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# Habitat use by roach (*Rutilus rutilus* L.) and perch (*Perca fluviatilis* L.) in response to the presence of cormorants (*Phalacrocorax carbo* L.) and artificial refuges

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## Abstract

The rise in cormorant numbers in England and Wales over the last 25 years and the greater use of inland feeding sites has increasingly brought these birds into conflict with freshwater fisheries. This has highlighted the need for effective management measures that will reduce the interaction between cormorants and their prey, and hence the level of impact on fish stocks and fisheries. One technique that is considered to have some potential in recreational coarse fisheries is the use of artificial refuges. In this study, the habitat of roach and perch was investigated in a small stillwater fishery in eastern England based on the movements of a small number of acoustically tagged fish and an acoustic positioning system. The main aims were to determine the extent to which the fish utilised natural and artificial refuges, and to assess whether cormorant foraging behaviour was influenced by the presence of artificial refuges. The results indicated that the tagged roach and perch both exhibited diurnal patterns of habitat use, utilising open water more by night. Roach tended to refuge in the marginal vegetation during the day and made no use of the artificial refuges. However, in the absence of cormorants the roach spent significantly more time in open water. The perch, in contrast, spent significantly less time in the marginal vegetation and more in one of the artificial refuges over the duration of the study; there was no significant increase in the use of open water. There was no evidence that cormorant foraging behaviour was influenced by deployment of the artificial fish refuges.

## Introduction

The increase in cormorant, *Phalacrocorax carbo* (L.), numbers across Europe over recent years has raised growing concerns about their impact on fish stocks (e.g. Carss, 2002). The population of cormorants wintering in Britain has increased four-fold over the last 25 years (Wernham *et al*., 1999) and, in England and Wales, cormorants have extended their range from coastal areas and now over-winter and feed in many inland areas (Russell *et al*., 1996). This range extension and increase in numbers of birds has increasingly brought cormorants into conflict with inland fisheries.

There is clear evidence that the impact of cormorants can be significant at some sites (Feltham *et al*., 1999), and this can have potentially serious economic implications for fisheries. In England and Wales, cormorants are protected under the Wildlife and Countryside Act (WCA) 1981, which implements the 1979 European Community Directive on the Conservation of Wild Birds (EEC/79/409). The WCA makes provision for killing or taking birds under licence for the purpose of preventing serious damage to fisheries, but licences only allow limited numbers of birds to be killed to reinforce the effects of other scaring methods, and where there are no other effective and practical alternatives. There is therefore a need for effective management measures that will reduce the interaction between cormorants and their prey, and hence the level of impact at affected sites.

As part of a review of potential cormorant management measures, M$^c$Kay *et al*. (1999) noted that underwater fish refuges might offer a relatively low cost option for reducing cormorant impact at certain sites, particularly smaller recreational (rod-and-line) coarse fisheries. Preliminary investigations indicated that underwater refuges could influence cormorant foraging behaviour and reduce levels of damage to fish (M$^c$Kay *et al*., 2003).

In England and Wales, cormorant numbers are highest on inland waters over winter, when natural cover for fish (e.g. weed beds) is at its lowest level and when fish swimming speeds are least (due to the low water temperatures). It is therefore envisaged that fish refuges might provide fish with additional cover and reduce their accessibility to cormorants at a period of the year when they might otherwise be particularly vulnerable to predation. In view of the fact that cormorants should be able to swim faster than most prey species over the winter months (Russell *et al*., 2003), to be effective, refuges would need to attract and ‘hold’ fish while providing protection from predators.

A preliminary appraisal (Russell *et al*., 2003) suggested that the features of artificial habitats most likely to attract freshwater fish are the presence of ‘structure’, to mimic natural habitat features, and overhead cover to provide shading and an enhanced ability to detect oncoming predators. To be effective as refuges from cormorants, structures designed to attract fish also need to provide additional protection from diving birds. For example, by surrounding potential fish holding sites with appropriate sized netting to make them unavailable to cormorants. An initial evaluation, which considered species’ biology/ecology (Russell *et al*., 2003) suggested that freshwater refuges might be most suitable for fish such as roach, *Rutilus rutilus* (L.), and perch, *Perca fluviatilis* L., which are the species most commonly consumed by cormorants at inland fishery sites in England and Wales (Russell, unpublished data).

The use of weed cover and other submerged structures by many freshwater fish species is widely regarded as an adaptation to reduce the constant risk of predation by piscivorous fish (e.g. Savino and Stein, 1989). However, such refuging behaviour tends to restrict the spatial use a species makes of the available food and other resources, and represents a trade-off between the benefits of predator avoidance and the cost of lost feeding opportunities (e.g. Krause *et al*., 1999). It has been noted that predatory success (by piscivorous fish) in aquatic systems decreases as vegetation density increases (e.g. Jacobsen and Perrow, 1998). The consequences include both improved survival of the prey and reduced growth rates in the predator (e.g. Persson and Eklöv, 1995). However, the extent to which freshwater fish species might utilise potential refuge areas as an evasive strategy in response to attack by pursuit divers, such as cormorants, is less clear.

