Paper No. 27 EFFECTS OF HABITAT MODIFICATION ON FRESHWATER CRAYFISH

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CONTENTS

SUMMARY

Technological and economical development has caused serious damage to freshwater crayfish stocks and fisheries in Europe. The crayfish is particularly sensitive to habitat modifications, because it is a slow-moving bottom dweller confined to a relatively narrow littoral zone. Construction frequently causes long-term turbidity in the water, increasing suspended solids, iron content, and acidification, and decreasing dissolved oxygen content. The crayfish is as demanding as the salmonids in regard to the oxygen content of the water and is also very sensitive to acidification, especially in hypoxic conditions. The combined effect of simultaneous acidification and an increase in iron content often seems to be lethal. Permanent or long-term alterations of crayfish habitat are often more detrimental than the more or-less temporary changes occurring during construction.

Several environmental factors are usually responsible for the adverse effects, making it very difficult to determine the reasons for the damage. This also impedes the planning of restoration and management measures. Adverse effects may often be considerably reduced through use of properly timed, appropriate construction methods. The restoration and management of crayfish stocks in permanently and profoundly modified habitats is very difficult. Management measures should be based on detailed studies made both prior to and on completion of construction. It is usually necessary to improve or restore habitats before stocking crayfish.

1. INTRODUCTION

According to a revised system of the European crayfish (Albrecht 1982), there are five native freshwater crayfish species in Europe: Astacus astacus, A. leptodactylus, A. pallipes, A. pachypus and A. torrentium. To restore crayfish production in waters devastated by the crayfish plague fungus, Aphanomyces astaci, a total of four exotic, plague-resistant, self-reproducing species have been introduced into European inland waters from North America: Orconectes limosus, Pacifastacus leniusculus, Procambarus clarkii and P. acutus (e.g., Westman, 1982).

During the last few decades, technological and economic development have brought with them marked changes in the condition of inland waters in Europe, which together with the crayfish plague have resulted in serious damage to crayfish stocks and fisheries.

2. ADVERSE EFFECTS ON FRESHWATER CRAYFISH OF HABITAT MODIFICATION

In Finland, it has been repeatedly observed, especially in the famous crayfish rivers flowing to the Gulf of Bothnia, that various types of hydraulic engineering operations cause great damage to the only endemic crayfish species, A. astacus. In many cases all the crayfish have been destroyed causing considerable economic losses. For example, the highly valuable stock in the River Pyhäjoki, which produced in the 1950s an annual catch of 750 000 - 1 000 000 legal size (>10 cm) specimens, was destroyed in 1960, most probably due to engineering operations in the upper course of the river (e.g., Niemi, 1977). Another example is the stock in the River Siikajoki, almost completely destroyed downstream of the Uljua Reservoir built in 1969. The loss was calculated at 0.5 million individuals annually (Westman, 1974; Pursiainen and Westman, 1982). Similar cases could be cited for a number of other rivers in Finland.

The seriousness of the situation in Finland is demonstrated by the fact that the total crayfish catch in the middle 1970's in rivers flowing to the Gulf of Bothnia was only some 600 000 per year, which is less than 10 % of that of the best years (Niemi, 1982).

Similar observations have also been reported for a number of other European countries. According to Vallin (1964), clearing and dredging of rivers in Sweden have often had a deleterious effect on crayfish populations. In Poland, the most important reason besides diseases for the disappearance of crayfish from a number of inland waters has been the destruction of the crayfish habitat by various construction operations (Kossakowski, 1973), and similar results have been found in France (Laurent, 1973), in Turkey (Erencin and Köksal, 1977), in Ireland (Reynolds, 1979) and in Hungary, the Netherlands, Spain and the UK (Westman and Pursiainen, 1982) and also in the USA where dredging and clearing operations have contributed to the disapppearance of crayfish from many waters (Hobbs and Hall, 1974).

These and other observations show that the most harmful operations include clearing, canalizing, dredging and embanking of rivers, changing of river beds, damming of rivers, construction of reservoirs, regulation of water levels and stream flows, and forest ditching. These can affect the crayfish stocks in many ways, both directly and indirectly.

