Predation on hatchery-reared lobsters released in the wild

Gro I. van der Meeren

Abstract: Predation on hatchery-reared lobsters (Homarus gammarus) in the wild was studied in order to identify predators in southwestern Norway on rocky and sandy substrates in winter and summer. Lobsters of 12–15 mm carapace length were tagged with magnetic microtags. About 51 000 juvenile lobsters were released on 10 occasions at three locations. Predator samplings were by trammel nets, eel traps, and videorecordings during the 24 h immediately following the releases. In summer, loss to predators occurred on both rocky and sandy substrates. The loss was lower in winter when lobsters were found as prey in predators caught on sand. The risk of fish predation was highest in the first hours after release, when the lobsters were out of shelter. The wrasses Labrus bergylta and Labrus mixtus were the major predators of lobsters, while Atlantic cod (Gadus morhua), shorthorn sculpin (MyxoceEFalus scorpius), and crab (Cancer pagurus) were mainly winter predators. Winter predators were never as abundant as summer predators. To minimize predatory loss of reared and costly lobsters, they should be released onto rocky substratum in winter. Due to the damage to the predated lobsters, it was not possible to correlate survival against lobster size.

Résumé: Nos études, menées dans le sud-ouest de la Norvège sur la prédation exercée dans le milieu naturel sur des homards d’élevage (Homarus gammarus), visaient à identifier les prédateurs sur des substrats rocheux et sableux, en hiver et en été. Des homards dont la longueur de carapace était de 12–15 mm ont été étiquetés avec des micromarques magnétiques. Environ 51 000 homards juvéniles ont été lâchés en dix occasions à trois endroits. Pour échantillonner les prédateurs, on a eu recours à des trémails, des pièges à anguille et des enregistrements vidéo pendant les 24 h qui suivaient immédiatement les lâchers. En été, la prédation se produisait à la fois sur les substrats rocheux et sur les substrats sableux. Elle était moins intense en hiver, les prédateurs ayant consommé des homards se retrouvant surtout sur le sable. Le risque de prédation par des poissons était au maximum dans les premières heures qui suivaient le lâcher, lorsque les homards étaient dépourvus d’abris. Les labres Labrus bergylta et Labrus mixtus étaient les principaux prédateurs des homards, tandis que la morue (Gadus morhua), le chaboisseau (MyxoceEFalus scorpius) et le crabe (Cancer pagurus) étaient surtout des prédateurs d’hiver. Les prédateurs d’hiver n’ont jamais été aussi abondants que les prédateurs d’été. Pour minimiser les pertes par prédation des coûteux homards d’élevage, il faudrait les lâcher en hiver sur des substrats rocheux. Étant donné les dommages subis par les homards soumis à la prédation, il n’a pas été possible de corrélérer la survie à la taille des homards.

J15264

G.I. van der Meeren. Institute of Marine Research, Austevoll Aquaculture Station, N-5392 Storebø, Norway. e-mail: gro.van.der.meeren@imr.no


Predation on hatchery-reared lobsters released in the wild

Gro I. van der Meeren

Introduction

Releases of reared juvenile lobsters (Homarus sp.) have been made for more than 100 years on both sides of the North Atlantic Ocean (Addison and Bannister 1994), including Norway (Appelöf 1909; Dannevig 1928; Tveite and Grimsen 1995). Through the development of the magnetic binary-coded microtag, it is possible to tag lobster juveniles before release into the sea for recognition years later in commercial landings (Jefferts et al. 1963; Wikins et al. 1986). A series of releases of tagged juvenile lobsters have since been conducted in Europe (LateFuite and Lorec 1991; Ban-

nister et al. 1994; Agnalt et al. 1999).

In Norway, a large-scale lobster hatchery at Kyrkseterøra was built in 1973 to produce juvenile European lobsters (Homarus gammarus) for stock enhancement and commercial sea ranching (Grimsen et al. 1987). Since 1988, the In-

stitute of Marine Research has studied the potential benefit of releasing juveniles into local lobster stocks (Borthen et al. 1998).

Information on predators of juvenile European lobsters is scarce and is usually based on anecdotes and not quantified observations during release of reared juveniles (Howard 1983; van der Meeren 1991). The aim of this paper is to identify seasonal variation in lobster loss to predators in the first 24 h following release, compare lobster loss to pred-

ators after release to rocky versus sandy bottom, and identify species of lobster predators and their occurrence and activity as predators during different seasons. Recommendations to re-

duce loss of juvenile lobsters in future releases will be made.

