Title:A preliminary study of the effect of meteorological factors on the live export trade of the Scottish Nephrops trawling fishery.
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Source:***Journal of Shellfish Research*** 26.2 (August 2007): p611(5). (4764 words)
Document Type:Magazine/Journal
Bookmark:Bookmark this Document
Library Links:

ABSTRACT The impact of meteorological factors on the condition of N. norvegicus caught for the live export market was assessed by correlating the mean wind speed and aerial temperature on the day of landing with the percentage of catch, on corresponding days, rejected for live transport. The study used the catch data from two Nephrops trawlers operating in the Clyde Sea area, Scotland. Results illustrated a large degree of variability in the condition of animals on arrival at the processing plant. Air temperature was the only meteorological factor, which significantly correlated with the morbidity and mortality of the catch. In one instance, mean air temperature on the day of capture had a significant negative impact on the health of the catch. This is the first study of its kind on the Nephrops fishery and although only a preliminary study demonstrates catch quality not only varies with the ambient temperature on the day of capture but also differs between trawlers. To conclude it is suggested that a larger study be commenced and a capture and post capture code of best practice be developed and used on all Nephrops trawlers.

KEY WORDS: Nephrops fishery, climate, crustacean, post-capture stress, mortality

INTRODUCTION

Stimulated by a growth in high quality shellfish markets over the last 30 y, the Scottish inshore fishery fleet has become almost entirely dependent on shellfish, of which the key species is the Norway lobster, Nephrops norvegicus. The majority of shellfish landed are exported as premium quality live chilled product, the main markets being France, Spain, Italy, and Portugal. Nephrops norvegicus are mainly fished by trawlers and landings into Scotland are valued at $103 million (Anon 2003). The Nephrops fishery is also of socio-economic importance, with the vast majority of vessels family owned, and, although difficult to quantify, the indirect and induced economic benefits of the inshore fleet undoubtedly make an important contribution to sustaining fragile rural communities (Anon 2005).

Previous work by Ridgway et al. (2006a) demonstrated that the temperature at which aerial exposure occurs significantly impacts on the degree of stress suffered by N. norvegicus. To summarize, the carbohydrate profile was significantly altered by the temperature and duration of aerial exposure. Severe depletion of the carbohydrate profile during high temperature aerial exposure represents a form of physiological stress that the animal cannot recover from. Immunologically, air exposure at the higher temperatures results in a significant reduction in total hemocyte counts (THC), a significant reduction in hemolymph phenoloxidase activity and elevated hemolymph bactereymia levels (Ridgway et al. 2006a). The consequence of these alterations was the high mortalities observed after aerial exposure at high temperatures (25[degrees]C). This study aims to demonstrate whether the susceptibility of N. norvegicus to elevated aerial temperatures is observed in the Nephrops fishery, specifically in the live export trade.

There has been no previous work correlating meteorological factors with the mortality and morbidity of N. norvegicus destined for the live transport trade. A similar study was conducted by Spanoghe and Bourne (1997) to ascertain the affect of a range of environmental factors on the morbidity and mortality of the western rock lobster, Panulirus cygnus. It was found that holding time in the export cartons, ambient temperature within the export cartons, and chilling period before packing the lobsters had the greatest impact on the morbidity and mortality observed.

After trawl capture N. norvegicus are exposed to air during sorting and then submerged in seawater tanks on the deck of the boat before being further exposed to the elements during transportation to the processing plants on flat bed trucks. At the processing plant, N. norvegicus are sorted into size categories and suitability for export. The objective was to correlate meteorological variables (mean air temperature and mean wind speed) on the day of capture with the quantity of animals rejected for the live export trade from that catch once at the processing plant over the study period.

Mean aerial temperature was selected for this study because of previous research by the author (Ridgway 2005, Ridgway et al. 2006a) and studies on other decapod crustaceans (Spanoghe & Bourne 1997) demonstrating the adverse affects of elevated aerial temperatures on the physiology and immunology of decapod crustaceans. Mean wind speed was also chosen as it has been hypothesized by Symonds and Simpson (1971) that during severe weather (when the boat might roll excessively during hauling) the mortality of rejected animals would be increased.