This study sought to describe the behaviour of roach and perch at a small stillwater fishery in Norfolk, eastern England, using acoustic tags and a high resolution positioning system. The aim was to investigate habitat use by the fish, determine the extent to which natural and artificial refuges were utilised, and assess whether fish behaviour was affected by the presence or absence of cormorants. Cormorant presence and activity was monitored simultaneously and related to refuge location and fish behaviour; cormorant foraging efficiency was also evaluated with and without refuges.

## Materials and methods

### *Study site*

The trial was conducted at Bawburgh Lakes Fishery, which is a complex of six lakes situated on the south-eastern outskirts of Norwich in eastern England (Fig. 1). The lake complex was created as a result of gravel extraction and is now managed as a recreational coarse fishery, supporting a range of species. The lake selected for the refuge trial, Works Lake, was one of the smallest lakes on the site (11,000 m$^2$) and was approximately rectangular in shape with a maximum depth of 5 m. The lake was known to hold reasonable numbers of roach and perch as well as a number of other cyprinid species and small numbers of pike (*Esox lucius* L.). Around

20 cormorants were recorded utilising the lake complex at the time of the study, using the site both for foraging and roosting (day and night). No active cormorant management was conducted at the site either before or during the study period.

Works Lake supports a relatively dense stand of submerged aquatic vegetation in the spring, summer and autumn, but at the time of the trial this had died back and the body of the lake was largely devoid of cover. However, the lake still had a strip of emergent vegetation around the margin, although this did not extend beyond 1-2 m in width (to a depth of about 1 m) at any point. The emergent vegetation was denser in some areas than others (Fig. 1).

*Experimental Design*

The refuge trial was conducted between 21st January and 19th February 2002 and comprised three sequential 10-day phases (Table 1), with each phase intended to provide data on a separate component of the fish/refuge/cormorant interaction. In phase 1, fish and cormorant activity was monitored in the absence of refuges, to provide baseline data. In phase 2, refuges were installed and monitoring was continued. In phase 3, active scaring, as necessary, prevented cormorants from alighting on this small lake and foraging, and fish behaviour was recorded in the absence of avian predators.

Two identical groups of refuges were deployed at the start of phase 2. The first (refuge 1) was located adjacent to the margin (~6 m from the bank), and the second (refuge 2) towards the centre of the lake in open water (Fig. 1). Each refuge group covered an area of approximately 7 m in diameter and had a volume of about 90 $m^3$; together the refuges comprised less than 1% of the lake volume. Each refuge comprised:

- four circular, 2 m diameter by 2 m high, free-standing cages constructed of 15 cm wire mesh and each incorporating overhead shade netting and internal ‘structure’ in the form of artificial weed;

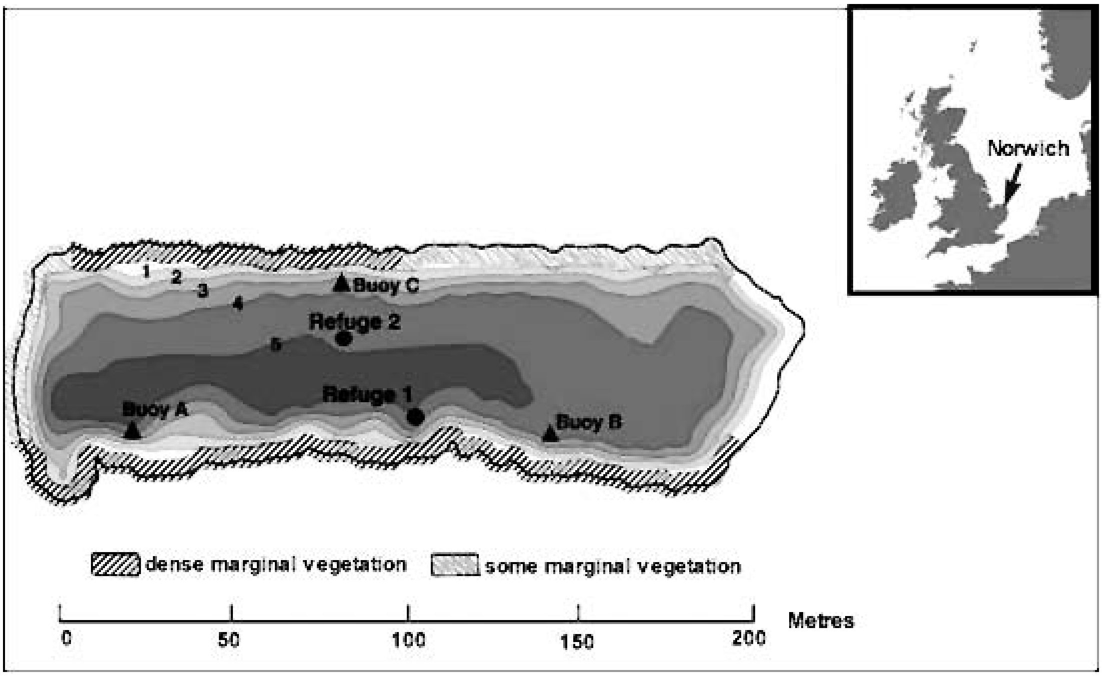

Fig. 1 – Schematic diagram of Works Lake indicating the dimensions, depth contours, refuge locations and the positions of the three fish positioning acoustic buoys, together with a map of the British Isles indicating the location of the study site in eastern England.