Materials and methods

Study sites

The research program, conducted between 1988 and 1994, consisted of two main components. First, there were a series of large-scale releases to evaluate the possibility of enhancing local lobster stocks, and hence the fishery (Agnalt et al. 1999). This project component was undertaken within the context of the Norwegian Sea Ranching Programme (PUSH) and in cooperation with local
fishermen. Lobsters were released at the complex archipelago of Kvitsøy, which has approximately 81 700 km of shoreline (Fig. 1). The project’s second component was designed to evaluate how, when, and where to release lobster juveniles so as to minimize postrelease loss. These latter releases took place at selected locations at Øygarden and Huftarøy, Hordaland County, Norway (Fig. 1). The releases at Øygarden were conducted in Langsyssundet, a narrow sound with shorelines exhibiting well-defined areas of rocky substrate covered with boulders and cobble (rocks) and also areas with soft bottoms (sand). Lobsters were released onto each habitat type. At Huftarøy, lobsters were released by divers onto three rocky areas simultaneously and in patches of high density.

Techniques for low-cost transportation and large-scale (>20 000 individuals·day−1) release of lobster juveniles, as well as lobster behaviour in the first minutes after a release, have been described elsewhere (van der Meer 1991, 1993).

Tagging and release techniques

Lobsters were hatched and reared at the large-scale lobster hatchery, Kyrksæterøra, Norway. Lobsters released from 1990 to 1994 were tagged with magnetic binary-coded microtags (North West Marine Technology Inc.) at 5–8 months of age, which represented a carapace length of approximately 12–15 mm. Older lobsters (12–24 months old, 22–32 mm carapace length), released in August 1988, were marked by burning small spots in their carapace (Abrahamsson 1965). They were packed in damp transportation boxes and cooled with ice and arrived at the release location within 18 h. On arrival, lobsters were given a minimum recovery time of 30 min in ambient seawater. They were then released into the sea surface in shallow waters (<10 m). All individuals were released within 3 h of opening the transportation boxes. Transport-related mortality was <5%.

Releases were conducted in summer (May, June, and August) and winter (December, February, March, and April). The releases were done at Langsyssundet and Kvitsøy were not more than one lobster per 1 m of running shoreline, as recommended by the Institute of Marine Research research team. However, the fishermen charged with conducting some of the releases often did so at higher densities, especially in areas that they thought were “good lobster places.”

Approximately 51 200 juvenile lobsters were released during this study. A total of 10 releases were done: four at Langsyssundet, four at Kvitsøy, and two at Huftarøy (Table 1). The releases in Langsyssundet consisted of three winter releases totalling 3850 lobsters and one summer release of 2100 lobsters. Winter releases of 35 688 lobsters, from 11 000 to 29 000 juveniles each year, were conducted at Kvitsøy, and two summer releases totalling 9500 lobsters were conducted at Huftarøy.

Winter releases at Kvitsøy were conducted by local lobster fishermen within their own established fishing grounds. Rocky substrates were favoured, but due to the complex and variable bottom topography and the high numbers of lobsters for release, individuals were probably also released onto sand. On one occasion (April 1993), the releasers were instructed to place groups of lobsters on rocky substrate and on sand for comparison (Table 1). Summer releases were not conducted at Kvitsøy. Divers were used occasionally to determine whether predation was a factor during winter releases in March at Kvitsøy and Langsyssundet.

For the August 1988 summer release at Huftarøy, lobsters were released at 3–6 m depth onto rocky substrate. They were released directly from the transportation boxes without acclimatisation. Divers observed the lobsters on the bottom for 45–60 min following this release.

The June 1991 release at Huftarøy was conducted to make videorecordings. These lobsters were acclimated to ambient seawater temperature in open trays for at least 1 h and were released one or two at a time over a seaweed-covered sand bottom. A diver with a video camera was situated on the bottom and recorded both the descent of the lobsters and the activity on the sea bottom. One series of releases was conducted at 1 m depth along a portion of the shore where the sandy and rocky bottom met, while the rest of the releases were at depths of 3 m on sand covered with kelp.

Predator sampling

The predation records and counts of eaten lobsters/lobster tags were made using 59 trammel net hauls, six eel trap hauls, approximately 20 min of videorecordings, and direct observation done by divers (Table 2). Similar trammel nets were available at all locations and were used to provide comparable data on the diversity of swimming organisms and potential predators. Eel traps were used on an occasional basis to fill in catches of bottom-dwelling species too small to be caught in trammel nets but still potential lobster predators. The sampling at Langsyssundet was undertaken using trammel nets set during the 24 h after each release. The nets covered more than half of the release area, and the number of nets varied according to the size of the release. The trammel nets were 2 × 28 m with a fine mesh of 70 mm and a coarse mesh of 460 mm.

At Kvitsøy, sampling was done during the 24 h after each lobster release. Due to the complex bottom structures at Kvitsøy, a mixture of the two bottom types could be found nearly everywhere, but the sampling was done by systematic fishing in eight selected areas: four dominated by rocks and four with more sand. Eight trammel nets, similar to those deployed at Langsyssundet, were used in the same locations immediately after each release once a month from April 1993 to April 1994. In addition, the one instance from the monthly fishery where a lobster predator was present is included in this paper.