This study was conducted over a 6-mo period from November 2002 until April 2003 using the landings from two boats in the Clyde Sea area. It is hoped that information obtained during this study will provide guidance to the industry so optimum returns from the fishery can be achieved.

MATERIALS AND METHODS

Between November 2002 and April 2003 catch data were collated from the landings of two Nephrops trawlers, named "Trawler A" and "Trawler D" as they wish to remain anonymous, at Carradale Harbour, north of Campbeltown in the Firth of Clyde, West of Scotland (Scotland, UK). The catch data contained information on the weight of N. norvegicus classified as "live" (sent for live export) or "dead" (rejected for the live trade and sold as whole animals or tailed for "scampi") from each size class (small, medium, or large) after arrival at the processing plant in Ayr. "Trawler A" is a twin-rigged trawler with a crew of 4, whereas "Trawler D" has only one rig and 3 crew members. A similar post capture treatment is used on both boats: N. norvegicus are exposed to air during sorting and then placed into "prawn tubes" (commercial shipping cartons) and submerged in seawater tanks on the deck of the boat. which is continually refreshed with running seawater pumped aboard from the surface waters of the sea. The trawling grounds for both boats are located in the Clyde sea area inside the Campbeltown peninsula; however the exact location is very variable and was not specified in the data provided. At Carradale the catch from both trawlers is transported on flat bed trucks to Campbeltown, a journey time of 40 min, in addition to the extra time taken for waiting/loading. During this stage the Prawn tubes are open to the elements, only covered by Hessian sacks that have been soaked in seawater. At Campbeltown they are transferred to refrigerated trucks and transported to a processing plant in Ayr (a journey time of 4 h 30 min). Again the processing plant wishes to remain anonymous for the purposes of this report.

At the processing plant, N. norvegicus are held in "'prawn tubes" in circulating filtered seawater tanks (6[degrees]C, 33 ppt salinity). The landings are sorted 24 h after arrival and classified for export. N. norvegicus are initially classified as small, medium or large, and then categorized into "live" or "'dead." N. norvegicus rejected for the live export market were classified as weak, moribund, or dead. The total number of rejected individuals was divided by the total number of lobsters to give a combined percentage of morbidity and mortality (M + M%). This method was used by Goodrick et al. (1993) when investigating the air transport of live Kuruma prawns (Peneaus japonicus).

The meteorological data was provided by Prestwick International Airport weather station (55[degrees]50'N, 4[degrees]50'W. World Meteorological Organization ID code: 03,135), the nearest weather station to the trawling locality. The mean wind speed and mean air temperature on the day of landing were correlated with the percentage of N. norvegicus rejected from the live trade and classified "dead" (M + M%), for each size class or from the total landings, for the corresponding day.

The meteorological data was not normally distributed and this distribution could not be normalized using the usual transformations. Pearson's correlation analysis could not be performed because the basic assumptions were not met: therefore Spearman's rank-order correlation analysis was performed using MINITAB statistical software. All the meteorological variables and the M + M% were therefore ranked and subjected to Spearman's rank-order analysis. Further analysis could be performed through regression analysis because the assumption that both variables be normally distributed is lifted (Dytham 1999).

For regression analysis a number of assumptions have to be met, specifically that the dependant (y) variable, the M + M%, is normally distributed. Percentages tend not to be normally distributed (Hampton 1994), requiring transformations that help to improve the normality of the distribution. In past studies an angular transformation of the M + M percentage was performed, with the transformed variable (Y) defined as arcsine[check] (M + M%) (Dagnelie 1975, Spanoghe & Bourne 1997). However, in the present study this method failed to result in a normally distributed variable, therefore a logarithmic transformation of the data was conducted and termed log (M + M%).

TABLE 1.

The results of the correlation analysis between the meteorological variables and the percentage of morbidity and mortality log (M + M%). The above value is the Spearman's Correlation coefficient and below the associated probability, <0.05 indicates a significant correlation between the two variables, as indicated by an asterisk ("Trawler D" d.f. 98, "Trawler A" d.f. 37).