3. THE TOLERANCE OF FRESHWATER CRAYFISH TO HABITAT MODIFICATION

The crayfish is naturally very sensitive to changes in water quality and other factors especially because it is a slow-moving bottom dweller confirmed to a relatively narrow littoral zone, making it particularly vulnerable to many engineering activities especially if these result in a sudden deteriotation in the habitat.

Construction operations, in particular dredging, clearing and embankment and similar measures, frequently cause long-term turbidity in the water with an increase in suspended solids and iron content, and acidification, and a decrease in dissolved oxygen content downstream, all of which have been considered as especially deleterious to the crayfish.

3.1 Dissolved oxygen

The crayfish is as demanding as salmonid regarding the oxygen content of the water. Even if adult A. astacus during the intermoult period is able to adapt in aquarium tests to a dissolved oxygen (DO) of 30 % of the air saturation value (ca. 3.2 mg/l) at 11-12oC in neutral water (pH 7.2) (Järvenpää et. al., 1983) and to survive at 2 mg/l at 15oC for some days (Lindroth, 1950), it has been supposed that the concentration under natural conditions should not fall for long below 5 mg/l in summer (Lindroth, 1950). However, very little is known concerning the oxygen demand of crayfish under natural conditions.

The effects of hypoxia have also been studied in several other crayfish species like Orconectes virilis (McMahon et. al., 1974), Austropotamobius pallipes (Wheatly and Taylor, 1981) and Orconectes rusticus (Wilkes and McMahon, 1982 a, b) in aquarium tests. The oxygen saturation level of the water has in these studies been about 30 %. Acute hypoxia increased gill ventilation, heart rate and stroke volume, and in longer-term exposures also the oxygen affinity. The acute responses are energetically costly and cannot be maintained for long.

Most of the hypoxia experiments have been carried out using crayfish in their intermoult period. Very little is known about the effects of low O2 saturation on crayfish young and on adults during their moulting period. Cukerzis (1968) has shown that the oxygen uptake of young crayfish is much bigger than that of adult ones.

3.2 Acidification

Acid rainfall is rapidly reducing the pH value of the poorly buffered inland waters especially in Southern Scandinavia and in Central Europe. Ditching as well as dredging and digging, especially when carried out in sulphide-rich soils, further increases the acidification of the water. *A. astacus* is sensitive to acidification and does not thrive in waters with a pH value below 6.0 (Larsen, 1947; Lund, 1969, Abrahamsson, 1972, Svärdson, 1974, Fürst, 1978) although it is able to withstand pH as low as 4.0 and even less for a short time (Cukerzis, 1970; Appelberg, 1979; Järvenpää *et al*., 1983). Similar observations have been made with e.g. *Austropotamobius* (*Astacus*) *pallipes* (Jay and Holdich, 1977).

The acidification of water causes several physiological problems. Sodium tends to be washed out from the animal (Morgan and McMahon, 1982; Nikinmaa *et*. *al*., 1983) and the haemolymph pH tends to decrease (Dejours and Armand, 1980; Nikinmaa *et*. *al*., 1983) which in turn decreases the oxygen affinity of the haemocyanin (for review see Mangum, 1980). Furthermore, the post-molt calcification of the exoskeleton is retarded by low pH in *A. astacus* (Appelberg, 1979) and *O. virilis* (Malley, 1980; France, 1983). The influx of calcium in *O. virilis* is inhibited by pH below 5.75 and ceased altogether below pH 4 (Malley, 1980).

The ability of crayfish to withstand acidification cannot, however, be unambiguously described by a certain limiting pH-value, as it depends on many factors, e.g. the rate and duration of the increase in acidity, the temperature of the water, its iron, DO, suspended solids and pollutant content, and the activity and life-stage of the animal (cf. Alabaster and Lloyd, 1982). For example, Järvenpää *et al*., (1983) and Nikinmaa *et al*., (1983) recently observed that acidification of the water alone (to pH 4), without a reduction in the dissolved oxygen, did not affect the haemolymph constituents appreciably. In acid water, of a DO of about 3.2 mg/l, however, respiratory adaption did not seem to take place; on the contrary, difficulties in pH- and osmoregulation were apparent. These observations are of considerable importance since construction and engineering works on good crayfish habitats often result in simultaneous reduction of both DO and pH value.