At Huftarøy, predator sampling was on rocks only, with one trammel net and two eel traps deployed at each of the three locations immediately after the release in August 1988 and then once a week for 4 more weeks. The three-chambered eel traps were circular, 1.5 × 0.45 m, with a 3.5 × 0.45 m leading net at the entrance. Mesh size of the leading net and first chamber was 35 mm, 30 mm in the second chamber, and 25 mm in the third chamber. Sampling was undertaken directly on the release sites and not in the surrounding areas.

Surface sea temperature was measured at release or was obtained from routine monitoring established at certain locations. These data were used to evaluate whether sea temperature and lobster predation were correlated.

Statistics

A $\chi^2$ test was used to compare the distribution of numbers of animals from the most important predatory groups in the samples (catch composition) during winter and summer at each location ($H_0$: no difference in the species composition between summer and winter at any given location). The same test was used to make between-location comparisons ($H_0$: no difference in the species composition between locations in either winter or summer).

Possible between-season (and bottom substrate) differences in predation were evaluated using the Fisher exact probability test and the $\chi^2$ test ($H_0$: no differences in predation on lobsters on rocky and sandy bottom in winter and summer). Each of the release locations was tested separately due to small differences in release technique between teams as well as regional differences in bottom substrates and local fauna.

Spearman rank correlations ($r_s$) were used to test the relationships between sea temperature and catch (fish and crustaceans) per net per day (CPUE), eaten lobster juveniles or lobster tags per net per day (LPUE), and numbers of individual predators per net per day (PPUE) using data from all three locations ($H_0$: no differences in catch of fish, number of lobsters eaten, or number of lobsters per predator at different temperatures). The correlations were based on
the nine samplings associated with the lobster releases for stock enhancement purposes. The data from June 1991 and June 1993 were therefore omitted.

A one-tailed Student’s $t$ test on log-transformed size measurements was used to compare the size of Atlantic cod (*Gadus morhua*) with versus without lobster remnants in the gut. In cases for which the size distributions were not normally distributed, the one-tailed Mann–Whitney $U$ test was used to evaluate size differ-
ences between other lobster predators and their conspecifics ($H_0$: individuals that preyed upon lobsters were not different in size from their conspecifics that did not prey upon lobsters).

## Results

### Season

The summer release at Huftarøy in August resulted in substantial losses of lobsters. When lobsters were released without prior acclimatisation, as in this case, they were either passive for at least 15 min, swimming vertically up and down in the water column, or climbing to the top of rocks and kelp. This was in gross contrast with later releases. When divers inspected parts of the release areas 30 min after release, the acclimatised lobsters had moved into shelter. Only on a few occasions could parts of antennae, claws, or tails be seen.

Divers commonly saw attacks by predators during summer releases, but not winter releases, at Kvitsøy and Langøysundet. The visual impression from Huftarøy was that Labridae were the dominant predators, and massive attacks on lobsters by the wrasse *Labrus bergylta* were recorded in June. Within 16 min, 17 attacks and nine killings were registered. In August 1988, reports from divers described numerous fish, mostly Labridae, attacking and eating lobsters within minutes after the release. At all three locations, divers estimated the immediate loss to be more than 10% of the lobsters within the first hour. Despite the limited fishing effort (Table 1), 0.17% of the released lobsters were found in the stomachs of fish the 24 h following the release (Table 2). Divers also reported crushed lobsters in Labridae feces at one of the release locations the next day, but no live lobsters. A significantly higher fraction of the released lobsters were eaten after the summer release at Langøysundet compared with winter releases at the same location ($p = 0.0001$). The predation in the summer at Langøysundet, as recorded from stomach analyses, and the visually observed predation at Huftarøy occurred with much less difference both on rocks and on sand (August 1988 and June 1991; Fisher exact probability test, $p = 0.814$) (Table 2).

### Bottom substrate

Significantly higher numbers of lobsters were found eaten by fish and crustaceans caught on sand than on rocks, both at winter releases at Langøysundet (73.7%; Fisher exact probability test, $p = 0.0012$) and at Kvitsøy (87.5%; Fisher exact probability test; $p < 0.0001$). The predation in the summer at Langøysundet, as recorded from stomach analyses, and the visually observed predation at Huftarøy occurred with much less difference both on rocks and on sand (August 1988 and June 1991; Fisher exact probability test, $p = 0.814$) (Table 2).

### Predators

The highest CPUE in the trammel net fishery occurred in the summer, with 32.5 at Kvitsøy and 13.3 at Hufthamar (Fig. 2). CPUE at Langøysundet fluctuated between 4.2 and 13.0, but both the highest and lowest CPUE were after winter releases. CPUE at Kvitsøy in winter were similar to those at Langøysundet and went from 5.8 to 11.9.

