The effects of trawling on the physical condition of the Norway lobster *Nephrops norvegicus* in relation to seasonal cycles in the Clyde Sea area

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The fishery for Norway lobster, *Nephrops norvegicus*, is the most valuable in Scotland, but few studies have examined the physical condition of the animals trawled. This study aimed to determine the extent of physical damage caused by trawling to *Nephrops* in the Clyde Sea area in relation to trawl duration, sex, size, and moult stage. Longer trawls (2.5–4 h) corresponded to increased damage in “hard” (intermoult) *Nephrops* compared with short (1 h) or very short (15 min) trawls, but there was no correlation in “soft” (late intermoult or recently moulted) or “jelly” (immediate post-moult) *Nephrops*. This effect appeared to be limited to *Nephrops* with a carapace length (CL) of 20.0–29.9 mm. Seasonal effects were also observed, with numbers of jelly *Nephrops* highest in May 2006, corresponding to a peak in female prevalence in the catches, an increase in the mean CL of females, and greater damage in females. The proportion of females was higher than males from May to September 2006, and it is suggested that this corresponds to female emergence patterns. As quality will be low, it may be pertinent to avoid fishing during the peak emergence period to maximize the quality and profitability of catches.

**Keywords:** Clyde, damage, injury, management, *Nephrops norvegicus*, trawling.

Received 19 September 2008; accepted 9 January 2009; advance access publication 19 February 2009.

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**Introduction**

Physical contact with trawling gear causes damage to benthic organisms and habitats (Kaiser and Spencer, 1995; Tuck et al., 1998; Collie et al., 2000) and increased mortality in both finfish and shellfish (Chopin and Arimoto, 1995; Kaiser and Spencer, 1995; Lancaster and Frid, 2002). Physical damage is detrimental to discarded species, because it may lead to reduced growth rates, increased risk of infection or predation, or mortality, whereas damage to the target species can lead to a lower quality catch and reduced yield for fishers and may be particularly important in organisms that are to be sold alive because physical damage can result in distressing blood loss (Uglow et al., 1986) that could affect rates of survival.

The fishery for *Nephrops norvegicus* (Norway lobster) is currently the most valuable in Scotland, with landings worth an estimated £89.3 million in 2006 (FRS, 2008). *Nephrops* is a mud-burrowing decapod crustacean, mainly caught by demersal trawl gear in Scottish waters, although creels are also used inshore. The landed catch may be sold as “tails” (the cephalothorax removed), or as whole or live animals. Whole and live *Nephrops* are more valuable than tails, which are typically processed as “scampi”, so reducing damage in these animals may improve the end product both in terms of aesthetics, and by improving survivability during processing. Physical damage and limb loss affect survival in decapod crustaceans (Juanes and Smith, 1995; Kaiser and Spencer, 1995; Bergmann and Moore, 2001), so may affect the quality of *Nephrops* being transported live or discarded at sea, with implications both for industry and the local environment. In *Nephrops*, damage to the abdomen reduces survival rates significantly in discarded individuals and may lead to necrosis of the tail muscles (Stentiford and Neil, 2000; Harris and Andrews, 2005). Such animals may be unfit for sale and will reduce the overall value of the catch.

As with many fisheries, the Scottish *Nephrops* fishery is subject to quota restrictions as defined by the EU Common Fisheries Policy, so it is important that landed catches are of the highest quality to maximize the profit to fishers and to minimize unnecessary loss (Ridgway et al., 2006). A minimum landing size (MLS) is also enforced in this fishery, and undersized *Nephrops* (<20 mm carapace length, CL, on the Scottish west coast) will be discarded at sea.

Most studies that have examined the effects of trawling on the physical condition of the catch focused on the discarded organisms and the rates of mortality (Wasasen and Hill, 1989; Juanes and Smith, 1995; Bergmann et al., 2001; Troffe et al., 2003), and few have examined the physical condition of *Nephrops* landings. Those completed include work by Symonds and Simpson (1971), who report a relationship between claw damage and mortality rates in undersized *Nephrops* as a result of trawling in the Irish Sea. For the Clyde *Nephrops* fishery,
Ridgway et al. (2006) reported a positive relationship between trawl duration and the extent of physical damage in *Nephrops*, with greater mortality of heavily damaged than undamaged animals. Both those studies were on a relatively small scale, however, and they only examined *Nephrops* from a few trawls once or twice in the year.

