so low or so quickly, but invariably the centre of crates rapidly dropped below the 50% saturation level.

Table 5 summarises data obtained on various water quality parameters and on the blood lactate levels of a group of crabs kept in crates for 23 hours. Although the main body of water in the tank was kept fully aerated, conditions at the centres of the crates soon become hypoxic. Also, the pH of the water dropped slightly which signified that the animals were excreting acidic products

(CO_2) to counteract the internal build-up of these acidic metabolites. This build-up is confirmed by the very large increases shown for the blood lactate levels – more than 10-fold at the end of 23 hours. Both the water nitrite and nitrate levels showed small increases during the experiment.

Information given by exporters at this stage of the studies was that the average ratio between the volumes of water in vivier tanks and their living contents was 2:1. Water temperatures were reputedly kept at 10°C. These given operating parameters were used in a simulation which provided the data given in Table 6. These dates are interesting because they illustrate that a very much decreased build-up in circulating blood lactate occurs at this temperature when compared with that At 16°C. The oxygen saturation values still followed the now familiar pattern of decline to hypoxic levels. This leads to the conclusion that the lower temperature was the main reason for the lower lactate production. As lactate is toxic to the animals the implication is clear. Temperatures of 10°C are ore conducive to survival and maintenance of condition of velvet crabs than 16°C when there is any likelihood of hypoxia occurring.

4.8. Water Conditions during Vivier Transport from Scotland to Spain

During this trip, crates of velvet crabs were packed 3 deep in the vivier tanks. An oxygen electrode was packed in the centre of one of the centre crates of a tier and, during the journey, whenever the opportunity arose, the dissolved oxygen value and water temperature data were recorded. A water sample was also taken for pH analysis.

The data obtained on these parameters is presented in Table 7. These data reveal some interesting points – not least that concerning temperature. In the vivier lorries the temperature control is by air-cooling. In this instance the seawater when loaded was at 12.7°C but some 54 hours into the journey it had only dropped to 12.2°C. This is surprising and, in view of the advantages of 10°C as a holding temperature, it has serious implications. As this trip was made in October when seawater temperatures were less and maximum it is interesting to speculate what happens in summer months. In this instance, the oxygen saturation had decreased to 50% after 54 hours and this rather good figure was due largely to the though which had gone into ensuring maximum aeration on the part of the exporter. Between samples 6 and 87 there was a complete water change in the tanks and this occurred after embarkation on the Plymouth/Santander ferry. Thus, again, the animals were subjected to warm water – usually this will probably involved water warmer than that taken onboard in Scotland and certainly warmer than that it was replacing. Interestingly, the change of water did nothing to alleviate the oxygen conditions in the centre of the crate, confirming that water exchange in this region is not very good. The pH data reflected these events with only a slight rise occurring suggesting that in these, not too hypoxic, conditions the animals were excreting ammonia.

During this trip it was not possible to monitor mortalities because of the difficulties of access to the crates.

4.9. The Effects of Hypoxia on Blood Lactate Levels

In view of the differences observed between lactate production during hypoxia at 10°C and at 16°C a controlled laboratory comparison was made. The levels to which lactate accumulated was determined for water temperatures of 10°C (the official temperature) and of 13°C (an actual transportation temperature).

The data obtained are given in Table 8. Statistically analysis revealed that the changes in lactate level which occurred at 10°C were non-significant at the 5% level. There was, however, a highly significant increase in lactate levels during the hypoxic period shown by the 13°C group. This increase was still significant after 4 hours recovery in normoxic conditions.

These findings reveal how important effective temperature control is for maintaining the animals in good condition when the risk of hypoxia is high. A matter of 3°C – which may well correspond to the temperature lag when air-cooling of viviers is in operation – may be sufficient to impair the quality of the crabs during a journey of several hours' duration.

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5. Discussion

One factor that has emerged clearly from these studies is just how difficult it is for laymen to establish the optimum conditions for holding *N. puber*.

Various species of crabs differ considerably in their tolerances to various stress-inducing factors including aerial exposure and hypoxia. The velvet crab superficially resembles the green crab in general size and in its distribution – the two commonly occur on the same fishing grounds. However, the two species are very different in their general tolerances to aerial exposure and to hypoxia. The green crab is extremely well-adapted physiologically to cope with low-oxygen conditions (and low-salinity conditions too). Any attempt to base handling/holding conditions for velvet crabs on those that the fishermen know are suitable for green crabs, is potentially dangerous as the present results show. In moist conditions at ambient air temperatures (15°C) more than 3 out of 4 velvet crabs died and the survivors were in poor condition and unsuitable for onward shipment. Under identical conditions not one green crab died and all were very lively and mobile at the end of 24 hours. It is, perhaps, ironic too that the stress of aerial exposure is also animal size-dependent. Even under very favourable conditions it is the very largest (hence commercially most valuable) animals which succumb first and our inspection of the rejected animals after packing at an exporter's premises revealed a high proportion of very large velvet crabs.

It would thus seem to be essential that all sectors should be made aware of the importance that should be attached to the effects of the combination of aerial exposure and high air temperatures – anything over 10°C. Any exposure periods should be kept to the barest minimum with no delays as crates remain in the sorting/packing areas before and after packing. The stresses imposed on the animals at such times effectively reduce their tolerances to further stresses which may be imposed during subsequent stages of their shipment.

In view of the large numbers of velvet crabs which are shipped at any one time, their generally high metabolic rate compared with brown or spider crabs, and the fact that this rate is raised still further by the stresses of handling and packing, adequate aeration of the seawater during shipment is vital. It is seldom appreciated just how little oxygen occurs in seawater. Figure 5 illustrates the values diagrammatically and shows that the amount of oxygen dissolved in fully saturated water is dependent upon the salinity of the water and the temperature, with seawater (30-34‰,s) carrying very much less than fresh water. The vivier lorry we accompanied had seawater of 31.5‰,s at a temperature of 12.5°C. Fully saturated this water would contain oxygen at 6.1ml/litre.