In winter, LPUE and PPUE were one to one, except for a December release at Langøysundet, while in summer, LPUE were higher than PPUE (Fig. 2). This difference was mainly due to three predatory species, *L. bergylta*, *G. morhua*, and European flounder (*Platichthys flesus*), often found with two or more lobsters eaten per fish. Usually, only one lobster per predator was found after winter releases, except for two lobster tags found in one shortnose sculpin (*Myxocephaulus scorpius*) stomach in April 1993 and six lobsters found in one *G. morhua* stomach in December 1992. No correlation between the size of the released lobsters and that of the eaten lobsters could be made due to the conditions of the eaten lobsters, being crushed and more or less digested by the predator.

Of the 32 species registered in the predator sampling, 29 were caught in the summer and 24 in the winter (Table 3). Nine of these species, mainly the Labridae, showed predator

### Table 1. Numbers of lobsters released and trammel nets used in the predator sampling.

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Lobsters released</th>
<th>Number of nets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Sum Rocks Sand</td>
<td>Sum Rocks Sand</td>
</tr>
<tr>
<td>Langøysundet</td>
<td>3 Dec. 1992</td>
<td>750 0 750</td>
<td>4 0 4</td>
</tr>
<tr>
<td></td>
<td>27 Mar. 1992</td>
<td>1000 1000</td>
<td>6 6 6</td>
</tr>
<tr>
<td></td>
<td>25 Feb. 1993</td>
<td>2000 1000</td>
<td>700 8 4 4</td>
</tr>
<tr>
<td></td>
<td>Sum</td>
<td>5950 1400 1950</td>
<td>24 14 10</td>
</tr>
<tr>
<td>Huftarøy</td>
<td>24 June 1991</td>
<td>75 – 100 0</td>
<td>75 – 100 16:10 min (video)</td>
</tr>
<tr>
<td></td>
<td>17 Aug. 1988</td>
<td>9500 9500</td>
<td>9 9 0</td>
</tr>
<tr>
<td>Kvitsøy</td>
<td>7 Dec. 1993</td>
<td>5576</td>
<td>8 4 4</td>
</tr>
<tr>
<td></td>
<td>10 Mar. 1994</td>
<td>14160</td>
<td>8 4 4</td>
</tr>
<tr>
<td></td>
<td>18 Apr. 1994</td>
<td>4168</td>
<td>8 4 4</td>
</tr>
<tr>
<td></td>
<td>23 Apr. 1993</td>
<td>11784 5897</td>
<td>8 4 4</td>
</tr>
<tr>
<td></td>
<td>Sum</td>
<td>35688</td>
<td>32 16 16</td>
</tr>
</tbody>
</table>

© 2000 NRC Canada
activity only in the summer. Although the crab *Cancer pagurus* and *M. scorpius* were registered as predators only in the winter, they were found in the catches year-round. Yet 71.4% (n = 5) and 96.0% (n = 48) of *M. scorpius* from Langøysundet and Kvitsøy, respectively, were landed in the winter, indicating a high winter activity of this species (Table 4). Only two species, *G. morhua* and the crab *Carcinus maenas*, were found as active predators in both seasons. In March, the only predator recorded was *M. scorpius*, even though more than 17 000 lobsters had been released at two locations.

The summer sampling from Huftarøy and Langøysundet showed no significant differences in species composition ($\chi^2 = 0.4702$, df = 2, $p > 0.05$) (Table 4). The difference in sampled species composition between summer and winter was highly significant, both at Langøysundet ($\chi^2 = 64.370$, df = 2, $p < 0.001$) and at Kvitsøy ($\chi^2 = 276.630$, df = 2, $p < 0.0001$). While the Labridae dominated in numbers in the summer, the Gadoidae and crustaceans were most numerous in the winter. The very high density of Labridae at Kvitsøy, compared with Langøysundet/Huftarøy, gave a significant difference between sampled species composition at Kvitsøy and at the other locations ($\chi^2 = 9.014$, df = 2, $p < 0.025$). The difference in species compositions between Langøysundet and Kvitsøy was even greater in winter, when the Gadoidae dominated at Langøysundet, while crustaceans and Cottidae were most numerous at Kvitsøy ($\chi^2 = 61.897$, df = 4, $p < 0.001$).

Juvenile lobsters were usually not found eaten at times other than the day of release at Huftarøy or Kvitsøy. The two possible exceptions were at Kvitsøy, where one lobster released in April was later recognised by the tag in an adult lobster delivered by fishermen 1 month after release and one tag found in an *L. bergylta* more than 2 months after release.