Table 1 – Timing and components of the three phases of the refuge trial.

| Phase | 1 | 2 | 3 |
|---|---|---|---|
| Date | 21 - 30 Jan. | 31 Jan. - 9 Feb. | 10 Feb. - 19 Feb. |
| Components | no refuges<br>tagged fish<br>cormorants | refuges<br>tagged fish<br>cormorants | refuges<br>tagged fish<br>no cormorants |

- two rectangular floating cages (2 m x 2 m x 1 m), also made of 15 cm wire mesh, one fitted with overhead shade netting, and the other with a cover of rooted emergent vegetation planted in coir matting;
- one unit comprising ten land drainage pipes (2 m long by 33 cm diameter) strapped together in a pyramid formation;
- two square (2.5 m x 2.5 m) floating covers constructed of black plastic tubing (10 cm diameter) fitted with overhead shade netting.

*The fish tracking system*

A Vemco 'VRAP' high resolution tracking system (Vemco Ltd., Canada) was used to monitor fish behaviour during the study. Three acoustic tracking buoys were deployed in a triangular formation in the lake and the associated tracking system base station and attached PC were positioned on the nearby bank, in a secure weatherproof container. Data were downloaded on a daily basis throughout the 30-day trial.

Roach were captured from the lake margins by electrofishing, but it was not possible to capture perch in this way and fish for tagging were therefore obtained from another site. Both species were retained in a large holding cage in the lake for a few days prior to tagging to ensure there were no adverse effects following capture. Perch varied in size from 17.9-19.7 cm fork length (FL), while roach ranged from 15.6-17.8 cm. Fish were subsequently removed from the holding cage and tagged with miniature acoustic transmitters (Vemco V8Sc). Tags measured 20 mm in length by 9 mm diameter and weighed 2.3 g in air. Fish were anaesthetised using 2-phenoxy ethanol (0.4 $mll^{-1}$) and the transmitters surgically implanted into the peritoneal cavity (Home Office Project Licence No. PPL 80/612). Following full recovery (~15 minutes from tagging) fish were released to the lake. This technique of transmitter attachment has been shown to have negligible physiological and behavioural effects on salmon, *Salmo salar* L., smolts (Moore *et al*., 1990), and has been widely used in fish telemetry studies (e.g. Moore *et al*., 1996; Bridger and Booth, 2003), including investigations of roach behaviour (Jepsen and Berg, 2002).

At the start of the trial on 21st January, eight acoustically tagged fish were released, the maximum number possible with the positioning system, comprising four roach and four perch (Table 2). In the event, only three of these fish, 2 perch and 1 roach, were recorded throughout the 30-day experiment and some of the tagged fish 'disappeared' relatively soon after tagging (Fig. 2). Therefore, two further roach were tagged and released on 5th February, during phase 2.

*Analysis of fish tracking data*

The tracking system was able to record about 20 'fixes' per hour for each tag. After initial filtering, these data were assigned, initially, to one of four categories: open water, lake margins (including '*no solution*' and '*out of range*'), refuge 1 and refuge 2. The co-ordinates delimiting refuges 1 and 2 were characterised prior to the study by using a dummy tag deployed around the edges (within 1 m) of each refuge position. Fish were assigned to 'refuge 1' and 'refuge 2' even for phase 1 (when no refuges were actually present), in order to provide a control. Given the small size of the lake and its relatively uniform shape, it was noted that tags were never recorded as '*out of range*' when tested within open water areas. However, tags deployed within the marginal vegetation did constitute effec-

Table 2 – Fish tagging details (species, length, weight) and track duration.

| Tag No. | Tag Freq kHz | Species | Fork Length cm | Weight g | Released |  | Last detection in open water |  | Track duration days |
|---|---|---|---|---|---|---|---|---|---|
|  |  |  |  |  | Date | Time | Date | Time |  |
| 2131B | 66 | Perch | 19.7 | 137 | 21-Jan | 11:50 | 5-Feb | 07:39 | 16 |
| 2138B | 75 | Perch | 18.6 | 113 | 21-Jan | 11:50 | 20-Feb | 12:33 | 30 |
| 2133B | 69 | Perch | 17.9 | 99 | 21-Jan | 11:50 | 29-Jan | 08:02 | 9 |
| 4834B | 81 | Perch | 18.5 | 111 | 21-Jan | 12:45 | 20-Feb | 12:34 | 30 |
| 2136B | 72 | Roach | 16.5 | 77 | 21-Jan | 12:45 | 26-Jan | 12:32 | 6 |
| 2129B | 63 | Roach | 17.8 | 100 | 21-Jan | 12:45 | 12-Feb | 15:47 | 23 |
| 2139B | 78 | Roach | 15.6 | 64 | 21-Jan | 12:45 | 20-Feb | 12:08 | 30 |
| 4837B | 84 | Roach | 16.0 | 70 | 21-Jan | 12:45 | 30-Jan | 08:13 | 10 |
| 4836B | 84 | Roach | 17.1 | 87 | 5-Feb | 13:30 | 20-Feb | 12:34 | 16 |
| 4831B | 72 | Roach | 15.8 | 67 | 5-Feb | 13:30 | 6-Feb | 11:44 | 2 |