Acidification of the water also causes disturbanses in the reproduction of crayfish. France (1983) noticed in an experimental lake (pH 5.35) that low pH caused incomplete hardening of the cuticular glair-cement compound, which forms the membrane of egg capsule and the egg stalk. As a result eggs failed to attach securely to the pleopods, and the population of Orconectes virilis was poorly recruited. Besides of that low pH led to increased bioaccumulation of Mn and Hg. Also, the frequency of Thelohania sp. infection in the population increased from 0.3 % to 6.5 % as a consequence of acidification.

The O2 uptake of Astacus astacus eggs is affected by acidification of water (Appelberg, 1983). A slight decrease in pH may increase O2 uptake but a more severe acid stress leads to reduced uptake of O_2.

3.3 Suspended solids and iron

Many construction operations often cause marked and extensive turbidity in the water and simultaneous increase in the iron content. For example, in the River Siikajoki, already mentioned, the maximum concentration of total iron was 97 mg/l during the construction of the reservoir, which is 20 to 50 times the highest values obtained during normal spring floods. The highest concentration of suspended solids measured were about 1 900 mg/l (Westman, 1974, Pursiainen and Westman, 1982).

Similarly in the River Iijoki, dredging increased the concentrations of suspended solids to 500-600 mg/l and total iron to 16-18 mg/l. These values were also many-fold compared with those obtained in the upper course of the river (Niemi, 1977, 1982).

The ability of crayfish to withstand increases in concentration of suspended solids and iron is little understood. According to Niemi (1977; 1982) the density of adult A. astacus population was reduced by 50-80 % in those areas in the River Pyhäjoki having the highest concentration of solids and iron but was not affected where they rose only to 100 mg/l and about 5 mg/l respectively.

The gills of crayfish are very fine and are easily clogged by sediment. Vey (1977) observed physio-pathological changes in the branchial filaments of the crayfish A. leptodactylus reared in ponds containing large quantities of suspended particles; some disturbance also occured in the reproduction of females.

3.4 Other factors and combined effects

To what degree solids and iron have detrimental effects depends, however, on many factors, such as the nature of the dissolved solids and, especially, the acidity of the water. The increase in iron concentration alone seems not to be lethal, at least in the short term. Sevola et al., (1977) observed that A. astacus kept in netted cages below a dredging area was able to withstand total concentration of 31 mg/l iron and 1 030 mg/l suspended solids. It is the combined effect of simultaneous acidification and increase in iron content that seems to be lethal. In acid water the iron easily precipitates as ferrichydroxide on the more alkaline gills of the crayfish, resulting in suffocation.

The ability of crayfish to withstand changes in water quality depends very much on the season and the life-stage. Hatching juveniles, young, and moulting individuals are for example very sensitive to increasing acidification (Fürst, 1978; Appelberg, 1979, 1983, France, 1983), so that construction works carried out in summer are the most deleterious.

3.5 Long-term and permanent habitat modification

Long-duration or permanent alteration of crayfish habitat are often more detrimental than more-or-less temporary chnages in water quality during the construction activities. Solid matter can accumulate on the bed in such quantities that it fills up the hiding places and holes imperative for the crayfish and often altering completely the habitat and devastating the benthic food oganisms and vegetation (e.g. Pursiainen and Westman, 1982).

Damming of rivers produces marked alterations in stream flow and upstream water level causing erosion of the littoral zone which otherwise provides shelter and also food for crayfish. Short-term fluctuation of water level is especially wearing on the littoral zone. Aquatic vegetation and bottom fauna are reduced and species diversity is impoverished. Hamrin (1979) observed that especially the youngest A. astacus age classes are very vulnerable to changes in the water level. Diel water level regulations will during summer and autumn force the crayfish away from shelter and expose them to predators.

In winter frequent changes in water level also cause freezing and sub-cooling problems, especially in the shallow rapids. These damages are difficult to avoid without eliminating or radically changing regulation of the stream flows.

Due to reconstruction and modification of rivers, parts, of former river beds remain partly or totally dry, or the flow diminishes to such an extent that it is insufficient for the survival of crayfish.