The predator size was usually between 15 and 40 cm (Table 5). Most predators did not differ significantly in size from other individuals of their species, but exceptions were seen. In the wrasse *Labrus mixtus*, all predators were females and were significantly smaller than the males and females with no lobster remnants in the stomach (one-tailed Mann–Whitney U test, $p = 0.022$). The wrasse *Crenilabrus melops* predators had a tendency to be among the smaller of that species (one-tailed Mann–Whitney U test, $p = 0.058$), while the wrasse *Ctenolabrus rupestris* tended to be among the larger, although not significantly so (one-tailed Mann–Whitney U test, $p = 0.055$). The two predatory poor cod (*Trisopterus minutus*) caught were both larger than the rest encountered.

**Discussion**

**Release and sampling techniques**

When releasing juvenile lobsters after transportation in cool, damp boxes, acclimatisation to ambient sea temperature is vital to keep the lobsters awake and alert and walking forwards while using the claws and antennae to investigate potential shelters (van der Meeren 1991). However, even when acclimatised and released at the sea bottom instead of the sea surface, summer releases continued to result in higher lobster mortality than winter releases. The most plausible cause for the difference in mortality is found in the predator species composition in summer and winter. The

<table>
<thead>
<tr>
<th>Location</th>
<th>Date</th>
<th>Sum</th>
<th>Rocks</th>
<th>Sand</th>
<th>Sum</th>
<th>Rocks</th>
<th>Sand</th>
</tr>
</thead>
<tbody>
<tr>
<td>Langøysundet</td>
<td>3 Dec. 1992</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>6</td>
<td>0</td>
<td>6</td>
</tr>
<tr>
<td></td>
<td>25 Feb. 1993</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>27 Mar. 1992</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>21 May 1992</td>
<td>6</td>
<td>3</td>
<td>3</td>
<td>13</td>
<td>5</td>
<td>8</td>
</tr>
<tr>
<td></td>
<td>Sum</td>
<td>7</td>
<td>3</td>
<td>4</td>
<td>19</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td></td>
<td>Frequency</td>
<td></td>
<td>42.9%</td>
<td>57.1</td>
<td>26.3</td>
<td>73.7</td>
<td></td>
</tr>
<tr>
<td>Huftarøy</td>
<td>24 June 1991</td>
<td>15*</td>
<td>0</td>
<td>15*</td>
<td>9*</td>
<td>0</td>
<td>9*</td>
</tr>
<tr>
<td></td>
<td>17 Aug. 1988</td>
<td>8</td>
<td>8</td>
<td>0</td>
<td>16</td>
<td>16</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td>Sum</td>
<td>&gt;23</td>
<td>8</td>
<td>&gt;15</td>
<td>25</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>Frequency</td>
<td></td>
<td>34.8%</td>
<td>62.5</td>
<td>64.0</td>
<td>36.0</td>
<td></td>
</tr>
<tr>
<td>Kvitsøy</td>
<td>7 Dec. 1993</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>10 Mar. 1994</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>18 Apr. 1994</td>
<td>4</td>
<td>1</td>
<td>3</td>
<td>5</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td></td>
<td>23 Apr. 1993</td>
<td>1</td>
<td>0</td>
<td>1</td>
<td>1</td>
<td>0</td>
<td>1</td>
</tr>
<tr>
<td></td>
<td>Sum</td>
<td>7</td>
<td>1</td>
<td>6</td>
<td>8</td>
<td>1</td>
<td>7</td>
</tr>
<tr>
<td></td>
<td>Frequency</td>
<td></td>
<td>14.3%</td>
<td>85.7</td>
<td>12.5</td>
<td>87.5</td>
<td></td>
</tr>
</tbody>
</table>

Note: Videorecordings are marked with an asterisk. Numbers of predators were in this case not certain due to the limited frame of the videocamera. Sum is the total numbers, in each region and totally, of lobster predators and eaten lobsters recovered. Frequency is the fraction of lobster predators and eaten lobsters recovered from captures in rocky and sandy habitat.

© 2000 NRC Canada
Fig. 2. CPUE (open bars), as fish/crustaceans per fishing gear, in the first 24 h after the releases of juvenile lobsters. For comparison, LPUE (solid bars) and PPUE (shaded bars) are also presented and are multiplied by 10 to fit onto the graph. Temperature (squares) at the release dates are shown, to see if predation might be temperature dependent. Trammel nets were used for predator fishing, while eel traps were used in addition at Huftarøy.

Van der Meer (1993) showed that a high density of Labridae in summer makes the risk of loss of newly released lobsters to predators much higher than in winter. Mortality could also be due to temperature-enhanced lobster activity, resulting in reduced shelter use and increased predator exposure (van der Meer 1993), but this is less likely. Shelter use in juvenile American lobster (H. americanus) is sensitive to predators (Wahle 1992b). Underwater observations and videorecordings showed that the acclimatised lobsters were seeking shelter within a few minutes after release even in the winter. No acclimatised lobsters could be seen on the sea bottom by divers 30 min after release at any time of the year.