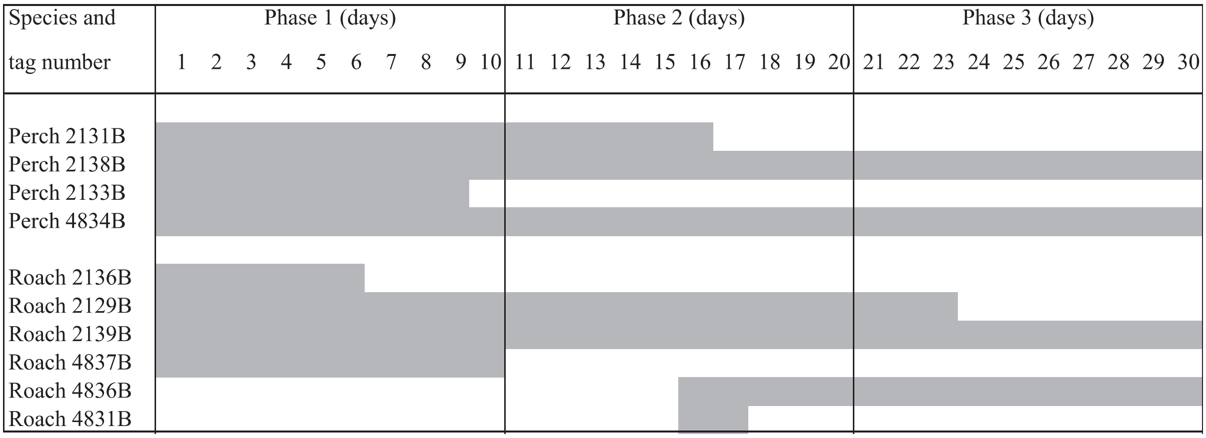

Fig. 2 – Schematic representation of the duration of each of the individual fish tracks (shaded blocks) relative to the three trial phases.

tive ‘blind spots’ for the tracking gear. Hence, for analysis purposes, fixes indicating ‘*no solution*’ or ‘*out of range*’ were also designated as being located in the lake margins.

The behaviour patterns exhibited by the roach and perch over the three phases of the investigation were assessed in two ways. For those individuals detected in all three periods (4 fish only), the data were expressed as histograms to illustrate the pattern of habitat use in each period. In addition, statistical analyses were applied to investigate the significance of particular behavioural changes. In view of the variable time periods over which tracking data were recorded, positional data for individual fish were aggregated by species to enable comparison of habitat use during the different phases. In view of concerns about auto-correlation, Monte Carlo randomisation procedures were carried out using the statistical package S-Plus (e.g. Venables and Ripley, 1994). Treatments were compared by randomly permuting the treatment labels before calculating the test statistic (e.g. the difference in means between the two treatments). This was repeated 1,000 times to obtain a simulated null distribution under the hypothesis that there was no difference between the treatments. A p-value was then calculated by comparing the observed value of the statistic against the null distribution.

### *Cormorant Foraging Parameters*

Data on cormorant foraging behaviour were recorded using focal bird sampling techniques.

Individual cormorants using the study lake were observed continuously from time of arrival until time of departure. All observations were conducted from a hide located on the south bank of the lake between sunrise and around 14:30; initial observations indicated that cormorant activity was minimal outside this period. All cormorant activity was recorded with respect to GMT.

For each focal bird, the following data were recorded: (i) length of time present on the lake (foraging bout length), (ii) number of dives, (iii) duration of dives, (iii) total prey consumed, (iv) foraging efficiency (dives per prey item), (v) inter-dive duration, and (vi) total loafing time. Two measures of total prey consumption were calculated: total observed prey and total estimated prey. Total observed prey comprised all fish brought to and consumed at the surface, whilst total estimated prey comprised all observed prey plus prey considered to have been swallowed underwater, evidenced by the bird showing vigorous head and neck movements upon surfacing, as though swallowing an item of prey (Hughes *et al*., 1999). A successful foraging dive was counted when a fish was brought to the surface or if the bird was thought to have consumed prey underwater. Foraging efficiency of individual birds was expressed as the number of dives per prey item consumed. Total loafing time comprised the aggregated periods between arrival and first dive, the period between final dive and departure and any intervals >60 seconds between successive dives during the foraging bout. The number of other cormorants present on the pond was also recorded throughout the stay of the focal bird.

For each focal bird, mean or total values were calculated for each foraging parameter (*mean*: foraging bout length, dive duration, dives per prey item, inter-dive duration; *total*: dives, prey consumed, loafing time). The non-parametric Mann-Whitney U-Test was used to test for differences in cormorant foraging parameters between phases 1 and 2.