Neither is it fully appreciated how quickly a large number of crabs can use the oxygen in the water. From studies on other species of crabs (e.g. Cumberlidge and Uglow, 1977) it can be estimated that an average to large sized *N. puber* would pump approximately 1 litre of water over its gills per minute. The average crate might contain something in the order of 80 crabs so 80 litres of water would be pumped each minute. The volume of an orange crate is approximately 20 litres so, assuming a water volume:crate volume of 2:1, 40 litres of water would be carried on the vivier lorry for each crate. Hence each litre of water could be pumped through gill chambers twice each minute. A conservative estimate of extraction efficiency of oxygen by the crabs would be in the order of 20% and, unless this is replaced by the aeration system then the system will rapidly become hypoxic and stabilize, as seen in these experiments, at somewhere around 50% saturation or less.

The results show also that the animals in the centre of each crate have to endure severely hypoxic conditions on occasions. When crates full of animals are stacked one on top of another and in adjacent tiers it effectively reduces the sites of entry of aerated water to relatively small areas. In view of the abovementioned respiratory activity of crabs at the periphery of the crates the centres must be relatively stagnant, hence hypoxic, compared with the periphery.

Experiments in America on the live shipment of Dungeness crabs (*Cancer magister*) showed that a tray-system with cascading aerated water was an effective means of transport. Of course this species is much larger than *N. puber* which makes this a more feasible and cost-effective method. Table 9 gives data obtained during these studies showing oxygen saturation levels both in the centres of orange crates packed with animals and in a cascading tray system. These experiments were made at an exporter's premises and give some indication of the efficacy of the tray system and how effective the crate system can be if oxygenation is such that the water is forced to pass through the crates instead of taking the easier path around them. Although time did not allow tests to be made it would seem a sensible precaution to include some means of conducting water to the centre of crates at the packing stage – a piece of perforated PVC piping would be sufficient to secure an improved circulation to animals packed in the centres of such crates.

During discussions with the exporters the question of insitu monitoring systems was brought up. Such a system would comprise a series of sensors which would monitor continuously the status of temperature and oxygen saturation in the various tanks of the vivier lorry and be displayed in the cab. What possible remedial action could be taken in the event of difficulties whilst the lorry was between Scotland and the South Coat is difficult to imagine but thee is some merit in the idea and this will be looked at further at Hull University.

One practice which may constitute a further stress to the animals occurs on the ferry to Spain. On the trip we made the vivier lorry had its seawater stock replaced whilst in mid-Channel. This water will almost inevitably have different temperature/salinity characteristics than that taken aboard in Scotland. Should it be several degrees warmer than the water it replaces then, if the aeration system is not adequate, the animals will fall to hypoxia between Plymouth and Santander.

6. Principal Recommendations and Conclusions

As a sequence for remedial action to reduce mortality rates, special attention should be paid to paragraph (a). Aerial exposure occurs at several points in between the main holding periods and is the single most important factor within the existing system which weakens velvet crabs. Given the constraints to investment in this fishery, and its relatively small size, paying attention to this one aspect should be the single most cost effective action that can be taken.

a) Aerial exposure must be kept to absolute minimum and where unavoidable to be in high RH/low temperature conditions.

b) Exporters should ensure that the water they use for their own holding tanks and for filling the vivier truck tanks should be of full salinity. This critical parameter of water quality should also be checked regularly, especially at times of heavy rainfall.

c) Water temperatures in vivier tanks should be subject to effective cooling to a temperature of 10°C ± 1°C. The cooling system should not influence any other water quality parameters – for example salinity through condensation effects.

d) The level of oxygenation of the water in vivier tanks should be as high as possible; preferably the water should be saturated. Bubbles should be as small as possible to increase surface area and absorption rates.

e) If crab must be transported in densely packed units then water/oxygen circulation to the centre of these units must be improved. A perforated plastic pipe can be packed with the crab and oxygenated water can be forced through containers by modifying the bottom of tanks.

f) Exporters should try to hold *N. puber* under favourable conditions for at least 24 hours prior to selecting and re-packing for export.

g) Changes of vivier tank water should not be made without first checking the temperature of the tank water and that of the new supply. Tank water must not be replaced by water of a higher temperature unless there is some compelling reason for doing so – contamination for example.

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7. Further Action

This report, and its recommendations, forms the basis for a sequence of remedial action as described in the preceding section.

As a first step the report will be distributed to all those with an interest in its content. It should be noted that, in the short term, very significant remedial actions are possible which do not involve much expenditure but could lead to much better financial returns:-

- Reduction of aerial exposure and more careful handling practices
- Checking holding water quality more thoroughly
- Maintaining lower holding water temperatures
- Improving water/oxygen penetration to the centre of crates

If these improvements were implemented carefully then a marked reduction in mortality rates would be seen. In the first instance, therefore, the Authority should monitor the implementation of the recommendations and the changes that result. This should all occur within perhaps six months.

In the longer term, more substantial improvements can be made as part of a strategy for upgrading the handling, holding and transport of all marketable species of crustacea. In Scotland, especially, where holding facilities are virtually non-existent, it should be fairly easy for the Authority to design and engineer an integrated handling system in co-operation with the major exporters of live shellfish. The need for this type of action will be assessed in the light of the improvements which result from publication of this report.

8. Acknowledgements

We should like to thank all of the exporters who generously provided us with information. Particular thanks are due to Mr. R. George who provided us with velvets for experiments, arranged for one of us to travel by vivier to Spain and provided hospitality at his home.

The SFIA would like to express its appreciation of the way in which the University of Hull's Department of Zoology carried out their share of the project and would hope this could be used as a model for other industry-university related projects.