	Mean Wind Speed	Mean Air Temperature
"Trawler A"	-0.122	0.167
	0.465	0.317
"Trawler D"	0.194	0.408
	0.055	< 0.001*

RESULTS

Impact of Meteorological Factors on the Suitability of Nephrops norvegicus for Export

Throughout the study period the catches from 137 days at sea were monitored, 99 from Trawler D and 38 from "Trawler A." The median percentage of morbidity and mortality (M + M%) from "Trawler D" (36.33%) 24 h after arrival at the processing factory was significantly higher than that of Trawler A (31.31%) (Mann-Whitney Test W value 2019, p 0.004, d.f. 136) and the mean amount received by the processing factory, before sorting, from "Trawler A" (70.9 kg) was higher than "Trawler D" (44.9 kg).

The results (Table 1) indicate that for N. norvegicus captured by "Trawler A," the meteorological factors analyzed demonstrated no significant correlation with the log(M + M%). However, for N. norvegicus caught by Trawler D, mean air temperature on the day of trawling was significantly correlated with the log (M + M%).

The relationship after regression analysis between the mean temperature on the day of capture and the log(M + M%) (Fig. 1) demonstrates the rate of increase of M + M% is greater at the higher mean temperatures. Interestingly, the low [R.sup.2] value associated with the regression analysis indicates that the response of the y variable (M + M%), although significantly dependant on the x variable (mean air temperature), is also affected by other factors, such as the duration of the trawl and the post capture treatment.

Impact of Meteorological Factors on Different Sized Nephrops norvegicus

The effect of the size of N. norvegicus on the percentage of morbidity and mortality observed after trawling was analyzed for each boat separately. Table 2 details the median M + M% for each boat in each size class. Large and medium sized N. norvegicus caught on the "Trawler A" have significantly higher M + M% than the small animals. However, there are significant differences between all of the size classes caught on the "Trawler D," with the small animals again having the lowest M + M%, but the medium sized N. norvegicus having a significantly higher M + M% than the large animals.

The correlations between the M + M% of large, medium and small N. norvegicus, and the mean air temperature on the day of capture for each boat (Table 3) suggests that the differences observed may be attributed to factors in addition to the mean air temperature on the day of capture. N. norvegicus classified as large from "Trawler A" exhibit a significant correlation with the mean air temperature; however, this is not the case for the medium sized class, which experienced a similar M + M%, suggesting that another factor may be responsible for the high M + M% observed. The landings from "Trawler D" demonstrate different relationships, with both the medium and small proportions of the catch, but not the large, exhibiting significant positive correlations with the mean air temperature on the day of landing. These findings may illustrate differences in the post capture handling of N. norvegicus on each boat according to size.

To summarize, the results have demonstrated that only on "Trawler D" did the mean air temperature on the day of capture significantly affect the M + M% of the catch. Interestingly the correlation analysis suggests that only the small and medium proportions of the catch were affected.

The data corresponding to capture by "Trawler A" inform that over the whole catch combined, M + M% was not significantly affected by the aerial temperature, however on further analysis the M + M% of the large sized proportion of the catch demonstrated the greatest positive correlation, although this was not quite significant (P value 0.056), with the mean air temperature on the day of capture.

DISCUSSION

There was a large degree of variability in the condition of N. norvegicus on arrival at the processing plant. However, on one of the boats, "Trawler D," the mean air temperature on the day of capture had a significant negative impact on the health of the catch. Mean wind speed did not appear to impact on the morbidity and mortality of the catch. The data from the two boats were not pooled as the catch pertaining to "Trawler A" were far less numerous than those of "Trawler D" and any correlations would be masked by the greater number of observations from "Trawler D".

A similar study by Spanoghe and Bourne (1997) was performed to ascertain the affect of a range of environmental factors on the morbidity and mortality of the western rock lobster, Panulirus cygnus. It was found that holding time in the export cartons, ambient temperature within the export cartons, and chilling period before packing the lobsters had the greatest impact on the morbidity and mortality observed.

