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ARE HATCHERY-REARED SOLE EQUIPPED FOR SURVIVAL IN THE SEA?

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ABSTRACT

There is accumulating evidence for a wide range of species that the survival of hatchery-reared fish in the natural environment is inferior to that of their wild counterparts. Limited releases have indicated that this is the case for hatchery-reared sole and preliminary laboratory investigations have identified some of the characteristics of the fish that may contribute to their increased vulnerability. The use of sub-optimal diets, particularly in relation to lipids, could have an immediate impact on the survival of released fish by reducing their tolerance to stress. The rapid establishment of feeding was shown to be desirable and was apparent among reared fish released into a mesocosm. Hatchery-reared fish, however, displayed atypical patterns of feeding in comparison with pond-reared fish and further studies are required to identify the causes of this behavioural anomaly. Cryptic behaviour is of particular importance to predator avoidance and the trials showed that conditioning may improve the both the burying response and the rate of the colour adaptation.

INTRODUCTION

Against the background of characteristically variable recruitment and intense exploitation of natural fish stocks it is not surprising that the comparatively new-found ability to mass produce juvenile marine fish in hatcheries has led to a resurgence of interest in the possibility of augmenting natural recruitment with reared fish. The extension of the pioneering work of Shelbourne (1964) on the rearing of the plaice (*Pleuronectes platessa*) and sole (*Solea solea*) to a wide range of species has provided the stimulus for stock enhancement trials in many parts of the world, notably in Japan, with red sea bream (*Pagrus major*) and Japanese flounder (*Paralichthys olivaceus*), and in Norway, with cod (*Gadus morhua*). The sole is arguably one of the most suitable candidates for investigation in this context. The species supports high value fisheries throughout Europe and is consequently subjected to intense fishing pressure. In addition, it is almost certainly one of the easiest of marine fish to rear through its larval stages. Mature fish spawn readily in captivity and the larvae can be reared to metamorphosis with consistently high survival on a diet of newly-hatched *Artemia* nauplii (Baynes et al., 1993) which, if judiciously selected, need no enrichment before use (Howell and Tzoumas, 1991). The juvenile stages do present feeding problems however, which need to be addressed, but current research at this laboratory, on the development of artificial feeds, is producing encouraging results

The success of stock enhancement exercises, however, is dependent on more than an ability to produce large numbers of juvenile fish. The collective experience of restocking programmes with salmonids, as well as the more recent work on marine fish, has demonstrated that intensively reared fish are less capable of survival in the natural environment than their wild counterparts (see e.g. Howell, in press). Recent experimental studies, which form part of a wider ecological investigation of the sole, have provided an indication of some of the factors which might reduce the survival potential of reared individuals in the sea. The observations discussed in this paper relate particularly to stress tolerance, the establishment of normal patterns of activity and cryptic behaviour.

MATERIALS AND METHODS

The juvenile sole used in all the trials described were reared from eggs spawned naturally by captive stocks. Larvae and juveniles, up to a length of about 2 cm, were fed on *Artemia* nauplii hatched from cysts of San Francisco origin. The nauplii were not enriched before use except in 1992 when they were enriched with a proprietary 'booster' diet (Selco) rich in (n-3) HUFAs before being fed to the early juvenile stages. Fish larger than 2 cm were generally fed on chopped fresh mussel (*Mytilus edulis*).

Mesocosms established in outdoor concrete ponds (see Jinadasa *et al.*, 1991) provided an opportunity to assess the performance of reared fish following release into a semi-natural environment. They also permitted a comparison of the characteristics of juveniles reared in ponds with those of fish retained in indoor intensive facilities. Further details of the experimental procedures are provided with the results.