*Nephrops* populations are known to undergo seasonal cycles of moulting and breeding, which may also affect the overall quality of catches. These cycles are well known in the Clyde Sea area and elsewhere (Thomas and Figueiredo, 1965; Bailey, 1984; Tuck et al., 1997, 2000; Bell et al., 2006). However, these seasonal changes have not been analysed in terms of their effects on the physical condition of *Nephrops* catches to date, nor has their impact on the quality of fishing catches throughout the year. Previous work has reported increased damage in decapods during the moulting season (Smith and Howell, 1987; Wassenberg and Hill, 1989), including *Nephrops* (Ridgway et al., 2006), but no studies have been carried out to explain changes over the course of an entire year. Differences between sexes may also be important in determining their availability and susceptibility to trawl gear.

Here, we examine the extent of physical damage in *N. norvegicus* from the north Clyde Sea area in relation to seasonal and trawling factors and propose modifications to current practice that may benefit commercial fishers in the region.

**Methods**

Between October 2005 and December 2006, 20 trawls were carried out in the north Clyde Sea area (Figure 1) by the RV “Aora” (22 m, 522 kW) from the University Marine Biological Station, Millport (UMBSM), using a commercial 80-mm, diamond-mesh, dual-purpose trawl with rubber groundrope and fitted with a square-mesh panel in compliance with regulations. Sampling took place on 1 or 2 d monthly, and one or two hauls were made per day. Trawl duration was either short (≈1 h) or long (2.5–4 h), although two very short trawls were also made in June 2006 lasting 15 min each. A minimum of one short trawl was made during each month sampled. All trawls were carried out during daylight.

Following the recovery of each trawl onto the deck, the *Nephrops* were separated from the rest of the catch. A random sub-sample of ~5 kg (up to 300 animals) was taken, and the sex, CL, carapace hardness, and level of damage of each were recorded. No fewer than 127 *Nephrops* were sampled from each trawl.

The carapace hardness was taken as a simple measure of the moult stage of individual *Nephrops*, and it was considered to be “hard” if there was no noticeable “give” when squeezed just behind the eyes, and “soft” if squeezing caused clear distortion. The entire exoskeleton of “jelly” animals was very soft and gave no resistance to pressure. Jelly animals were assumed to have moulted very recently, soft animals to be late intermoult (i.e. calcium withdrawn from exoskeleton) or to have recently moulted (but no longer jelly-like), and hard animals to be intermoult. This methodology is somewhat subjective, but it was deemed to be suitable for this study because just two people were involved in the analysis.

Damage was scored against a three-level index (no damage, slight damage, severe damage) introduced by Ridgway et al. (2006) and presented in Table 1. Injuries were not counted if there was evidence of tissue regeneration indicative of an old injury.

**Data analysis**

The data were analysed using ANOVA or t-tests where the relevant assumptions could be met. Any proportions were arcsine-transformed before testing. Where assumptions could not be met, a non-parametric Kruskal–Wallis, Mann–Whitney, or Chi-squared test was used. Post hoc Kruskal–Wallis multiple-comparisons analysis was used to determine where differences existed within significant relationships. A 95% significance level was used throughout.

**Results**

**Trawl duration and damage**

Overall, trawl duration appeared to have a significant impact on the physical condition of the *Nephrops* captured, with more slightly and severely damaged animals in long trawls than expected from a Chi-squared analysis (*p* < 0.001) compared with short and very short trawls. Very short trawls appeared to cause significantly

![Figure 1. Map of the study area and surrounding waters. The boxes indicate the regions from which the trawl samples were taken (after Stentiford et al., 2001).](https://academic.oup.com/icesjms/article-abstract/66/3/488/816719/1)
less damage than both short and long trawls \( (p < 0.001) \), as shown in Figure 2.

The level of damage was also affected by carapace hardness. Jelly animals were more likely to be severely damaged than soft or hard ones, whereas hard animals were more likely to be undamaged \( (\chi^2 = 1108.982, \text{d.f.} = 4, p < 0.001) \). When carapace hardness was taken into account, trawl duration had a significant effect only on hard Nephrops, with more animals slightly and severely damaged in long trawls than in short and very short trawls (Figure 3). Trawl duration did not significantly affect the extent of damage in soft or jelly Nephrops \( (\chi^2 = 29.44, \text{d.f.} = 4, p < 0.001) \). There was no significant difference in carapace hardness between long and short trawls \( (\chi^2 = 0.638, \text{d.f.} = 2, p > 0.05) \).

The CLs of Nephrops were significantly less in long trawls (median 27.3 mm) than in short (median 28.1 mm) and very short (median 28.4 mm) trawls \( (p < 0.001) \). Smaller animals were more likely to be slightly or severely damaged (median 27.3 mm) than in short (median 28.1 mm) and very short (median 28.4 mm) trawls \( (p < 0.001) \). There was no significant difference in carapace hardness between long and short trawls \( (\chi^2 = 0.638, \text{d.f.} = 2, p > 0.05) \).