9. Bibliography

1. Cumberlidge, N. 7 R.F. Uglow (1977). Size, Temperature, and Scaphognathite Frequency Dependent Variations of Ventilation Volumes in Carcinus maenas (L). J. Exp. Mar. Biol. Ecol. 30, pp 85-93.

2. Green, E. J. & D. E. Carritt (1967). New Tables for Oxygen Saturation of Seawater. J. Marine Res. 25, pp 140-147.

Appendix I

Exporters Contacted

Appendix 1 – Exporters Contracted

Rodney George
The Portakabin
Glenborradale Road
Salen
Acharacle
Argyll

Monteum Limited
27 East Street
Shoreham by Sea
Sussex

Copine Fish Limited
Castletown
Portland
Dorset

G M Hogg Limited
4 Taylor Street
Ayr
Strathclyde

Wilson's of Holyhead
The Lobster Pot
Rhydwun
Holyhead
Anglesey

John Arrow (Freshfish) Limited
Ffrond Dau Quarry
New Quay
Dyfed

Appendix 2

Export Routes and Duration

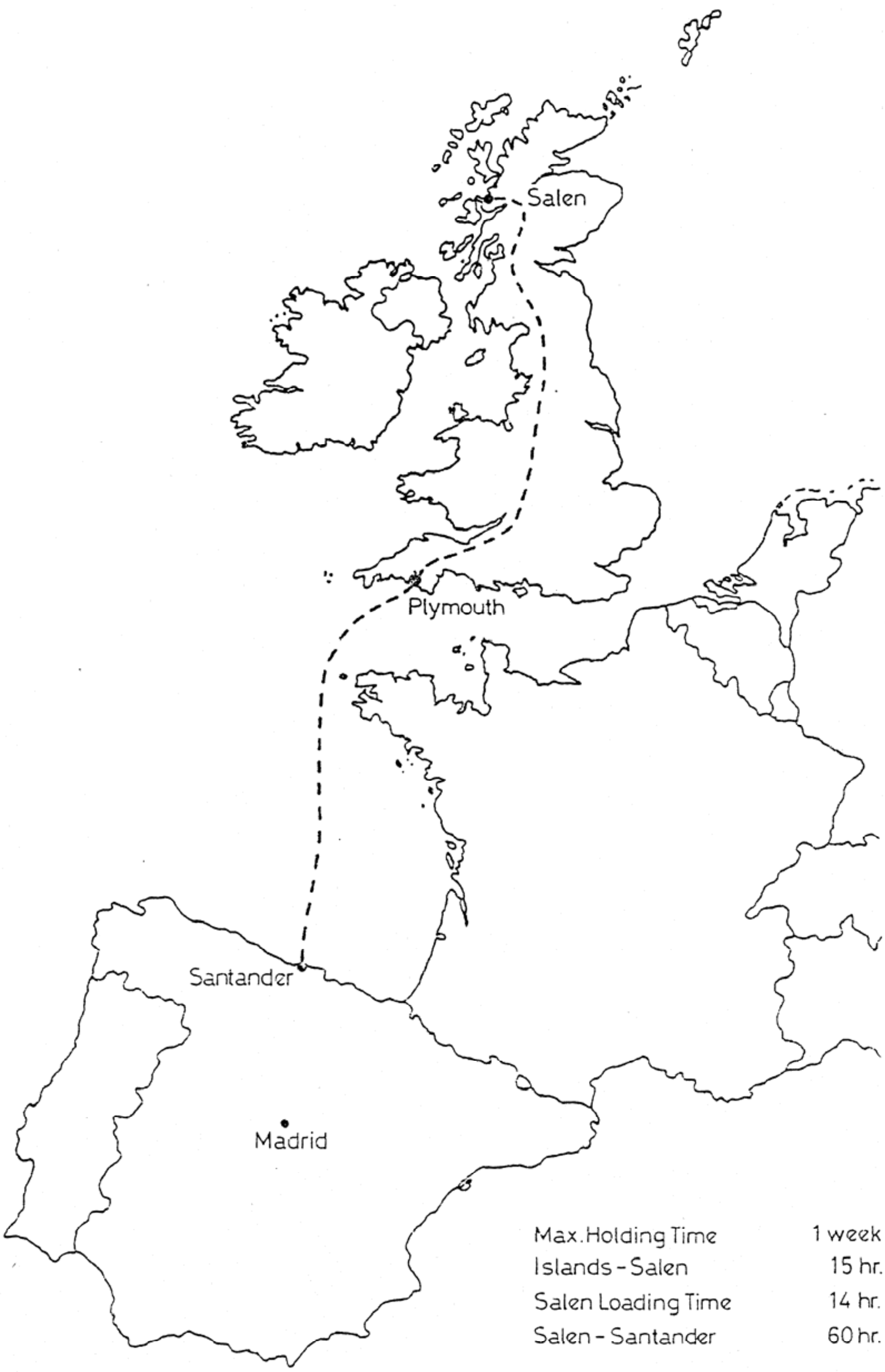

Figure A2.1 – Export Route – R. George

Figure A2.2 – Export Route – Wilsons of Holyhead Limited

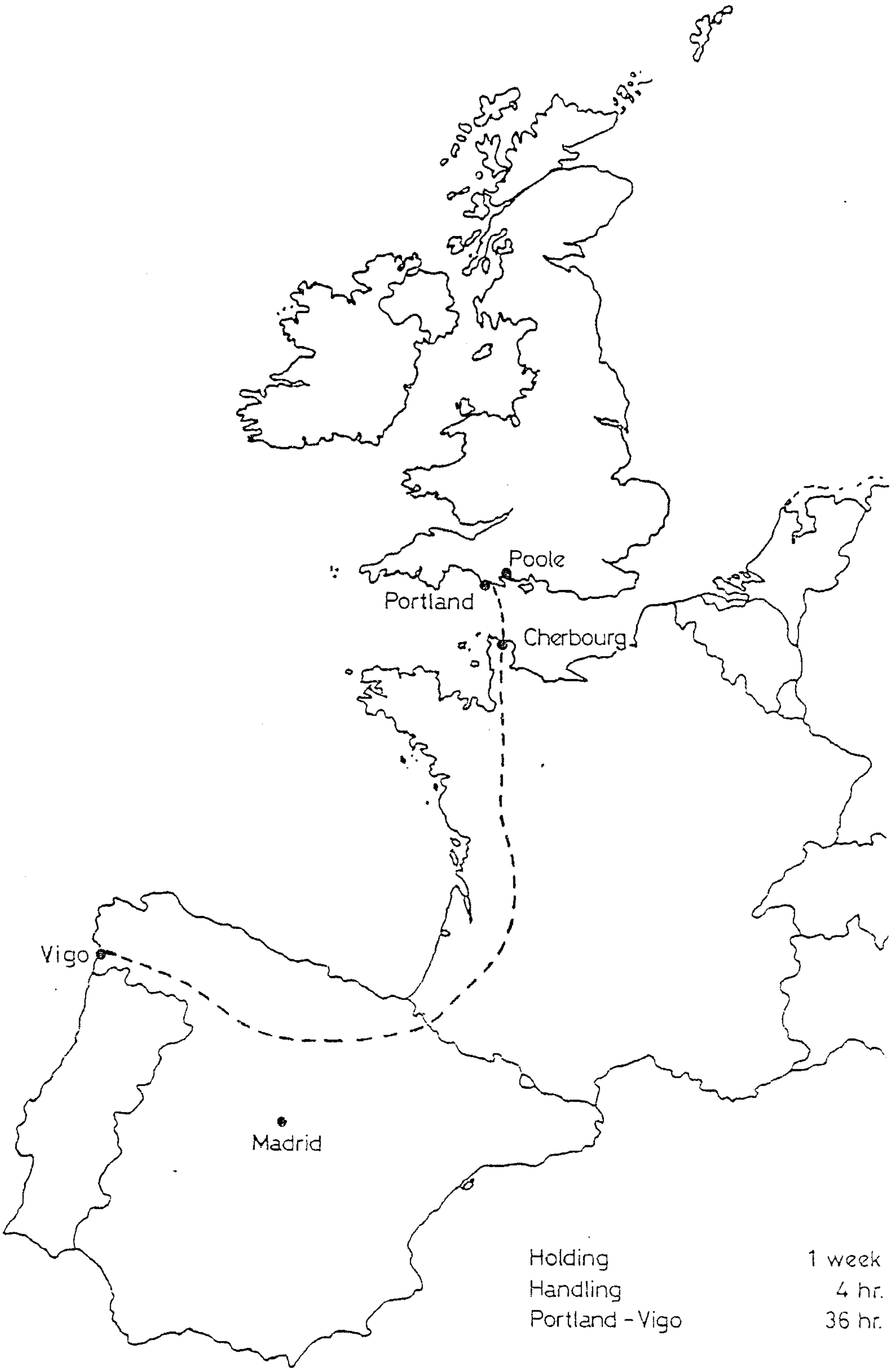

Figure A2.3 – Export Route – Copine Fish Limited

Figure A2.4 – Export Route – Monteum Ltd

Table 1 – Survival Data of Three Crab Species subjected to 24 hours aerial exposure (RH = 80%, Temp = 15°C)

	C. maenas	*C. pagurus*	*N. puber*
Mortality (%) after 24 hours aerial exposure	0.0	15.4	76.9
Lethal exposure time for 50% mortality (LT 50) (hrs)	-	-	17.0

(n = 13 in all cases)