The magnetic steel tag in a released lobster made it easily identifiable even in the stomach of a live fish when checking the catch with a tag detector. Even when the lobster had been dissolved, the tag would reveal age and origin of the lobster. Due to the tags, the quantification of lost lobsters in the samples should be reliable, although it might be underestimated due to lobsters and tags being discarded from the predators before examination. Lobster remnants in Labridae feces were observed less than 24 h after the release in August.

**Bottom substrate and season**

Even though the samplings were not designed to catch all the lobster predators but to present a subsample of the present fauna, this study showed that both the time of year and the bottom substratum are of importance for survival of newly released juvenile lobsters. The distribution of predators could be confused by fish swimming between the bottom types. Yet significantly more predators were captured on sand in winter, in spite of the fact that most of the lobsters were released onto rocks, and one of the important winter predators, Cottidae, is known to be a rock-prefering species (Pethon 1985). This difference in lobster predation between rocks and sand was not found in summer, but that might be due to the change in predator species from bottom-dwelling fish to more mobile species. The Labridae, visually observed when eating lobsters in the summer, seemed to be attracted into the release area. It could also be due to the feeding activity of conspecifics, by the presence of the lobsters, or by the human activity in connection to the releases. Specific substrates, usually cobble grounds, are important nursery grounds for juvenile H. americanus (Wahle and Steneck 1991; Wahle 1992a, 1992b). The vulnerability of juvenile lobsters out of shelter has been demonstrated in H. americanus (Lavalli and Barshaw 1986; Barshaw and Lavalli 1988; Wahle and Steneck 1992) and also recently in H. gammarus (Mercer et al. 2000).

Except for two cases, all the eaten lobsters in this study were found within 24 h after release. This indicates that predators are a hazard mainly to lobsters immediately after release, before they are established within shelters. The major predator groups of H. americanus are similar to the predators found in this study, with Labridae, Cottidae, and crustaceans being the most important predatory taxa. In addition, this study found that the Gadoidae were among the important predators. More species than those presented here have been observed attacking tethered early benthic lobsters in European waters (Mercer et al. 2000).

A remaining unsolved problem is to find the optimal shelter habitats for juvenile H. gammarus. Distribution of settling juveniles in several Brachyura species is caused by habitat selection (Eggleston and Armstrong 1995; Hedvall et al. 1998). Wild juveniles have never been found in Europe either in cobble or in any other habitat (Mercer et al. 2000). On the other hand, the fauna living in cobble grounds in Europe is much more diverse than that in North America (Wahle 1998; Mercer et al. 2000). To develop successful...
lobster release programmes anywhere, it is important to describe the best habitats for juvenile stages in order to offer released juveniles the best possibilities for survival.

Predators
Potential predators were probably missed due to low fishing intensity in relation to the area into which the lobsters were released, gear selectivity, choice of fishing location, or low density of that species compared with fishing effort. Some species might also be potential predators on lobsters of a size another than that of the released lobsters. The lobsters released were all relatively large juveniles in the early benthic phase and some near transition to the adolescent phase in August 1988. *Ctenolabrus rupestris* and *T. minutus* found as predators after this release tended to be among the larger of these species. It is plausible that smaller sized fish of both species would succeed in eating smaller lobsters than the released ones. The data set assembled in this study was not fit for statistical tests of the relationship between predator and lobster size. The lobsters were produced to meet the standard set by the Institute for Marine Research for stock enhancement purposes and not for qualitative ecological experiments. In addition, even if lobsters of various sizes were released, the remnants recovered were usually only the tags or too fragmented to be remeasured. Despite methodical flaws in order to get a more detailed picture of potential lobster predators, our documented predator list presents a series of important predators in European waters, where some are seasonally present in sufficient numbers to negatively impact the survival of released lobsters.

The Labridae, known as an important group of shallow-water predators in tropical and temperate waters (Wahle and Steneck 1992), include the most numerous fish species in Nordic European shallow waters in the summer (Hildén 1984). Representatives of this fish family were found to be the most important lobster predators in this study. These species are active only in summer and autumn in temperate waters, leaving the shallow waters in the winter (Hildén 1984).
The Labridae are more or less dependent on rocky substratum (Hildén 1984), like the habitat into which many of the lobsters were released. Sand occurs in patches within and below rocky shores, well within the swimming range of the Labridae, in most places along the Norwegian coast. Four out of five Labridae species were lobster predators, and *Labrus bergylta* and *L. mixtus* had usually eaten more than one lobster per fish. In this study, most of the Labridae were between 10 and 50 cm. The larger sized species *L. bergylta* and *L. mixtus* are both known to mainly consume decapod crustaceans. Why only female *L. mixtus* were found to be predatory might be due to the territorial males being busy fending off nonterritorial intruders, attracted into their territory by the lobster release, or to size-selective feeding by the smaller females. *Labrus mixtus* is hermaphroditic, and large dominant females in the harem turn into males after the territorial males disappear (Hildén 1984). The smaller Labridae species mainly consume amphipods and copepods (Hildén 1984) but can be expected to be predators on smaller juvenile lobsters than those released in this study.