When this was taken into account, a greater number of smaller animals, all Nephrops from short and long trawls were divided into size categories (Table 2), then analysed separately for damage. Very short trawls were not considered because they were likely to be affected by the small number of samples. Differences in the damage levels were only significant for Nephrops with CLs of 20.0–29.9 mm \( (p < 0.005) \), with greater damage in long trawls. Nephrops of that size range constituted 63.5% of those sampled from short trawls and 69.2% from long trawls. Between 25.0 and 29.9 mm CL, however, there were significantly more females in long trawls than in short trawls. When this was taken into account, a significant difference in damage was found for males only \( (p < 0.01) \). The numbers of each sex did not vary with trawl duration in any other size category, and no category showed differences in carapace hardness.

The mean damage score can be calculated for each trawl, if no damage is arbitrarily scored as 0, slight damage as 1, and severe damage as 2. For Nephrops between 20.0 and 29.9 mm CL, long trawls had a higher mean damage score than short trawls (Table 2). The short trawls scored higher for Nephrops between 10.0 and 19.9 mm CL and >40.0 mm CL.

### Seasonal patterns

At least one short trawl was carried out during each month of sampling, which provided a time-series of data for the entire trial. Long trawl durations were not included in this analysis because the characteristics of the Nephrops were different from those taken in short trawls. Variations in mean CL (MCL) of Nephrops appeared to follow a seasonal pattern (Figure 4). The mean size of males was greater than for females during 8 of the 11 months that sampling took place (MCL: males 29.3 mm, females 25.4 mm; Kruskal–Wallis test, \( p < 0.05 \)). During May, June, and September 2006, the MCL of female Nephrops was greater than in other months and was no longer significantly different from that of males (MCL: males 29.8 mm, females 30.0 mm; Kruskal–Wallis test, May, June, September; \( p > 0.05 \)).

The sex ratio also shifted during this summer period, with more females than males present in the catches in May, June, and October 2006. Males were more abundant in the catches during the rest of the year, as shown in Figure 5.
Figure 6 demonstrates the changes in the mean proportion of hard, soft, and jelly animals during each month of sampling, subdivided by sex. Overall, hard animals dominated all samples, and jelly animals were most common in May 2006. In males, hard animals also dominated all samples, and no clear patterns were apparent by month. Female *Nephrops* appeared to show more seasonality, with peaks of jelly *Nephrops* in May 2006, soft in June 2006, and hard in October 2005 and September 2006.

The mean damage score varied through the course of the year, and differed between males and females in certain months (Figure 7). For females, scores were highest in May and December 2006, the peak in May coinciding with the peak proportion of females and the greatest proportion of jelly *Nephrops* (Figure 8). For males, scores were highest in November 2005 and December 2006.

For both males and females, Spearman’s ranked correlation shows a significant positive correlation between the mean damage score and proportion of jelly animals. For males, the significance level is 5%, and for females 0.1% ($r_s$: males 0.56, females 0.778). There was a significant negative correlation between the proportion of hard females and the mean damage score at a significance level of 1% ($r_s = -0.705$), but the relationship was not significant for males.

**Discussion**

**Trawl duration and damage**

Overall, our results show that a large proportion of *Nephrops* is damaged during capture and that this is linked to trawl duration in hard animals: long trawls apparently cause more damage than short or very short trawls. However, because only two very short trawls were carried out, and both during the same month, the data for those trawls should be viewed with caution. The lack of any correlation between soft and jelly animals and trawl duration suggests that these animals may simply be more vulnerable to damage during trawling. Ridgway et al. (2006) reported more damaged animals when the proportion of soft *Nephrops* was higher (May/June 2004), although it is unclear how they assessed the moult stage. Results are similar for other decapods. For example, recently moulted *Portunus pelagicus* suffer more severe damage and greater mortality as a result of trawling (Wassenberg and Hill, 1989), and *Homarus americanus* suffer most damage from trawling during the moulting season (Smith and Howell, 1987). Increasing the duration of trawls would be expected to increase the likelihood of an animal coming into
contact with both the trawl gear and other organisms in the haul, as well as increasing the frequency of such contacts. For the Clyde Nephrops fishery, Ridgway et al. (2006) reported a positive correlation between trawl duration and the extent of damage in Nephrops, and Bergmann et al. (2001) reported a similar relationship in certain bycatch organisms.