Table 2 – *N. puber*. The effects of aerial exposure (RH = 80%; Temp = 16°C) and recovery in normoxic seawater on circulating levels of glucose and lactate

	Initial Level	4 hr Aerial Exposure	Recovery in Aerated Seawater	
			4 hr	6 hr
Lactate (mg.100 ml^{-1})	4.86 ± 0.43 4.86 ± 0.67	58.50 ± 2.70 59.44 ± 3.74	26.03 ± 3.70-	-16.30 ± 6.50
Control	4.57 ± 0.35	4.51 ± 0.16	4.22 ± 0.13	
Glucose (mg.100 ml^{-1})	1.48 ± 0.24 1.63 ± 0.22	10.71 ± 2.73 12.50 ± 2.45	9.60 ± 2.21-	-8.26 ± 3.49
Control	3.80 ± 1.24	1.95 ± 0.32	2.06 ± 0.20	-

(n = 5 in all cases. Values as means ± standard error)

Table 3a – Mean Levels of Circulating Lactate during Aerial Exposure in Three Species of Crabs

Hrs Aerial Exposure	*C. maenas* (Green Crab)	*C. pagurus* (Brown Crab)	*N. puber* (Velvet Crab)
0	7.17 ± 0.27	3.36 ± 0.71	5.44 ± 0.35
4	7.53 ± 0.33	18.76 ± 4.02	30.29 ± 4.64
24	9.219 ± 0.62	59.83 ± 14.18	101.07 ± 2.47

(n = 5 in all cases. Values are means ± standard error and are given in mg.100 $m1^{-1}$. The *N. puber* 24 hr data refer to 2 animals that survived the exposure period).

Table 3b – Mean Levels of Circulating Glucose during Aerial Exposure in Three Species of Crabs

Hrs Aerial Exposure	*C. maenas* (Green Crab)	*C. pagurus* (Brown Crab)	*N. puber* (Velvet Crab)
0	4.38 ± 0.70	3.33 ± 0.64	6.30 ± 1.25
4	8.31 ± 1.33	16.07 ± 1.34	22.48 ± 5.89
24	6.56 ± 1.29	24.09 ± 6.00	1.99 ± 0.13

Table 4 – *N. puber* Handling/Transport Simulation Effects on Blood Glucose and Lactate Levels. Details given in text.