RESULTS AND DISCUSSION

Stress tolerance

Survival rates following release into predator-free mesocosms have been highly variable ranging from 10 to 95%. In trials conducted during 1990 and 1991, survival rates of fish ranging in mean length from 1.5 to 4.0 cm were significantly correlated ($r=0.99$; $p<0.01$; $n=5$) with their length at release indicating that larger fish were better able to tolerate the stress of transfer than smaller fish. There is some evidence that this may reflect a nutritional deficiency during the larval and early juvenile stages when the fish were fed on *Artemia* nauplii. The lipids of *Artemia* nauplii are known to be low in the essential (n-3) HUFAs with correspondingly low (n-3):(n-6) ratios (see, for example, Navarro *et al.*, 1991). Bell *et al.* (1991) found that diets with a low (n-3):(n-6) ratio were deleterious to the health of salmonid fish when subjected to stress. The high survival of larval sole fed on unenriched *Artemia* nauplii (Baynes *et al.*, 1993) is not inconsistent with the view that their nutritional requirements are not being fully met. Watanabe (in press), for example, found that the larvae of some marine species survived well on low (n-3) HUFA diets but that fewer of these larvae survived an arbitrary stress test than groups fed a high (n-3) HUFA diet.

There may also be longer-term consequences of such nutritional imbalances. The survival of 0-gp sole reared in 1991 and 1992 differed appreciably when subjected to similar low temperature regimes (Figure 1). These experiments were not contemporaneous, but the fish were of similar mean length (5-7 cm) and had previously experienced similar environmental conditions (e.g. temperature and photoperiod). Their dietary history, however, did differ, the (n-3) HUFA content of the *Artemia* on which the 1992 fish were fed having been enriched prior to use.

Activity patterns

Trials conducted in actographs, in collaboration with colleagues at the University of Marseille (Macquart-Moulin *et al.*, 1991), showed that unfed juvenile sole exhibited marked nocturnal patterns of swimming activity but that these were totally suppressed when the fish were fed (Figure 2). Thus, a delay in the establishment of feeding of released fish could lead to elevated levels of locomotory activity which would increase their vulnerability to predation and possibly result in them being carried away from the release site to less favourable areas.

Juvenile sole, however, did establish feeding within a short time of release into mesocosms. Two size groups of fish were transferred to cages within the ponds during the late afternoon. Samples were recovered shortly after dusk 6 h later, when feeding activity was expected to be most intense, and at the same time on the two following days. The predominant food items were harpacticoid copepods and chironomid larvae. The mean number of food organisms in the gut showed that the feeding intensity of both size groups was as intense within 6 h of release as it was during the following two days (Figure 3). Although the mean number of prey consumed by the larger fish increased, this was accompanied by a switch from chironomid larvae to the much smaller harpacticoids, possibly reflecting a change in availability, but there was probably no increase in the biomass consumed. The smaller fish showed a consistent preference for harpacticoids. Studies on salmon, for example (Olla *et al.*, 1992), have also shown that feeding on natural prey may be established rapidly after release. Several other species, however, have shown differences in the feeding behaviour of wild and released fish which Suboski and Templeton (1989) suggested could be reduced by pre-conditioning to natural prey before release.

Patterns of feeding may also influence the vulnerability of fish to predation. The diel pattern of feeding of juvenile sole which had been grown in a mesocosm was compared in the laboratory to that of fish which had been retained in intensive indoor systems. Those reared under semi-natural conditions displayed a marked nocturnal pattern of feeding consuming almost 90% of their total daily intake during the dark period (Figure 4). This pattern was much less pronounced among the intensively reared fish which consumed only 63% of their total daily intake during the dark period. This observation supports the contention that fish reared, or at least conditioned, in a semi-natural environment may be better fitted for survival in the sea than those reared under totally artificial conditions.

Cryptic behaviour

Flatfish reduce their conspicuousness to predators mainly by burying in the substrate and by adapting their colour to match that of the background. Both these protective measures were shown to be influenced by experience.

Juvenile sole that had been maintained on a sand substrate for more than 4 months showed a greater tendency to bury following transfer to a test tank than fish that had been held on a clean bottom. The experienced fish maintained a burying score of over 90% from the day of transfer whereas the inexperienced fish took about 5 days to display the same degree of burying (Figure 5).