Slightly smaller animals were caught in long trawls than in short or very short trawls. Diamond-mesh nets are known to distort under the strain of trawling and can become blocked by debris (Main and Sangster, 1981), reducing their effective mesh size. If long trawls also catch more than shorter trawls, the strain on the net would increase, physically preventing animals from escaping from the net. However, the difference in median CL between short and long trawls was small (∼1 mm), and it is unclear whether such a slight difference would have a meaningful effect commercially on the landed catch.

When the sampled Nephrops were subdivided into size categories, it became apparent that increasing trawl duration increased damage only in female Nephrops between 20.0 and 24.9 mm CL and in male Nephrops between 20.0 and 29.9 mm CL. It is unclear why there should be a difference in the extent of damage between male and female Nephrops between 25 and 29.9 mm CL. It may reflect behavioural differences between mature females and males and immature females, but more detailed work would be required to determine this.

Damage to undersize (<20 mm CL) and larger (>30 mm CL) Nephrops was not enhanced by trawl duration during this study. Perhaps undersize Nephrops are simply more fragile and would be damaged by trawling regardless of the duration. If this is the case, then alternative means (such as modifying the trawl gear) could be sought to reduce the numbers of undersize Nephrops appearing in the catches. In contrast, larger Nephrops have a stronger carapace and may be better able to withstand physical damage during trawling. This statement is supported by the mean damage scores in each category, which generally decrease with increasing CL. Our study only examined trawl durations of up to 4 h, so it is possible, although highly speculative, that trawling for longer durations may cause greater damage in larger Nephrops too.

Nephrops with a CL of 20–30 mm are typically “tailed” (the cephalothorax removed) and sold for processing into scampi. The quality of the animal, while important to some extent, will therefore not need to be as high as for larger Nephrops, which are more likely to be sold whole or live. Whole and live Nephrops need to be intact and aesthetically acceptable to be marketable. The results from this study suggest that trawls of up to 4 h duration will not have a detrimental effect on the physical condition of that portion of the catch.

Considering the marketability of trawled Nephrops, product quality depends not only on external appearance, but also on the taste and texture of the meat, which in turn depend on the physiological condition of the animals after being trawled. The physiological condition of Nephrops is compromised by the process of capture (Chang et al., 2005; Ridgway et al., 2006; Bernasconi and Uglow, 2008), and creel-caught Nephrops are in a better physiological condition than trawled animals. Further, Ridgway et al. (2006) found greater mortality associated with longer tow times in the first 24 h after capture, suggesting that animals trawled for a long duration were in a poorer physiological condition than animals trawled for a shorter period. The stresses imposed by trawling are not simply time-dependent, however, as indicated by the recent finding (Albalat et al., 2009) that animals trawled for a short time (as short as 15 min) suffer a reduction in adenylate energy charge values almost equal to those of animals trawled for a long time. This suggests that the exhaustive stresses on Nephrops occur mainly during their first attempts to escape from the net. Studies are required to determine how well the whole, undamaged Nephrops destined for the live market can recover from such capture stresses. Account also needs to be taken of other factors, such as the health status of the animals, which, for the population of Nephrops in the Clyde Sea area, is affected by a seasonal infection by the dinoflagellate parasite Hematodinium (Stentiford et al., 2001).

**Seasonal patterns**

Strong seasonal patterns of spawning and moulting in female Nephrops have been documented for all Scottish Nephrops fishing grounds (Thomas and Figueiredo, 1965; Chapman, 1980; Bailey, 1984; Bell et al., 2006). Mature females typically emerge from their burrows to moult and mate in early summer (April/May) after spawning, and become more prevalent in catches through summer. This greater prevalence generally lasts until late summer, when the females return to their burrows for ~9 months (in the Clyde Sea area) to incubate their eggs.

The increase in MCL and prevalence of female Nephrops in the catches during May, June, and September 2006 determined in this work follows a similar pattern to that reported by Stentiford et al. (2001), although the subject was not specifically discussed in the latter work. Their research was on seasonal patterns in the North
Clyde Nephrops population (following the same transect as the present study) between 1998 and 2000. It also appears that the MCL of Nephrops in the area did not decrease between 2000 and 2006, despite heavy fishing pressure there, suggesting that the Nephrops stock in this area may have remained stable over that period. Over a longer time-scale, however, there is some evidence that the MCL has decreased, because Bailey and Chapman (1983) reported that the typical MCLs of male and female Nephrops were 37.7 and 35.1 mm, respectively, when sampled in 1980/1981. However, the size range of Nephrops is known to vary greatly by area (Bailey and Chapman, 1983; Bell et al., 2006), so it is difficult to draw comparisons with historical data without possessing more detailed information on the Nephrops population in the study area now.