The study lake was partitioned into a number of sectors, each measuring approximately 44x14 m and these were further partitioned into edge, marginal and open water zones. The edge zone was defined as the water immediately adjacent to the bank out to a width of ~1.5 m, which included all emergent aquatic vegetation. The marginal zone extended for a further ~3.5 m out from the edge zone. The remaining area of the lake comprised the open water zone. During focal bird monitoring, records were made of the sector and zone in which each dive was initiated, that in which the bird resurfaced and that in which prey capture occurred. This also enabled foraging site preferences within the lake to be compared between the phases.

Variation in cormorant attendance between phases was investigated by comparing daily total counts of cormorant-visits to the trial lake, as it was not possible to identify repeat visits by the same birds in the unmarked population.

## Results

### *Fish behaviour patterns relative to available habitat*

The behaviour patterns exhibited by the two roach tracked throughout the study (Fig. 2) were broadly similar within each of the phases (Fig. 3). Both fish exhibited a diurnal pattern of behaviour, making extensive use of the marginal vegetation during the daylight hours and the open water at night. This diurnal pattern was retained throughout the study; randomisation tests confirmed that throughout all three phases roach made significantly more use of open water habitat during the hours of darkness than in daylight ($p<0.001$). However, the degree of marginal use was observed to fall markedly in phase 3. The mean number of 'fixes' per hour in the margins decreased from an average of 9.6 in phases 1 and 2 to 4.9 in phase 3. The Monte Carlo randomisation test indicated a highly significant increase ($p<0.001$) in the use of the open water in phase 3 compared with the earlier phases. Neither of the roach made positive use of the artificial refuge structures and there was no change in the degree of refuge use over the three phases.

The two perch tracked throughout the study also displayed reasonably similar behaviour patterns within each of the phases (Fig. 4). As with the roach, the perch displayed a diurnal pattern of behaviour, tending to favour open water during the night. The Monte Carlo randomisation test confirmed that, in all three phases, perch also made significantly more use of open water habitat during the hours of darkness than in daylight ($p<0.05$). However, in contrast to the roach, there was no significant increase in the use of the open water by perch in phase 3 compared with the earlier phases. The mean number of 'fixes' per hour in the margins for the perch decreased from an average of 8.1 in phases 1 and 2 to 3.7 in phase 3; a very similar reduction to the roach. The randomisation test of the pooled data confirmed that the perch used the margins significantly less ($p<0.001$) and refuge area 1 (located adjacent to the lake margins) significantly more ($p<0.001$) in phase 3 than phases 1 and 2. None of the tagged perch made more than passing use of refuge 2 during the investigation.