The second important predator, *Gadus morhua*, is common along the Norwegian coast throughout the year (Pethon 1985). Most of the specimens caught during this study did not contain any lobsters or lobster remnants. However, the ones that did prey on lobsters had eaten several lobsters per fish. If lobsters released in high densities can induce search selectivity in these highly mobile predators, the potential for substantial loss of lobsters is high.

Crustaceans, like the Brachyura *C. pagurus* and *C. maenas*, are commonly found along the Norwegian coast (Christiansen 1969). They are known to have temperature-dependent activity, being active in the summer (Naylor 1963; Crothers 1968; Karlsson and Christiansen 1996). Yet, predation on juvenile lobsters was seen in the spring, summer, and winter. Still, the number of lobsters taken by crustacean predators was low. The videorecorded crab attacks showed that lobsters had to walk in close to the crab before the crab attacked. Crab predation was recorded on sand, but crabs can catch juvenile lobsters on rocky substrate also (Lavalli and Barshaw 1986). Predation by crabs might be cumulative over time; since they can also forage within rocky shelters, they can probably catch shelter-living lobsters in the weeks and months after the release. In addition, intraspecific competition and predation in newly settled and juvenile Brachyura species, which in many ways are comparable with lobsters, are the most common regulation of population size besides refuge habitats (Kurihara and Okamoto 1987; Pile et al. 1996; Moksnes 1999). This also seems to be true for the European lobster (Mercer et al. 2000). Long-term mortality due to intra- and inter-specific predation needs further study.

*Myoxocephalus scorpius* was the only species to be active

---

**Table 4.** Comparisons of occurrence between the four major predatory families and a fifth group, mainly composed of flatfish and eels, as total number of animals caught at each release location in the summer and winter.

<table>
<thead>
<tr>
<th>Predators (%)</th>
<th>Labridae</th>
<th>Gadoidae</th>
<th>Cottidae</th>
<th>Decapoda</th>
<th>Other</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Langøyssundet (winter)</td>
<td>7</td>
<td>63</td>
<td>5</td>
<td>28</td>
<td>5</td>
<td>108</td>
</tr>
<tr>
<td>Kvitsøy (winter)</td>
<td>12</td>
<td>36</td>
<td>48</td>
<td>102</td>
<td>10</td>
<td>208</td>
</tr>
<tr>
<td>Langøyssundet (summer)</td>
<td>9.8</td>
<td>5.6</td>
<td>0</td>
<td>0</td>
<td>16.7</td>
<td>9.0</td>
</tr>
<tr>
<td>Huftarøy (summer)</td>
<td>86</td>
<td>37</td>
<td>1</td>
<td>0</td>
<td>15</td>
<td>135</td>
</tr>
<tr>
<td>Kvitsøy (summer)</td>
<td>11.6</td>
<td>5.4</td>
<td>100</td>
<td>25</td>
<td>28.6</td>
<td>11.9</td>
</tr>
</tbody>
</table>

*Note:* The frequency of active lobster predators within each group is shown for each region.

*a* The summer sampling at Kvitsøy was not related to a lobster release.

**Table 5.** List of predatory fish species, with mean size, SD, and numbers of documented predators and as well as the rest of catch of the same species.

<table>
<thead>
<tr>
<th>Species</th>
<th>Predators</th>
<th>Others</th>
</tr>
</thead>
<tbody>
<tr>
<td>Size (mm)</td>
<td>SD</td>
<td>n</td>
</tr>
<tr>
<td><em>Labrus bergylta</em></td>
<td>280.0</td>
<td>60.0</td>
</tr>
<tr>
<td><em>Labrus mixtus</em></td>
<td>208.0</td>
<td>14.4</td>
</tr>
<tr>
<td><em>Crenilabrus melops</em></td>
<td>172.5</td>
<td>2.5</td>
</tr>
<tr>
<td><em>Ctenolabrus rupestris</em></td>
<td>180.0</td>
<td>0</td>
</tr>
<tr>
<td><em>Gadus morhua</em></td>
<td>280.0</td>
<td>50.0</td>
</tr>
<tr>
<td><em>Trisopterus minutus</em></td>
<td>300.0</td>
<td>0</td>
</tr>
<tr>
<td><em>Myxocephalus scorpius</em></td>
<td>193.3</td>
<td>31.1</td>
</tr>
<tr>
<td><em>Anguilla anguilla</em></td>
<td>550.0</td>
<td>0</td>
</tr>
<tr>
<td><em>Gobius niger</em></td>
<td>150.0</td>
<td>0</td>
</tr>
<tr>
<td><em>Platichthys flesus</em></td>
<td>360.0</td>
<td>0</td>
</tr>
</tbody>
</table>
as a predator mainly in the winter. One individual of this species was the only predator registered after the release of 17,000 juvenile lobsters in February–March. Due to the low density and its sit-and-wait foraging tactic, it will probably not contribute to lobster mortality in winter at the same scale as the Labridae do in the summer.