Carapace hardness varied over time, with a greater proportion in jelly form in May than any other month (54% of females, 21% of males). That month coincides with the peak in the proportion of females in the catch, supporting previous evidence that female Nephrops emerge from their burrows in synchrony to moult after their eggs have hatched in spring (Figueiredo and Thomas, 1967; Aguzzi et al., 2004). The peak in jelly animals was followed by peaks in soft and hard Nephrops in June and September 2006, respectively, apparently showing the progressive stages of carapace hardening. Tuck et al. (2000) reported that the onset of sexual maturity was at a CL of ~34.6 mm for female Nephrops in the north Clyde Sea area, although they did report that their estimates were highly variable across a relatively small spatial scale (tens of kilometres) and were much lower for sites farther south in the Clyde Sea area. Similar variability in the size at onset of sexual maturity was also reported by McQuaid et al. (2006) for the Irish Sea. The summer availability to trawlers of large, mature females would explain the increased MCL of female Nephrops in catches between May and September 2006.

Stentiford et al. (2001) reported similar patterns from the Clyde region and gave the main moulting season as spring and summer, with more evidence of synchrony in female Nephrops. We collected jelly Nephrops throughout our sampling period, but this most likely reflects the shorter intervals between moults in immature animals, which moult more frequently than mature ones (Bell et al., 2006), perhaps combined with the lack of synchronicity in mouthing mature males.

Ridgway et al. (2006) reported that 87% of Nephrops catches were soft and 2.1% very soft in May/June 2004, and suggested that very soft animals may remain in their burrows for protection while they are vulnerable. However, perhaps Ridgway et al. (2006) sampled just after the major moult, resulting in the capture of more soft and fewer very soft Nephrops. A shift from a high percentage (~22% of the total catch) of jelly Nephrops to a high percentage (~25% of the total catch) of soft animals (and correspondingly lower percentages of jelly Nephrops) between May and June of 2006 is most likely related to the hardening of the exoskeleton after moultting. If, as appears to be the case, a large proportion of the Nephrops population moultts in synchrony, the timing of sampling becomes crucial, and long-term seasonal studies are the only way of detecting such changes.

There are implications of the results of our study for the fishing industry if it is important to maximize the quality of Nephrops in catches. It would seem that a series of short trawls, rather than fewer long trawls, would help minimize physical damage to the catch. Moreover, for reasons that are not yet clear to us, longer trawls generated catches of Nephrops with a smaller mean size.

If this is a consistent trend, then it provides further argument in favour of short-duration trawls, because larger animals are potentially better able to survive post-capture, which is particularly important if they are sold to the live market (Ridgway et al., 2007). However, the increased cost involved in shooting and hauling fishing gear more frequently would also need to be considered.

Female prevalence peaked in May, and it also remained relatively high through June and September 2006, coinciding with an increased MCL of females and the highest proportion of jelly animals taken throughout our study. When examining females only, the mean damage score also correlates very closely with the proportion of jelly animals, indicating that reduced catch quality is particularly likely through summer.

Jelly animals are unlikely to be marketable owing to the high levels of damage they sustain during trawling and the difficulties in processing them. As female Nephrops (particularly berried females) are obviously much valued as potential broodstock, avoidable depredation should be minimized. In addition, there is increasing evidence that the higher air temperatures during summer cause increased stress and mortality in fish crustaceans (Giomi et al., 2008) and that environmental stressors such as high temperature and aerial exposure during handling may exacerbate conditions such as idiopathic muscle necrosis in Nephrops (Stentiford and Neil, 2000; Ridgway et al., 2007). Some vessels in the Clyde fleet stop fishing voluntarily during the peak moult season in early summer and use the time to carry out maintenance on their vessels (Marrs et al., 2000). Therefore, a voluntary moratorium exists at least to some degree and is a feature that the emerging Scottish Inshore Fishing Group may wish to explore. As such, continuous monitoring of the stocks in the area could be useful to advise fishers and management groups of the best times to stop and to restart fishing, to maximize the profitability of the catches while concurrently minimizing damage loss.

Acknowledgements
We thank the crew of the RV “Aora” (University Marine Biological Station, Millport) for their assistance in the collection of trawl animals, and Sebastian Gornik for his help. The work was supported by a grant from the EU Financial Instrument for Fisheries Guidance (FIFG) Scheme through the Scottish Executive, and by Young’s Seafood Ltd.

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