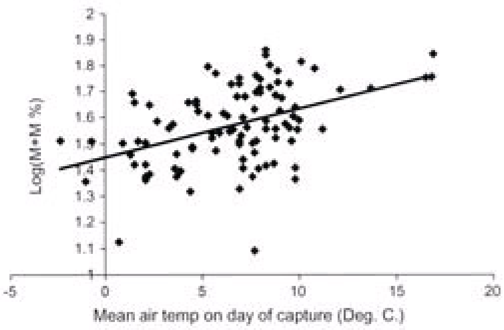

Figure 1. Regression analysis of $\log_{10}$ M + M% observed after capture on "Trawler D" and the mean temperature on the day of capture (°C). The regression equation is: Log_{10} (M + M%) = 1.44739 + 0.0185618 Mean air temp. R^2 (adj.) = 18.3%. (F value 23.00, $P < 0.001$, d.f. 98).

It is well established that the duration of which crustaceans can be exposed to air for varies greatly amongst species (Taylor & Whiteley 1989, De Fur et al. 1988, Zainal et al. 1992, Goodrick et al. 1993, Paterson et al. 1997), but these studies have suggested that the environmental factors, particularly temperature, play an important role in survival during live transport. There have been few studies on the tolerance of N. norvegicus to a range of temperatures during aerial exposure. Ridgway et al. (2006a) demonstrated that mortality of N. norvegicus is greatly increased once air temperatures rise above 15[degrees]C. Studies on other crustaceans have also indicated that survival is improved if the temperature of aerial exposure is reduced. Whiteley and Taylor (1990, 1992) and Whiteley et al. (1990) reported increased survival rates of Homarus gammarus when a temperature of 5[degrees]C to 10[degrees]C was maintained in the export cartons, whereas Goodrick et al. (1993) and Paterson (1993) reported that 12[degrees]C to 15[degrees]C was the optimum temperature range for the live export of Penaeus japonicus.

TABLE 2.

The median percentage of morbidity and mortality experienced by different sized *N. norvegicus* from each boat, "Trawler A" and "Trawler D". Significant differences between each size class from the same boat is indicated by a different letter, as indicated by Mann-Whitney nonparametric test.

	"Trawler A"	"Trawler D"
Large M + M%	38.61 A	40.53 A
Medium M + M%	38.41 A	46.94 B
Small M + M%	26.16 B	32.58 C

A likely cause of death for animals exposed to air is idiopathic muscle necrosis (IMN). This muscle wasting disease, where the entire abdomen turns necrotic, with death usually within 24-48 h has been reported as a problem for decades in other crustaceans (Nash et al. 1987, Lindqvist & Mikkola 1978). Research into IMN has failed to discover its etiology, although its occurrence after exposure to stressors such as trawl capture (Rigdon & Baxter 1970, Stentiford & Neil 2000), temperature and salinity changes (Lakshmi et al. 1978), handling and air exposure (Venkataramaiah 1971), and starvation (Lindqvist & Mikkola 1978) has been reported. However it was only recently observed affecting N. norvegicus destined for the live export trade (Stentiford & Neil 2000), the researchers termed it a rapid onset postcapture muscle necrosis. Further work by Ridgway et al. (2007) demonstrated that the condition in N. norvegicus could be induced through periods of aerial exposure and that, prior to death, IMN progresses to bacteremia. Ridgway et al. (2007) also estimated the prevalence of IMN in N. norvegicus 48 h after trawl capture to be around 38%, a figure remarkably similar to the morbidity and mortality figures reported in the present study.

TABLE 3.

The results of correlation analysis between the percentage of morbidity and mortality observed in large, medium and small *N. norvegicus* landed on each boat and the mean air temperature. The value above is Spearman's Correlation coefficient, and below the associated probability, a probability <0.05 indicates a significant correlation between the two variables, and is indicated by an asterisk.

	Mean Air Temperature "Trawler A" Catch	Mean Air Temperature "Trawler D" Catch
Large M + M%	0.313	−0.074
	0.056	0.493
Medium M + M%	0.058	0.483
	0.730	<0.001*
Small M + M%	0.052	0.327
	0.756	0.001*

It was observed that on both vessels the smaller N. norvegicus exhibited the lowest M + M%. It has been suggested that crustaceans have the ability to cope with the increased concentrations of L-lactate, which accumulates in the hemolymph because of the anaerobic metabolism required during periods of aerial exposure (Burnett 1988). There have been few studies on the ability of different sized crustaceans to compensate for increased concentrations of L-lactate, but DeFur and McMahon (1984) reported that the degree of compensation was greater in smaller Cancer productus. However, on "Trawler D" the large sized N. norvegicus were the only category where the mean air temperature on the day of capture did not have a negative impact. This may reflect preferential treatment of the larger animals by the crew, because these animals obtain a higher market value and are generally more robust.