The water quality of modified rivers often remains poor for long periods, especially when dredging, clearing and ditching has uncovered sulphiderich alum soils. Furthermore, the reservoirs may cause longterm worsening of the water quality downstream. In the River Siikajoki for example, more than ten years after the construction of the Uljua Reservoir a lack of DO has still been observed in spring in the water course downstream (Pursiainen and Westman, 1982).

The adverse effects of habitat modifications may be observable in many ways including mortality, emigration, reduction in growth rate and production and impairment of reproduction. The quantity and quality of damage often depends on several factors, such as the magnitude of the operations, the working methods used, soil type, the state of the watercourse, flow of the water, temperature, state of the crayfish population, life-stage of the crayfish, and quantity and quality of biotopes suitable for crayfish (Westman, 1979).

The adverse effects do not generally result from a change in one particular environment factor; rather several factors are usually responsible. This makes the reasons for the damage very difficult to determine and hence also impedes the planning of restoration and management measures. Furthermore, information relating to the combined effect of different environmental factors on crayfish stocks is very scarce.

4. THE PREVENTION AND MINIMIZING OF ADVERSE EFFECTS

Prior to initiation of construction operations which will alter the natural state of water bodies, a detailed, preliminary appraisal of the crayfish stocks including their density and structure and areas of occurrence and crayfish fisheries should be made. The study should also assess any potential damage and extent to which measures could be taken to prevent and ameliorate such adverse effects (Westman, 1979).

The extent to which damage may be prevented or minimized depend on each case but by selecting proper construction methods and timing of operations, adverse effects may often be considerably reduced. For example, in the River Pyhäjoki, at least 40 % of adults (> 70 mm in body length) remained a year after the dredging operations which were carried out late in the autumn and on only one of the river banks. (Niemi, 1977).

Engineering operations that alter water quality should not be carried out when the water flow is low, the temperature high, or during the moulting period of crayfish. Destruction of the best and most productive crayfish habitats should be avoided. As a precautionary measure, crayfish should be caught and removed from areas of potential damage and stocked in other water bodies or returned when construction activities are over.

Deterioration of water quality during the construction period can often be markedly reduced by building coffer dams around the construction areas. Also the chances of crayfish survival could be increased by running additional clean water in the river below the place of construction.

5. THE RESTORATION AND MANAGEMENT OF CRAYFISH STOCKS IN MODIFIED WATERS

The restoration and preservation of crayfish stocks in permanently and profoundly altered environments is a most difficult task. Management measures should be based on detailed studies in which the main causes and extent of damage, the state of the water body, especially as concerns the water quality and state of the littoral zone and the possibilities for crayfish to live and reproduce in the damaged areas, are all carefully evaluated. Studies made before the construction operations were begun should be used for comparative purposes. Restoration and management measures, which are not based on such investigations, remain uncertain and should not be put into effect.

5.1 Appraisal of the crayfish stocks

In these studies reliable sampling methods are of great importance, a special problem being the great variation in activity and catchability caused by moulting. Moreover, the crayfish is a bottom-dwelling creature and requires special sampling techniques. Sampling with baited traps is the method most commonly used in research but it has some restrictions (Brown and Bowlen, 1977, Brown and Brewis, 1979) and, in order to obtain reliable population estimates, a trap model from which the crayfish are not able to escape should be used (Westman _et al_., 1979a). Each sex, and preferably also the different size groups, should be treated separately (Abrahamsson, 1966), the trapping techniques should be standardized and sifficient catching effort during a period of high activity for both males and females should be used (Westman and Pursiainen, 1981).

The main limitation of sampling with traps is that only adult crayfish, actively entering the traps can be caught, even with fine-meshed traps. To examine the whole population, trapping must be supplemented with a method suitable for sampling small crayfish as well. Where conditions are suitable, electric fishing (Westman *et al.*, 1979b), dredge-sieves (Odelström, 1983), zoobenthos samplers (Dye and Jones, 1975) and diving (Abrahamsson and Goldman, 1970) have proved to be practical and useful methods for obtaining representative samples of the whole crayfish population.