	1st Sample	2nd Sample	3rd Sample
Glucose Mg.100ml^{-1} Experimental	14.55 ± 2.57	31.45 ± 4.53	26.28 ± 3.55
Control	15.78 ± 5.04	-	9.76 ± 2.76
Lactate Mg.100ml^{-1} Experimental	5.24 ± 0.91	23.02 ± 1.95	16.70 ± 2.47
Control	9.19 ± 1.71	-	9.48 ± 1.39

Values given as means ± standard error

Table 5 – *N. puber* The Effects of Some Water and Blood Parameters of 23 hours of Crate Storage in Fully Oxygenated Water (12°C). Water Volume – 60 litres animal weight = 9 kilo

	Initial Value (o.hr)	Final Value (23 hr)
0_2 saturation inside crate	84%	19%
0_2 saturation outside crate	84%	85%
pH	7.25	6.92
Nitrite	1 ppm	5 ppm
Nitrate	50 ppm	50 ppm
Blood Lactate	3.39 ± 0.32	39.44 (mg.100ml^{-1}) 4.85
(mg.100ml^{-1})	(n = 10)	(n = 8)

Table 6 – *N. puber*. Blood Lactate Levels of a Group (n = 6) Animals packed into Centre of Crate, and of Oxygen Saturation Values of the Water surrounding them, during a 24 hour period.. (Water Volume: Crate Volume Ration = 2:1. Temp = 10°C)

Time (hr)	Oxygen Saturation (%)	Blood Lactate Levels (mg.100ml^{-1})
0	64	3.72 ± 0.32
4	60	2.06 ± 0.92
8	19	4.66 ± 0.50
24	14	6.34 ± 0.61

Lactate values are given as means ± standard error

Table 7 – Water Conditions in Vivier Lorry during Trip from Scotland to Spain

No.	Time Sample Taken (hr)	Temp (°C)	Oxygen Saturation (%)	pH
1	0.0	12.7	84	6.60
2	18.0	12.5	98	6.76
3	23.0	12.0	94	6.80
4	27.0	12.0	88	7.04
5	30.5	12.1	78	7.05
6	54.5	12.2	50	7.09
7	57.0	12.7	50	6.85
8	67.25	12.9	48	6.87
9	83.50	12.1	46	7.07

Table 8 – *N. puber* The Effects of Hypoxia on Blood Lactate Levels at Two Temperatures

	Blood Lactate Concentration ($mg.100ml^{-1}$)	
	10°C	13°C
Initial Value	5.72 ± 0.87	9.17 ± 1.22
After 4 hr & 25% 0_2 saturation	7.05 ± 1.54	17.26 ± 2.00
After 4 hr recovery in fully aerated conditions	7.82 ± 0.53	12.39 ± 0.50

(n = 6 in all cases, Values given as means ± standard error)

Table 9 – Comparison of Oxygen Saturation Conditions for Storage Conditions of *N. puber*. Tank A, animals were stored in crates; Tank B animals stored in trays. Circulation of 'fresh' seawater (60% saturation) was maintained and further aeration provided.

Time (hr)	Tank A		Tank B	
	T°C	Oxygen Saturation (%)	T°C	Oxygen Saturation (%)
0	12.5	50	12.5	58
17	12.5	75	12.5	136
48	12.5	90	12.5	140
67	12.5	81	12.5	130
98	12.5	91	12.5	164