The large variability observed in the data is likely to be a result of other variables. The trawling grounds that each boat uses varies largely on a daily basis and so the steaming time back to harbor may vary greatly resulting in a longer recovery time in the onboard seawater tanks before further stress during the road transport stage (handling and further aerial exposure). Ridgway et al. (2006b) reported that mortality rates were significantly reduced after prolonged periods of recovery before further transport. The oxygen debt and respiratory acidosis (after trawling and subsequent aerial exposure) are reduced during the periods that N. norvegicus are submerged in the seawater tanks. However, if lobsters are further stressed, by rehandling or aerial exposure before this recovery is complete, the acidiotic stress is compounded. After this treatment acid-base stress is consequently more severe and survival times in air potentially reduced (Taylor et al. 1997).

Interestingly, Spanoghe and Bourne (1997) also reported that survival was greater if lobsters were packaged at the processing units during the day compared with the evenings. This was attributed to the peak foraging time of P. cygnus being in the evenings, which is reflected in the circadian rhythm of the crustacean hyperglycemic hormone (CHH) (Kallen et al. 1990).

The study period was from November 2002, until April 2003. During the March and April months there is a peak in the occurrence of Hematodinium in N. norvegicus (see Field et al. 1992, Appleton et al. 1997, Field et al. 1998, Stentiford et al. 2001), which coincides with the peak temperatures observed during the study period. Hematodinium is a motile protozoan parasite, which infects N. norvegicus rendering them moribund, exhibiting an opaque appearance and white hemolymph. This poor appearance and condition causes N. norvegicus to be rejected for the live transport market. It could be suggested that the high degree of morbidity and mortality observed during the spring periods, when air temperature would be at its highest, could be because of Hematodinium infection, however if this were the case then the catch from both boats would exhibit similar morbidity and mortality rates. Because this does not occur this hypothesis is unlikely.

Other factors are likely to result in the observed variations in M + M%. Ridgway et al. (2006b) reported that increasing the duration of the trawl results in higher stress levels and increased physical damage and that greater catches were obtained in the spring, which may result in greater crush forces in the net, potentially causing more damage. Sea temperature varies little through the seasons, but surface waters vary in terms of temperature and salinity, because it is this water, which is used to submerge the export cartons, higher aerial temperatures resulting in higher surface temperatures may have a negative impact on the health status of the catch. Interestingly the boat with the lowest rate of morbidity and mortality also had one more crew member, which may result in faster sorting times, reducing the periods of aerial exposure.

Symonds and Simpson (1971) studied the survival of small discarded N. norvegicus and hypothesized that during severe weather (when the boat might roll excessively during hauling) the mortality of rejected animals would be increased. In the present study there was no correlation observed between the degree of mortality observed and the wind speed on the day of capture.

This study has demonstrated the need for a standard post capture protocol in the Clyde Sea Nephrops fishery to reduce the variability observed in the M + M% of the catch. A larger study, with more detailed information on the post capture treatment, as done by Spanoghe and Bourne (1997), including surface seawater temperature, estimates of economic losses, and the negative effect of prolonged sorting times will aid in optimizing the returns from the fishery. The Clyde Sea fishery and related industries have become increasingly reliant on the Nephrops fishery, through optimizing catch condition and survival, reducing the amount of rejected N. norvegicus, the impact of the fishery on the population can be minimized resulting in a more sustainable fishery.

ACKNOWLEDGMENTS

The author thanks the anonymous processing plant for supplying the data on the suitability of N. norvegicus for the live export trade and especially staff member Mr. Simon Sinclair for information regarding the landing and transporting of the catch. The Met Office is also acknowledged for supplying meteorological data from Prestwick International Airport Weather Station. This work at the University of Glasgow was supported by a Natural Environment Research Council CASE studentship (NER/S/A/2001/06194) in co-operation with CEFAS under the supervision of Dr Douglas Neil, Professor Alan Taylor, Professor Jim Atkinson and Dr Grant Stentiford.

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