The coloration of hatchery-reared sole may differ markedly from that of wild fish. The time required to adapt will depend not only on the degree of change required but on the rate at which the change is accomplished. The latter varies considerably between species and for some species has been shown to be dependent on the constancy of the background which the fish have experienced (Odiorne, 1957). Juvenile sole characteristically respond slowly to a change of background colour requiring at least 3 to 4 days before a reasonable match is obtained. Adaption was quicker, however, among individuals which had been subjected to a repeatedly changing background than those maintained on a background of constant colour. A group of juvenile sole were exposed to a background which alternated between black and white each day for a month. These fish were then adapted to a black background until they were indistinguishable from a group of fish which had been maintained constantly on a black background. When both groups were transferred to a white background those that had experienced a variable background achieved a level of 50% adaptation about two days before those that had been maintained on a constant background (Figure 6).

CONCLUSIONS

Larval survival and subsequent performance in intensive systems have been the main criteria by which larvae culture methods have been judged. It is becoming increasingly evident from these and other studies that these criteria are inadequate when the fish are destined for release into the sea. Suggestions for improving the survival of released fish include the modification of rearing procedures to, for example, reduce sensory deprivation (Blaxter, 1970), the introduction of a conditioning period before release to normalise responses to prey and predators (see, for example, Suboski and Templeton, 1989) and the protection of the fish from predators during the immediate post-release period (see Koshiishi *et al.*, 1991). A considerable amount, however, remains to be learned about the way in which the hatchery environment influences the characteristics of the fish and the persistence of those traits before appropriate procedures can be developed.

These studies have revealed some of the characteristics of hatchery-reared sole which may adversely affect their survival in a natural environment. The use of sub-optimal diets, particularly in relation to lipids, could have an immediate impact on the survival of released fish by reducing their tolerance to stress. The rapid establishment of feeding was shown to be desirable and was apparent among reared fish released into a mesocosm. Hatchery-reared fish, however, displayed atypical patterns of feeding in comparison with pond-reared fish and further studies are required to identify the causes of this behavioural anomaly. Cryptic behaviour is of particular importance to predator avoidance and the trials showed that conditioning may improve the both the burying response and the rate of the colour adaptation.

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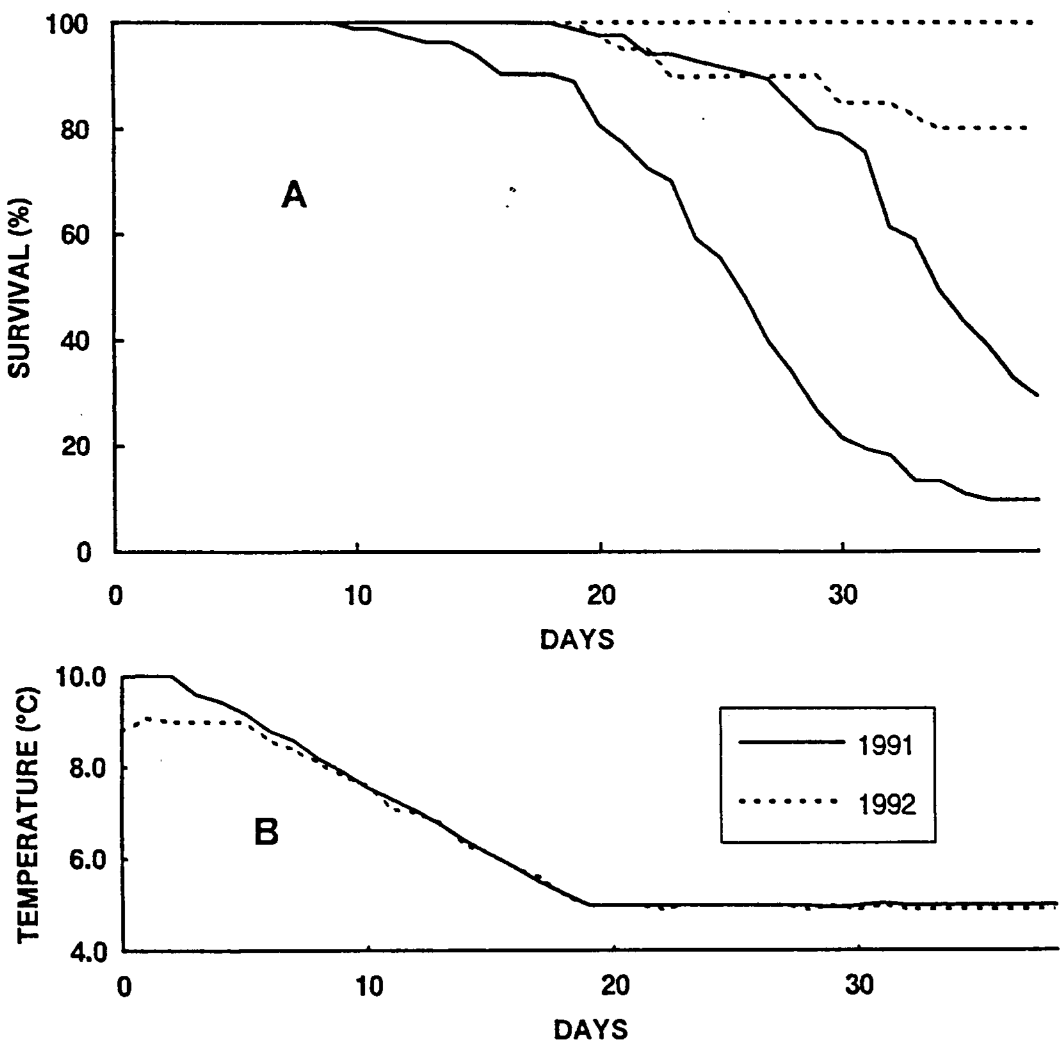