5.2 Appraisal of environments suitable for crayfish

Water quality during the summer and the critical, sensitive, stages of the crayfish should be carefully investigated, of special importance being DO, pH, Fe and suspended solid contents.

The permanent altration and erosion and, very often, even total destruction, of the littoral zone has proved to be an especially difficult problem in the restoration of crayfish stocks. Areas where the reduction of the water flow, short-term fluctuation of water level and silting-up prevent the maintenance of hiding places and food supply for crayfish require special attention.

Crayfish stocks can be managed in many ways depending on the situation and prevailing conditions. The aim may be direct restoration and preservation of the populations e.g. by stocking, or it may be to affect the crayfish indirectly e.g. by habitat improvement. Stocking of crayfish, which is the most common and also too often, the only management method, presupposes that there are still possibilities for the crayfish to survive in the modified habitat even though the former stock has been destroyed. The situation is, however, seldom that good. Even if the quality of the water, as well as other conditions, seem to be suitable for crayfish, it is nonetheless difficult to evaluate underwater conditions reliably e.g. to assess to what extent holes and other hiding places remain open, the possibilities of the animals obtaining food, and the combined effects of different factors. Therefore, prior to extensive stocking it should be determined whether crayfish could survive in the altered environment for example by holding test batches in netted cages in modified areas and by small-scale test-stockings (Pursiainen and Westman, 1982).

The advantages of the test-batch approach are that survival can be tested exactly where desired and also observation and sampling of the crayfish can be made even at moulting and other periods when they are inactive and otherwise difficult to catch. The test cages should be placed in different areas of the modified water body and control batches should be kept in unmodified areas where crayfish naturally exist.

This method has been used successfully in modified rivers in Finland.

With test-stocking it is possible to obtain information additional to that on water quality, namely concerning shelter, food supply and other factors important for survival. Stocking should be made in various parts of the modified habitats in order to get information on the biotopes remaining suitable for crayfish. It is advisable to use adult, sexually mature animals in order to also obtain, as soon as possible, information on reproduction. At least 400 crayfish should be stocked in each of the habitats studied at a density of up to 5 per metre of shore. They should be permanently marked e.g. by electric cauterization (Abrahamsson, 1965) so that they can be identified later. The survival, growth, reproduction, migration etc. should be observed by regular sampling (Pursiainen and Westman, 1982).

Providing that the above-mentioned methods indicate that the crayfish will survive at the modified sites, management stocking can be initiated. Construction operations, however, usually cause such profound modification in the crayfish habitats that, without habitat improvement even extensive stocking are often of little economic value.

5.3 Habitat improvement

Measures which are most commonly required in habitat improvement are the improvement of water quality, increasing of water flow, moderation of short-term, fluctuations in water level and increasing of shelter for the crayfish. For example, low DO of water run from reservoirs can be increased with aeration. The calcium content and pH value of the water can be increased by liming which should be made with agricultural chalk to avoid the danger of over-dosing. Chalk should be spread mainly in the crayfish habitats in the littoral zone.

Short-term fluctuations of water level are often the most difficult problem but by constructing bottom-dams and diminishing the amplitude the adverse effects of regulation can be mitigated.

In cases where dredging and clearing have destroyed hiding places, artificial shelters can be created. Drainpipes and similar hides placed at the shoreline below the lowest water level provides quite satisfactory shelters for large individuals, while bricks with holes and bunches of twigs and straw are very suitable for juveniles. Soft substrates lacking hiding places can be improved with heaps of stones. There is only sparse information available concerning the effect of increasing hides under natural conditions but these measures have at least proved successful in crayfish cultivation in ponds and basins (e.g. Arrignon, 1981).

The restoration and management of crayfish stocks in modified habitats has, in practice, proved to be a very difficult problem. Freshwater crayfish seem to adapt poorly to alterations in their environment. It is difficult and, very often, even impossible, to restore an abundant and productive crayfish stock e.g. in a river which has been dredged and cleared and in which flow and water level are also regulated. Effective means of mitigation for many adverse effects are as yet not even known. There is only one secure way to preserve valuable and productive crayfish stocks and profitable crayfish fisheries and that is by preserving their habitats intact in their natural state.

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