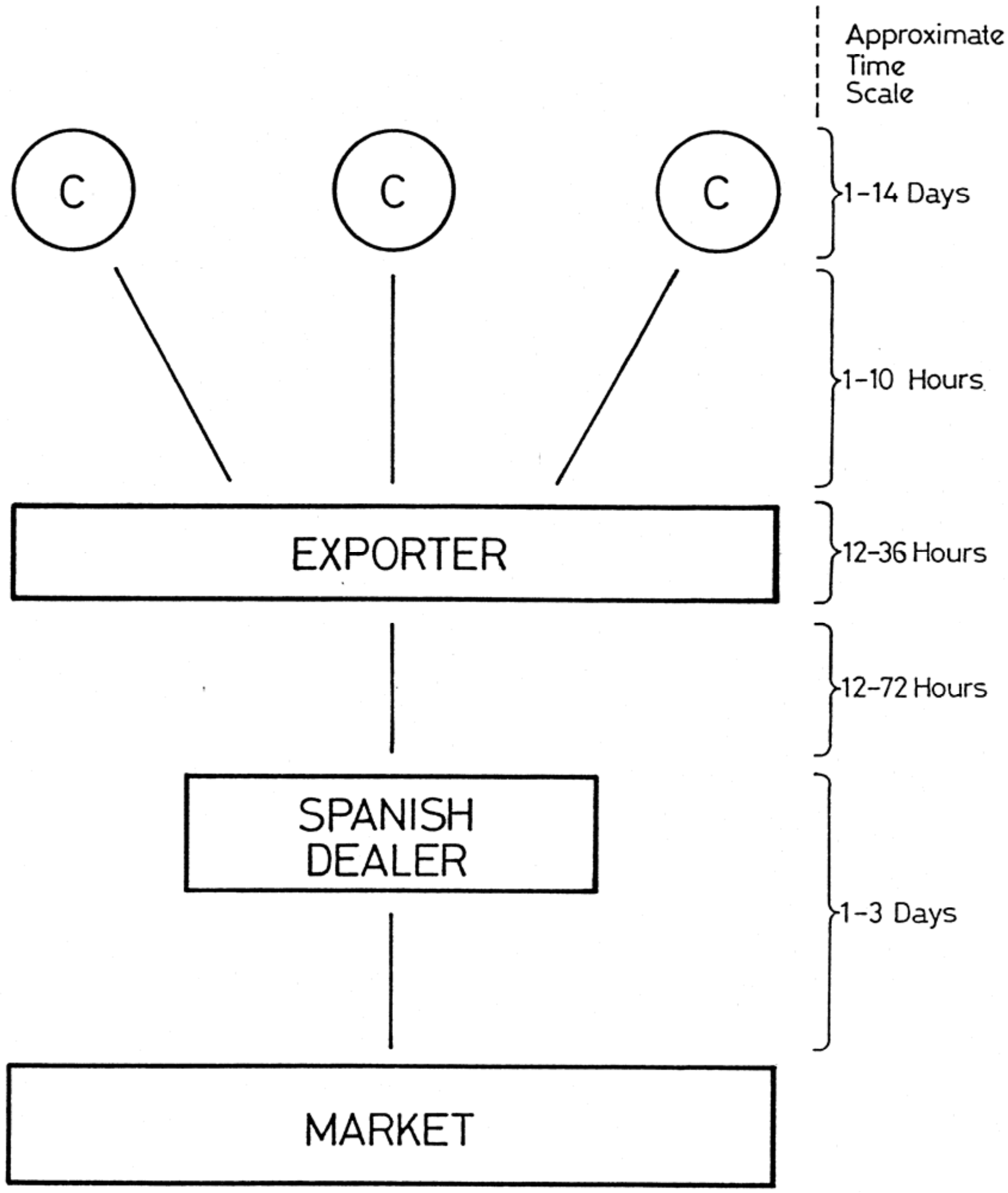

Fig 1 – Marketing Chain for Velvet Crabs

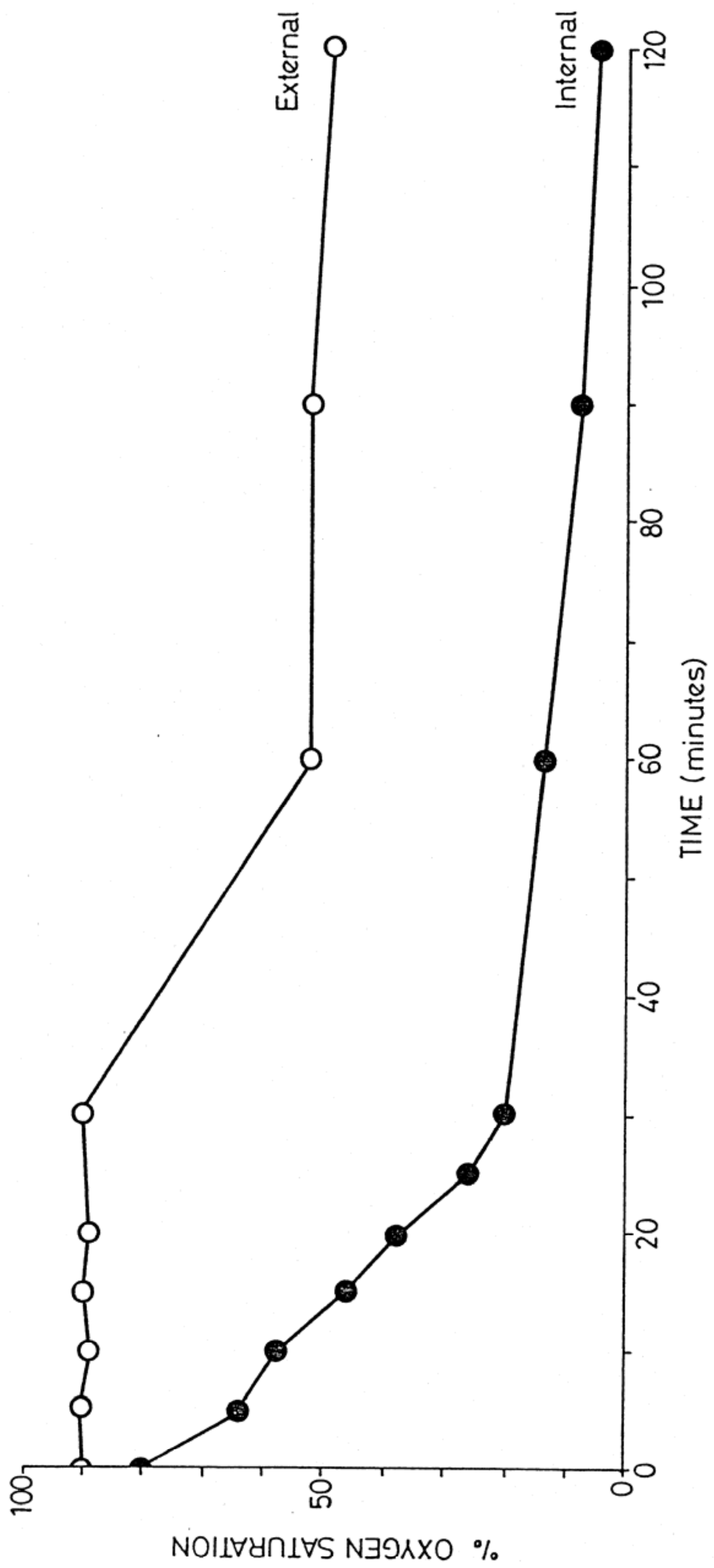

Fig 2 – Oxygen saturation values of the water external and internal to an orange crate packed with 9kg. of live *N. puber* sited in a simulated vivier tank. The water volume to crate volume ratio was 2:1 and the temperature was 10°C.