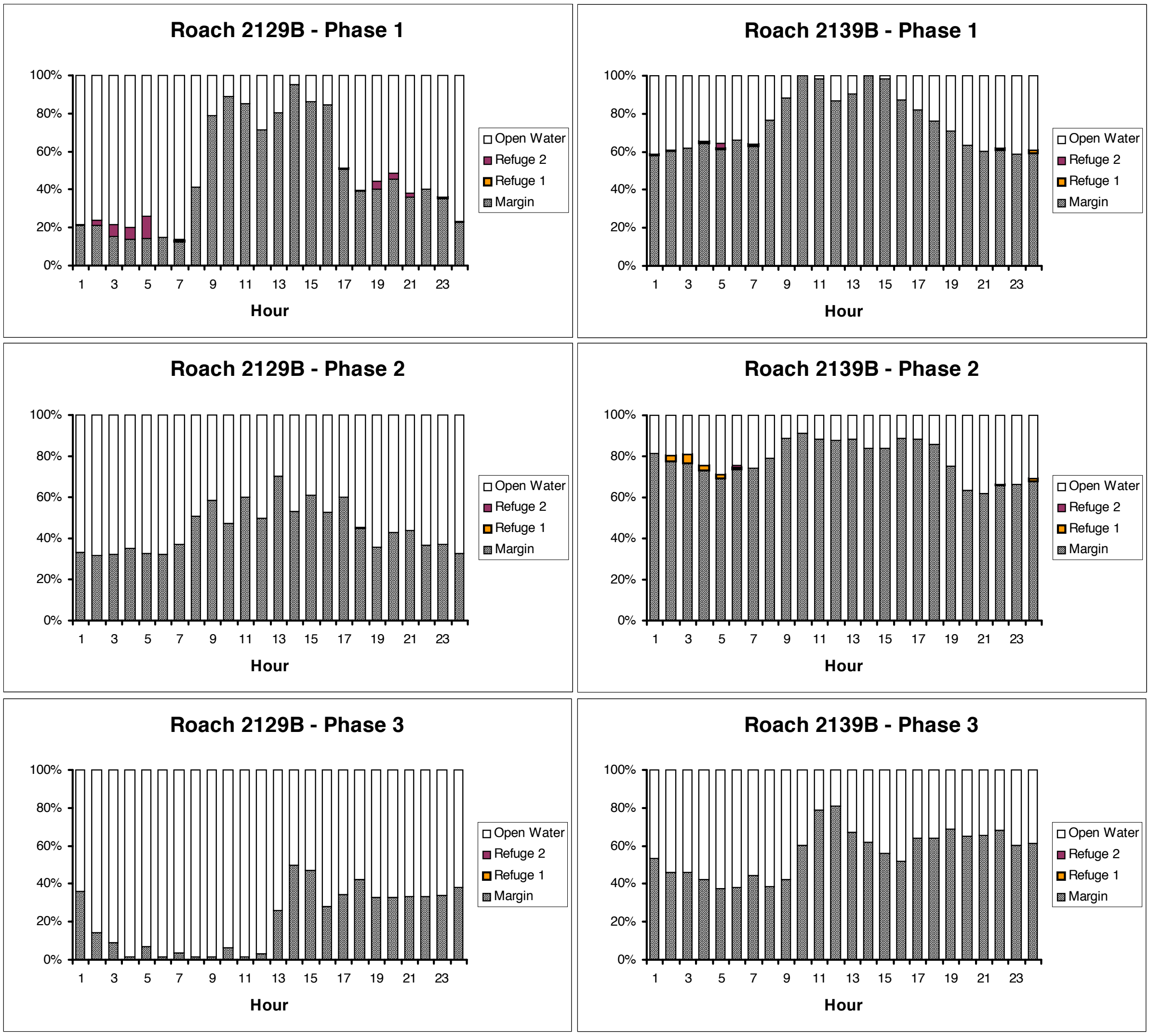

Fig. 3 – Relative habitat use for open water, refuge 1 (adjacent to the margin), refuge 2 (in open water in the centre of the lake), and the margins by two tagged roach tracked throughout the study period.

*Cormorant foraging behaviour*

Observations were conducted on seven days (totalling 48 hr 10 min.) in phase 1 and eight days (54 hr 40 min.) in phase 2. A total of 33 cormorants were recorded visiting the lake during phase 1 and 65 in phase 2. Focal observations were collected from 23 cormorants in phase 1 and 38 cormorants in phase 2. In phase 2, however, 7 of the 38 cormorants fed on mackerel that had been discarded by an angler; these birds, therefore, were omitted from the analysis. Birds were observed to have a diurnal attendance pattern, with peak numbers being recorded between 08:00 and 09:30 and again between 13:00 and 14:00. Although the total number of cormorant-visits virtually doubled in phase 2 compared to phase 1, the median daily number of cormorant-visits did not vary significantly between phases (Mann-Whitney U-Test: $U_{7,8}=18.5$, $p>0.05$).

Cormorant foraging parameters were compared between phase 1 and phase 2 to investigate