Figure 1. The percentage survival of duplicate groups of 5-7 cm long juvenile sole reared in 1991 and 1992 (A) during exposure to similar low temperature regimes (B).

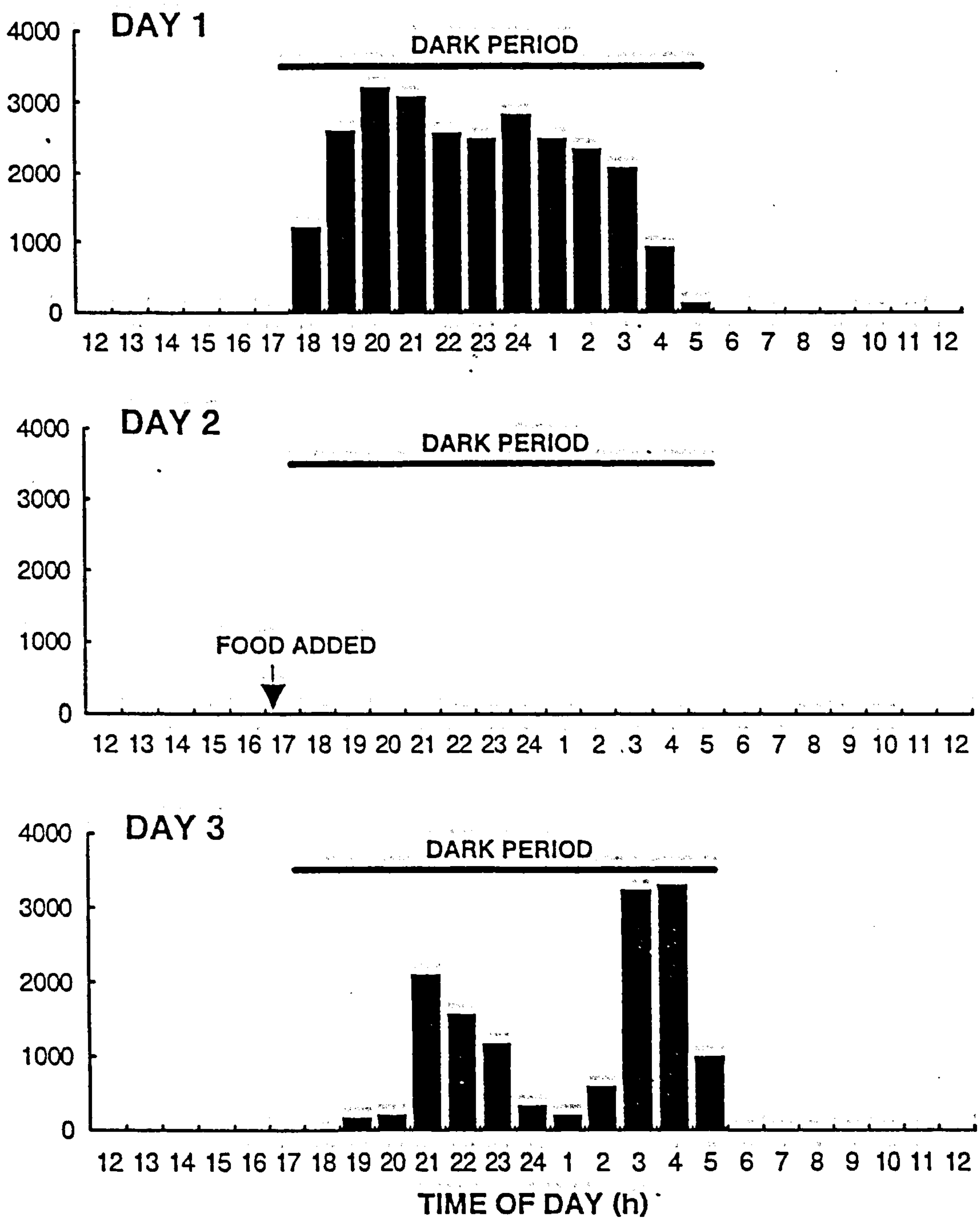

Figure 2. The influence of feeding on diel patterns of activity (arbitrary units) of 4-5 cm long juvenile sole in an actograph. The fish were fed at dusk on Day 2 but were unfed on Days 1 & 3. (redrawn from Macquart-Moulin *et al.*, 1991)