The small-sized members of the fish families Gobiidae, Blenniidae, and Pholididae as well as *C. maenas*, *Liocarcinus arcuatus*, and other portunid and xanthid crabs are representative of known and potential predators living in the shallow waters of Europe, presenting a threat to early benthic phase lobsters, at least when the lobsters are out of shelter (Mercer et al. 2000). Rearing the lobsters to more than 15 mm carapace length might protect them from smaller fishes and crustaceans, but they are still vulnerable to predatory fishes longer than 15–18 cm. Due to the high density of the Labridae from May to October, releases of lobsters during this period can be expected to induce high mortality in the lobsters. Predator-deterrent actions could be carried out in order to diminish the numbers of predators from a location prior to releasing the lobsters. Large-scale fishing operations to remove the numerous Brachyura and Labridae living along the coast may disrupt local ecosystems and create unwanted ecological side effects. In addition, if the predators are of commercial importance themselves, such as *G. morhua* and the Labridae in some regions of Norway, removal of the fish will create conflicts with local fisheries. Since the lobsters seem to be quite safe from fish predators as soon as they find shelter, it is not necessary to remove the fish permanently. One tempting, but not tested, solution might be to scare the predators temporarily away by the use of acoustic soundings a short time before the release at the chosen location (E. Ona, Institute of Marine Research, P.O. Box 1870, N-5817 Bergen, Norway, personal communication).

The numbers of lobsters found in fish and invertebrate predators in this study were quite low. When divers estimated the loss after an August release to be more than 10%, the recollection of juveniles from fish stomachs was only 0.17%. The present quantity of predatory lobsters must therefore be regarded as subsamples and should not be expected to represent the total loss within 24 h from release. The actual loss could be up to 100 times the observed 0.17% mortality based on stomach contents. In addition longer term mortality must be expected, even if it was not identified in this study. Because little is known of the natural abundance of European lobsters (Mercer et al. 2000), it is difficult to make recommendations on optimal lobster juvenile density to avoid intraspecific competition and predation, but the new knowledge of predators on newly released lobster juveniles can be used to refine release techniques.

Even if the release techniques used so far were crude and based on guessing more than on fact, recaptures of both winter- and summer-released lobsters do occur regularly today. Relatively high numbers of released lobsters are landed compared with wild lobsters in the commercial lobster fishery of Kvitsøy 3–10 years after the release (van der Meeren and Ness 1991; Tveite and Grimsen 1995; Agnalt et al. 1999) but not enough to make it economically feasible. As long as the production price is more than £1 per released lobster juvenile, loss of juvenile lobsters must be minimised to make the releases economically viable (Borthen et al. 1999).

Based on the present results and previous experience from lobster releases in Norway, the recommendations for when and where to release juvenile lobsters are as follows.

(i) Make a faunal investigation of the chosen release location by monitoring the fish and crustacean species in the area a full year prior to release. This should be done to be able to conduct the releases at the time of year for release when seasonally active predators are not present. In Nordic waters, the releases should be carried out in late winter – early spring to avoid loss due to the summer-active Labridae.

(ii) Release the juvenile lobsters on a substratum that offers sufficient shelter. Rocky bottoms are expected to be suitable, as long as they offer many crevices. Even if the diversity of other crustaceans and small fish is high in such habitats, the alternative sandy bottoms with no shelters have been found to result in higher loss to predators.

(iii) Predator-deterrent actions should not harm existing commercially and ecologically important species in the area to avoid conflicts with local fisheries and the possibility of disruption of the ecosystem supporting the commercial stocks.

Until more knowledge on the ecology of *H. gammarus* is available, the recommendations for where and when to release juvenile lobsters must be given with precautions, and further studies will be needed to confirm or refine the recommendations suggested.

**Acknowledgements**

I wish to thank the Norwegian Sea Ranching Programme (PUSH) and the Institute of Marine Research for their financial support. I am grateful for the field assistance and commitment of Leif Ydstebø and Einar Naustvold from Kvitsøy and of my assistants Harald Ness and Eva Farestveit. Thanks also to Anne Berit Skiftesvik, Jens Chr. Holm, and Rick Wahlke for valuable comments on the manuscript, which clearly improved the quality of the presentation, and Howard Browman for correcting the language in the Materials and methods and Results sections.

**References**


© 2000 NRC Canada


© 2000 NRC Canada