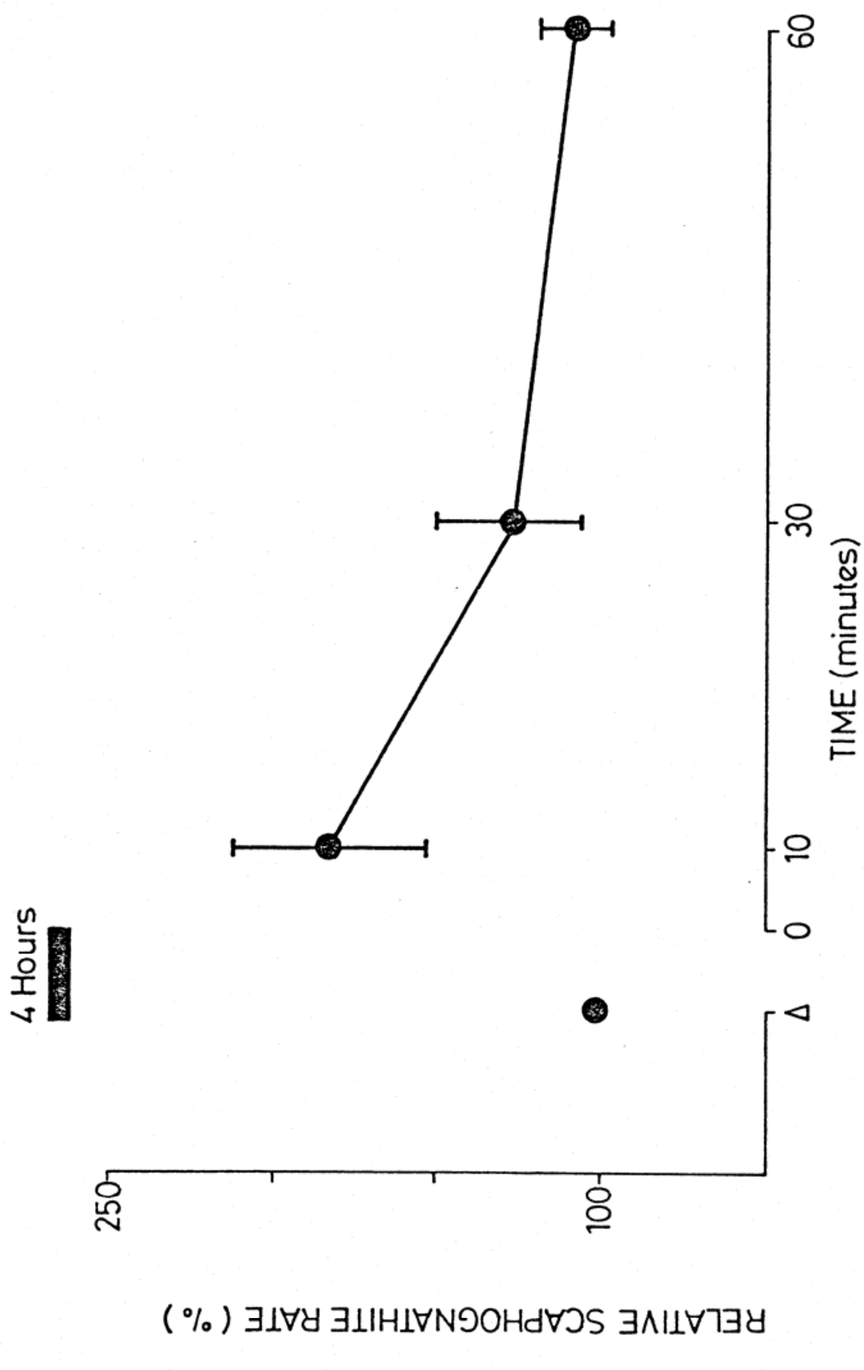

Fig 3 – Relative scraphognathite [time Δ = 100%] following 4 hours of aerial exposure [R.H. = 80%, t = 15°C]. The black bar represents the aerial exposure period which started after the first blood [haemolymph] sample ws taken. The second blood sample was taken 5 minutes after return to normmoxic water. Values are means ± standard errors; n = 5 animals in each case.