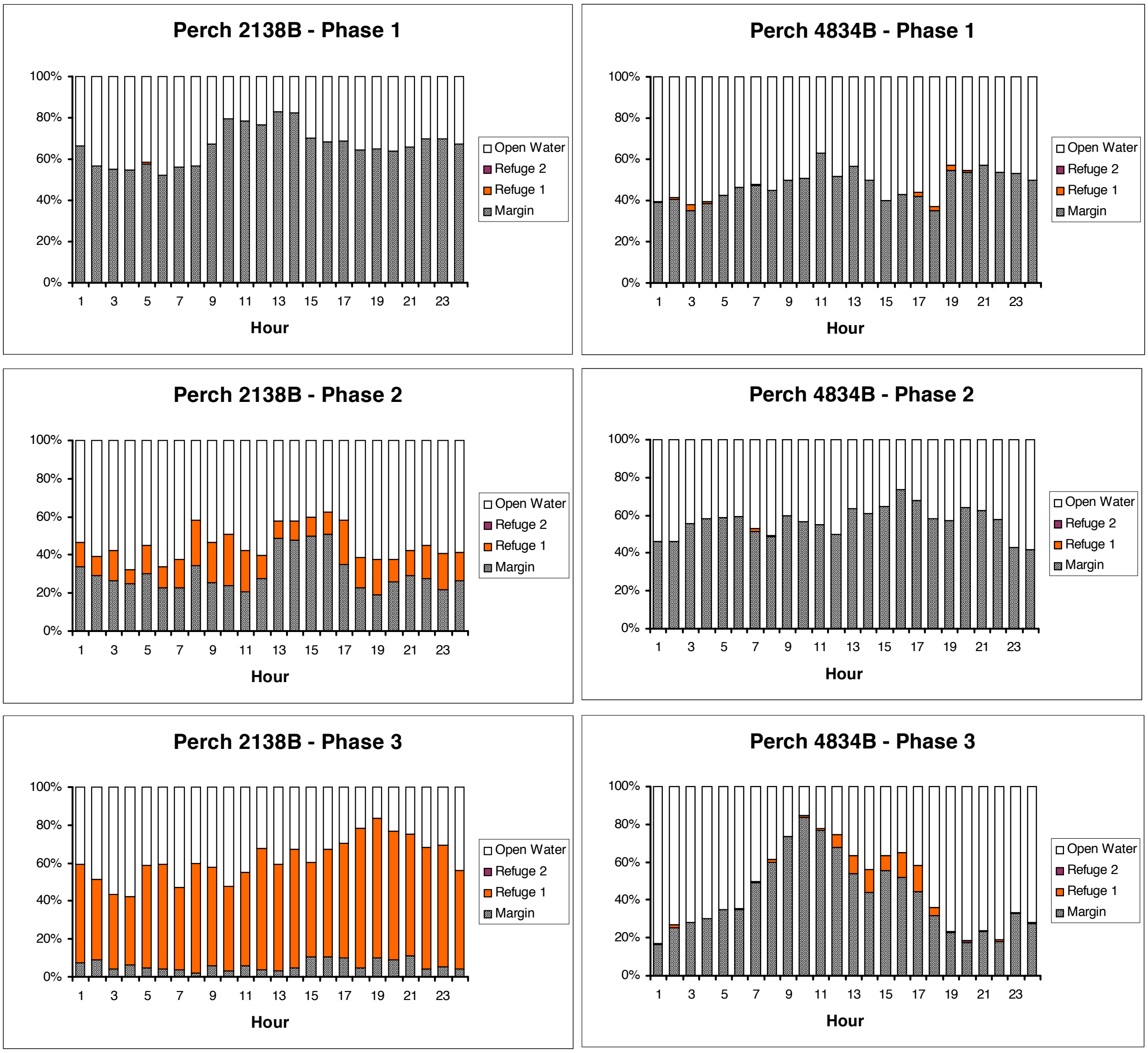

Fig. 4 – Relative habitat use for open water, refuge 1 (adjacent to the margin), refuge 2 (in open water in the centre of the lake), and the margins by two tagged perch tracked throughout the study period.

Table 3 – Comparison of cormorant foraging parameters between phases.

| Foraging parameter | Phase 1 (no refuges) | | Phase 2 (refuges) | | n | U $^{\#}$ | p |
|---|---|---|---|---|---|---|---|
| | median | range | median | range | | | |
| foraging bout (min) | 7.6 | 1.4 - 40.2 | 13.6 | 1.2 - 42.5 | 20, 28 | 173 | 0.025 |
| no. dives | 13 | 1 - 56 | 15 | 3 - 53 | 21, 31 | 265.5 | ns |
| dive duration (sec) | 21 | 16 - 28 | 21 | 12 - 29 | 23, 31 | 316.5 | ns |
| estimated prey consumed | 2 | 0 - 9 | 2 | 0 - 8 | 21, 31 | 290 | ns |
| observed prey consumed | 2 | 0 - 9 | 1 | 0 - 6 | 21, 31 | 263.5 | ns |
| dives/prey item | 6.5 | 1.5 - 16 | 5.8 | 1.5 - 33 | 21, 27 | 242.5 | ns |
| inter dive duration (sec) | 10 | 4 - 18 | 10 | 5 - 24 | 22, 31 | 318 | ns |
| total loafing time (min) | 0.73 | 0.15 – 6.22 | 0.57 | 0.17 – 12.7 | 18, 25 | 208.5 | ns |

$^{\#}$ Mann Whitney U-Test

whether foraging behaviour and/or efficiency differed in the presence of refuges. Foraging bouts were significantly longer during phase 2 compared to phase 1 (Mann Whitney U-Test, p<0.05). However, there was no significant difference in any other foraging parameter (Table 3). That is, although cormorants spent longer periods on the water during phase 2 there was no significant change in foraging intensity or efficiency.

Within both phases 1 and 2, cormorants conducted a greater percentage of dives in open water than close to the margins. However, in general, while birds tended to dive in the open water/marginal zones they were observed to capture prey and resurface more in the edge/marginal zones. The percentage of total dives and resurfaces in the edge zone were 4% and 19% respectively in phase 1 (n=345), and 12% and 48% in phase 2 (n=534). With respect to the location of the two refuges, changes in the relative magnitude of cormorant dives (+4.3%, +1.2%), prey capture (+2.5%, 0%) and overall foraging efficiency (only 2 prey items caught near refuges) in areas adjacent to the refuges did not change disproportionately compared to non-refuge sectors following refuge deployment. Thus, cormorants appeared to be neither attracted to the refuges nor deterred by them.

## Discussion

It is recognised that the fish behaviour data are based on only a very small sample. Only four of the eight fish initially tagged were recorded in each phase of the study, and a number of the other fish were only detected for relatively short periods (Fig. 2). While tag failure cannot be discounted, it is thought that these fish were more probably removed by predators. In two cases, cormorants were observed to be foraging on the lake at the time that the fish were last recorded. This is perhaps not surprising given the level of cormorant occupancy and small size of the lake. It is impossible to assess whether the tagged fish were any more vulnerable to predation. In any event, the results are based only on a small sample of fish and need to be interpreted with caution.