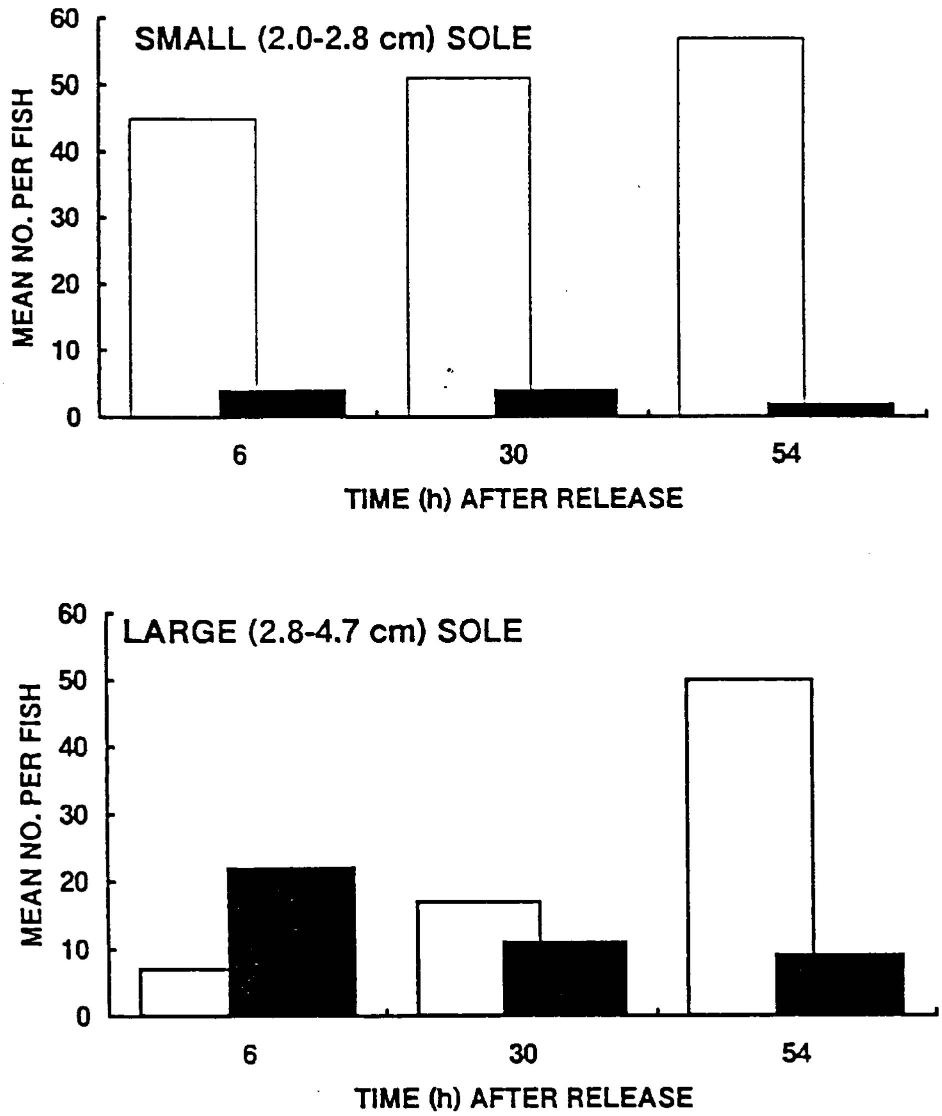

Figure 3. The mean number of harpacticoid copepods (unshaded columns) and chironomid larvae (shaded columns) in the guts of two size groups of juvenile sole following release into a mesocosm.