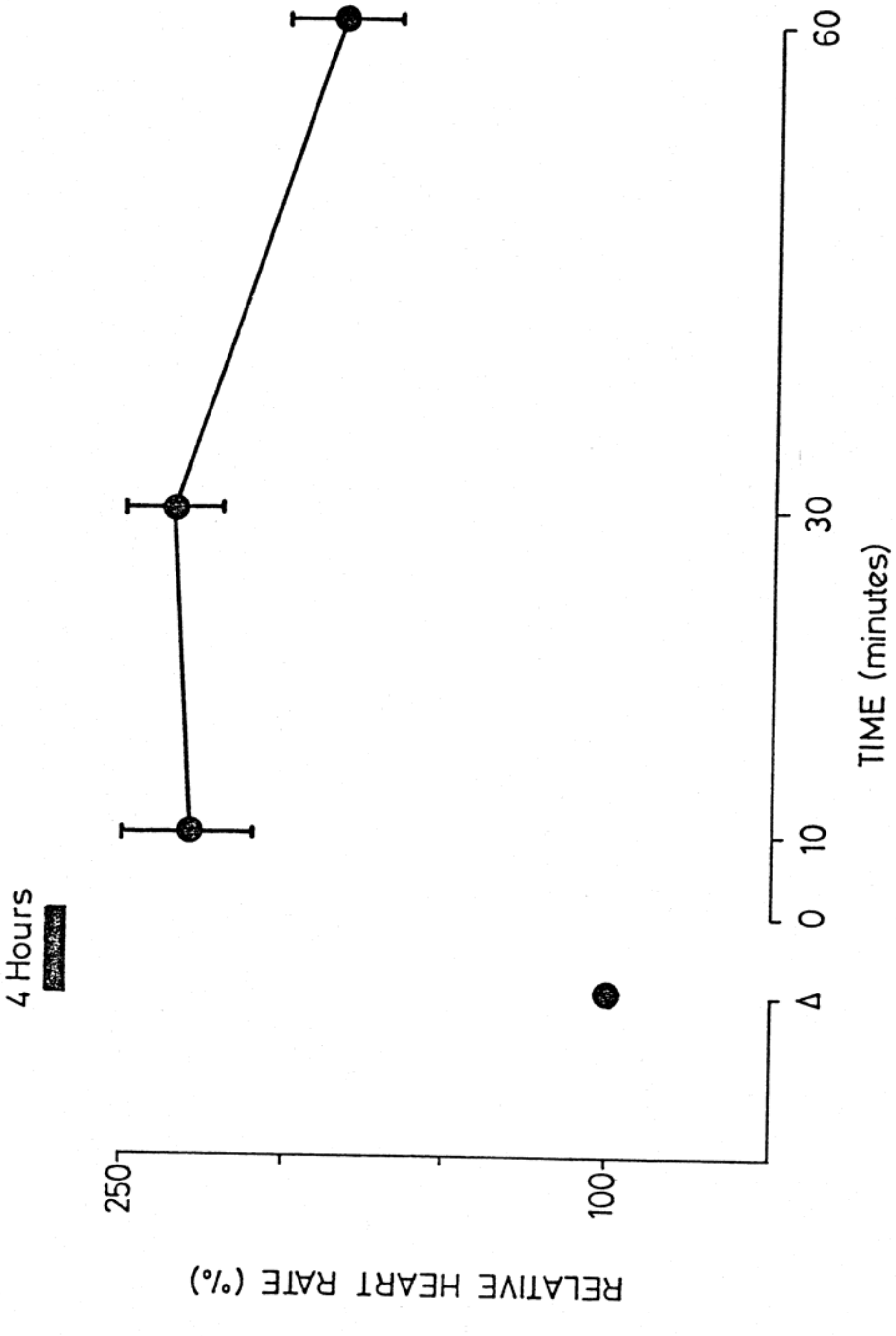

Figure 4 – Relative heart rate [time Δ = 100%] following 4 hours of aerial exposure [R.H. =80%, t = 15°C]. The black bar represents the aerial exposure period which started after the first blood haemolymph sample was taken. The second blood sample was taken 5 minutes after return to normoxic water. Values are means ± standard errors; n = 5 animals in each case.

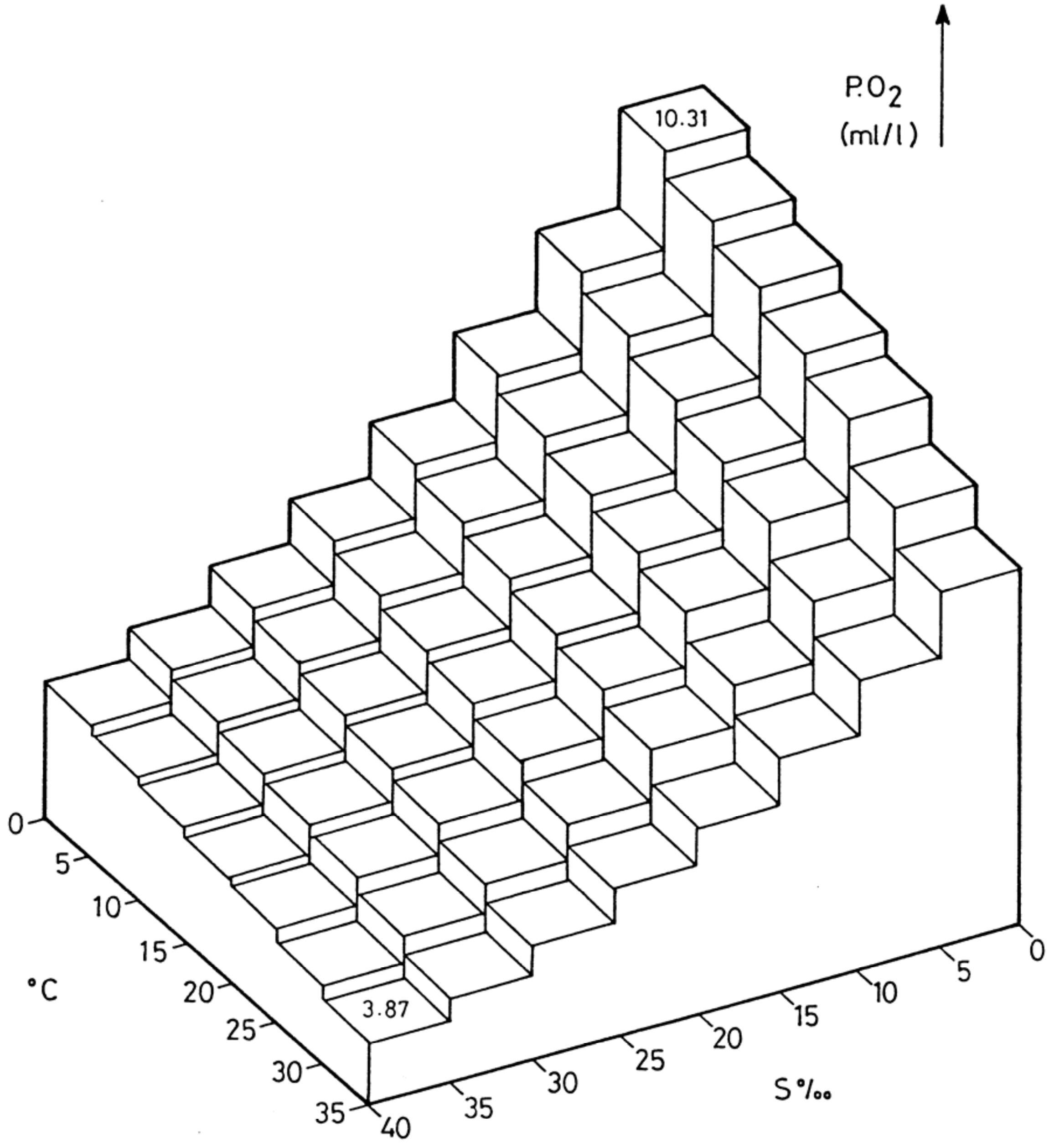

Figure 5 – Oxygen Saturation Values (after Green 1967)