The behaviour of all the tagged perch and roach was consistent in indicating extensive use of the available cover within the lake and highlights the importance of habitat features for both these species. The tagged roach utilised the emergent marginal vegetation throughout the study, despite the relatively limited extent of this cover and the very close proximity of the adjacent reed stems. [N.B. Electrofishing of the margins, outside the study period, confirmed the presence of large numbers of roach, in particular, among this marginal vegetation].

Both the roach and perch displayed clear diurnal behaviour patterns, making significantly more use of the open water during the hours of darkness. This diel movement pattern has long been recognised in common prey species, such as roach and perch (e.g. Allen, 1935; Goldspink, 1990), often with peaks of activity at dawn and dusk (Cowx, 2001). The movements are thought to be influenced by the need to optimise feeding opportunities, mediated by the risk of predation. Movement by prey species is believed to carry a high risk of attracting predators (e.g. Ware, 1973) and fish migrations can affect levels of predation by cormorants (Adams *et al*., 1994; Neuman *et al*., 1997).

Cormorants are normally diurnal feeders and forage especially in the early morning (e.g. van Dobben, 1952), although a second feeding bout can also occur in the afternoon (Hughes *et al*.,1999). The early feeding bout thus coincides with peaks in activity and diel movements in certain key prey species and probably indicates a causative relationship. It has been noted that the precise timing and extent of diel movements by prey species is likely to influence the level of interaction with cormorants (Gliwicz and Jachner, 1992). In this study, the tagged roach were significantly more likely to be found in open water when cormorants were foraging, and the perch also displayed a similar tendency. Hence there was no evidence, in the short-term at least, that the fish were responding to the presence of the birds by moving into refuge areas, either the artificial refuges or the marginal vegetation.

Chub, *Leuciscus cephalus* (L.), have been shown to alter their behaviour patterns in response to the threat of avian predation (Allouche and Gaudin, 2001). Further, it has been noted that some populations of perch adopt 'reverse' diurnal behaviour patterns, feeding in open water by day and moving to the margins at night, suggesting some degree of flexibility and the ability to adapt to local situations (Cowx, 2001). In this study, it was evident that while an element of diurnal habitat use was retained, the roach made significantly more use of open water in phase 3 when there were no cormorants on the water. This suggests increased levels of foraging and may well represent a trade-off between predator avoidance and maximising feeding opportunities. It is difficult to assess the relative extent to which cormorant presence might impact upon fish stocks through lost foraging opportunities, slower growth or increased mortality, although Allouche and Gaudin (2001) suggested that in some circumstances fish-eating birds may affect local prey populations more through sub-lethal effects on growth rates than directly through death rates

There were no significant differences in the cormorant foraging parameters between phase 1 and phase 2, however, the duration of foraging bouts was significantly longer during phase 2. Thus, although cormorants spent longer on the water when refuges were present, there was no evidence that cormorant foraging intensity or foraging efficiency was affected by their deployment. In a previous study (M$^c$Kay *et al*., 2003), artificial refuges resulted in a significant increase in cormorant dive duration and also appeared to reduce the availability of fish to cormorants. Other, more recent studies have confirmed that fish refuges can reduce fish losses and cormorant foraging efficiency (Russell *et al*., unpublished data). The absence of such an effect in this investigation may reflect site-specific factors, for example, the extent of alternative cover or variability in the fish population.

While no significant effect of the refuges on cormorant foraging efficiency was detected, it might be noted that the trial was not designed specifically to investigate this. The principal aim of the trial was to investigate the extent to which fish utilised the refuges and whether usage was influenced by cormorant presence. The most important aspect of cormorant behaviour addressed by this trial was whether cormorants were attracted to possible fish activity in and around the refuges and consequently would focus their foraging activities there. Such behaviour may have important implications for the design and use of refuges. Despite some evidence for refuge use by the perch, there was no such indication of an influence on cormorant foraging location from this study. However, it was not possible to assess the overall extent of fish presence in the refuge areas.

Overall, there was no evidence that cormorant foraging behaviour was influenced by deployment of the fish refuges. That is, refuge deployment was not associated with either a decrease in cormorant foraging efficiency or a change in preferred foraging location, as predicted if refuges decreased the availability of fish. Likewise, there was no increase in either foraging efficiency or activity within the vicinity of refuges, as might be expected if refuges aggregated fish in vulnerable areas. Rather, cormorant foraging activity appeared to be, in the main, directed toward the natural marginal aquatic vegetation. This foraging strategy would be consistent with the evident extensive use of this habitat feature by the fish. By approaching the vegetation from open water cormorants may reduce the escape options available to fish and hence maximise their probability of prey capture.

On the basis of this investigation, it is not possible to make any clear assessment of the potential utility of fish refuges for reducing cormorant impact at freshwater fisheries. The work has provided some evidence that perch, at least, can be attracted to artificial refuge structures. Further, the work suggests that foraging opportunities for such prey species can be influenced by cormorant presence. Further work is required to assess whether refuge structures might be effective at reducing the overall impact of the birds at fisheries. It is probable that any potential benefits will vary from site to site and with the fish species present. The features of a fishery, particularly its size and the extent of existing natural cover, are likely to be important in deciding whether refuges might be effective and where they might be deployed.

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