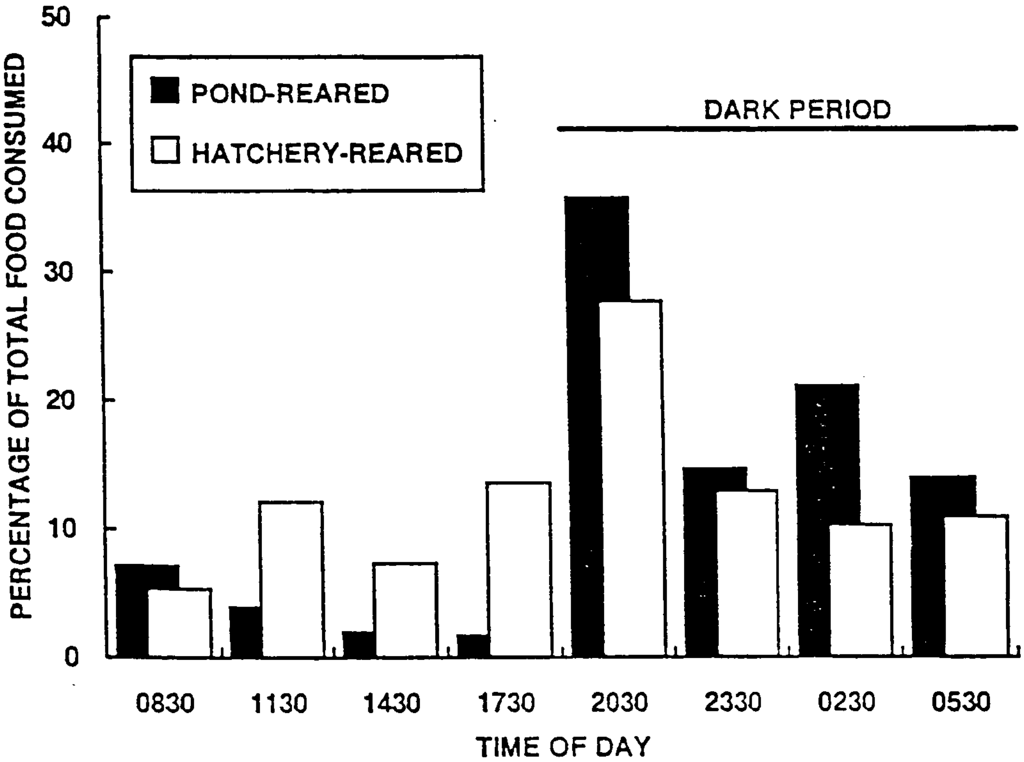

Figure 4. The diel pattern of feeding, expressed as a percentage of the total daily food intake, of pond-reared and hatchery-reared sole.

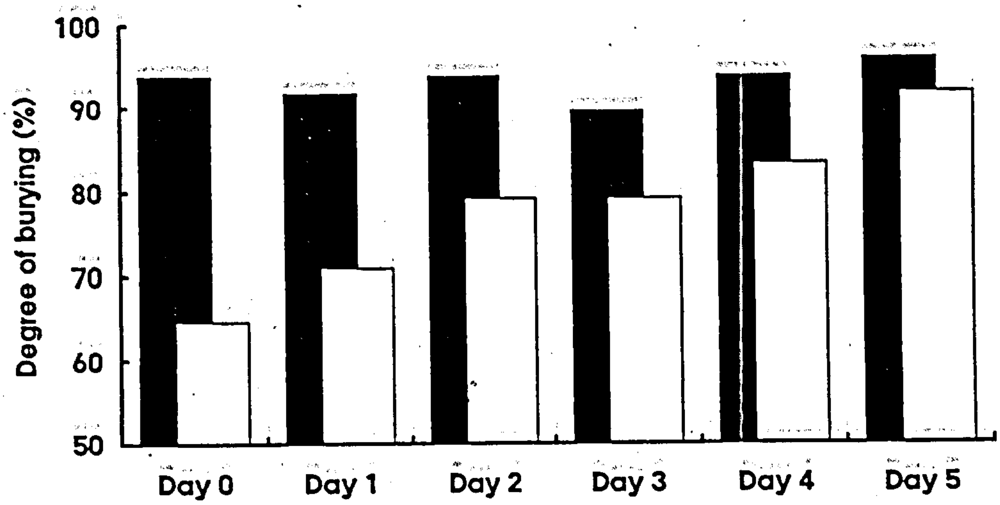

Figure 5. The incidence of burying among experienced (shaded) and naïve sole following transfer to test tanks containing a sand substrate.

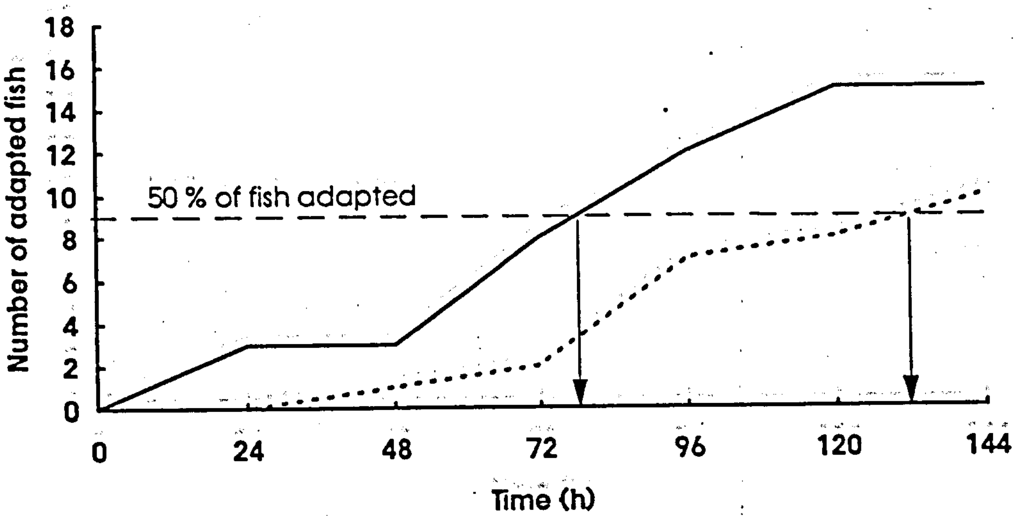

Figure 6. The adaptation to a white background of juvenile sole previously held on either a constant black background (broken line) or a background which was alternated between black and white each day for a month. Both groups were adapted to a black background and were indistinguishable before the beginning of the trial.