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A review of astaciculture : freshwater crayfish farming

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Abstract

The farming of freshwater crayfish (astaciculture) is mainly carried out in the southern states of the USA, and in Australia and Europe. Production levels vary with climate but are in the region of 40 000 to 60 000 tonnes per annum. In addition, at least an equivalent amounts is harvested from the wild, particularly in North America, China, Australia, Kenya, Turkey and Europe. Crayfish farming is usually either of an extensive (ranching) or semi-intensive nature, intensive methods being infrequent, except for the rearing of juveniles for stocking (or restocking of natural waters depleted of crayfish). As crayfish do not have larvae and are polytrophic, they are relatively easy to rear, although fecundity is much lower when compared with other cultured crustaceans. At least 85% of world production is based on the red swamp crayfish, *Procambarus clarkii*, mainly from Louisiana and other southern USA states, but also from China, Kenya and Spain, where it has been introduced. In Australia, three species are of aquacultural importance, the yabbie, *Cherax destructor*; the marron, *C. tenuimanus*; and the red claw, *C. quadricarinatus*. Some very large production units have been built but none have lived up to their promise. The red claw is thought to have considerable aquacultural potential, but, being a tropical species, needs warm water for good growth. In Europe, the only endemic species cultured to any extent is the noble crayfish, *Astacus astacus*, mainly as juveniles for restocking. It fetches a higher price than other crayfish. The North American signal crayfish, *Pacifastacus leniusculus*, has been introduced to most European countries, but farmed production is relatively low. About 98% of crayfish consumed in Europe come from extensive systems or the wild harvest. European crayfish markets were upset by the collapse of the Turkish crayfishery (based on *Astacus leptodactylus*) due to overfishing and disease in the mid-1980s. The environmental impact of crayfish farming is most noticeable in Europe. Crayfish plague, introduced from North America last century, has devastated populations of the native species in many countries. Its spread has been exasperated by the translocation of foreign crayfish (and probably by fish) for aquacultural purposes. In addition, introduced crayfish frequently escape into the wild and form large populations, often in direct competition with native species. Burrowing and prolific species, such as *P. clarkii*, can also do considerable environmental damage.

Keywords: Astaciculture, *Astacus*, *Pacifastacus*, *Cherax*, *Procambarus*, extensive culture, crayfish.

Une synthèse de l'astaciculture : l'élevage d'écrevisse en eau douce.

Résumé

L'élevage d'écrevisse (astaciculture) est principalement mené dans les états du Sud des Etats-Unis, en Australie et en Europe. Les niveaux de production varient avec le climat mais atteignent dans cette région 40 000 à 60 000 tonnes par an. Il faut y ajouter une production équivalente, provenant du milieu naturel, en particulier d'Amérique du Nord, de Chine, d'Australie, de Turquie et d'Europe. L'élevage d'écrevisse est habituellement soit extensif ou semi-intensif, les méthodes intensives ne sont pas fréquentes, à l'exception de l'élevage de juvéniles pour le peuplement (ou le repeuplement des cours d'eau). Les écrevisses n'ayant pas de stade larvaire et étant omnivores, il est relativement aisé d'en faire l'élevage, bien que la fécondité est très inférieure à celle des autres crustacés mis en élevage. Au moins 85% de la production mondiale est basée sur *Procambarus clarkii*, principalement de Louisiane et d'autres états du Sud des Etats-Unis mais aussi de Chine, du Kenya et d'Espagne où cette espèce a été introduite. En Australie, trois espèces sont importantes en aquaculture, *Cherax destructor*, *C. tenuimanus* et *C. quadricarinatus*. De grandes unités de production ont été construites mais aucune n'a atteint les promesses attendues. On pensait que

Cherax quadricarinatus avait un potentiel considérable en aquaculture mais étant une espèce tropicale, elle nécessite des eaux chaudes pour une bonne croissance. En Europe, la seule espèce endémique élevée, considérée comme espèce noble, est l'écrevisse *Astacus astacus*, principalement des juvéniles pour le repeuplement. Elle atteint un prix plus élevé que toutes les autres espèces. L'écrevisse nord-américaine, *Pacifastacus leniusculus*, a été introduite dans la plupart des pays européens mais la production en élevage est relativement bas. Environ 98% des écrevisses consommées en Europe viennent de systèmes extensifs ou de captures en milieu sauvage. Les marchés européens d'écrevisse ont été marqués par la chute la pêche d'écrevisse en Turquie (basée sur *Astacus leptodactylus*) due a la surpêche et à la maladie du milieu des années 1980. L'impact environnemental des élevages d'écrevisse est le plus notable en Europe. L'écrevisse, introduite d'Amérique du Nord le siècle dernier, a dévasté des populations d'espèces endémiques dans beaucoup de pays. Sa diffusion a été perturbée par l'introduction d'écrevisses étrangères (et probablement par les poissons) à des fins d'aquaculture. De plus, les écrevisses introduites s'échappent fréquemment dans la nature et forment de grandes populations, souvent en compétition directe avec les espèces endémiques. Des espèces fouisseuses et prolifiques, telle que *P. clarkii*, peuvent également causer des dommages considérables dans l'environnement.

Mots-clés : Astaciculture, écrevisse, *Astacus, Pacifastacus, Cherax, Procambarus*, élevage extensif.

INTRODUCTION

A wide variety of decapod crustaceans are harvested from the wild and cultivated for human consumption. They are a luxury food which commands a high price, particularly in western markets. In 1990 approximately 722 000 t (metric tons) of decapods were produced by aquaculture in the form of marine and brackish-water prawns and shrimps, freshwater prawns, freshwater crayfish, clawed and spiny lobsters, and crabs (Lee and Wickins, 1992). In 1991, the marine shrimp/prawn harvest from aquaculture had risen to 700 000 t with China, Thailand, Indonesia and Ecuador being the main producers (Anon., 1992*b*). By comparison, 10-20 000 t of the freshwater prawn, *Macrobrachium*, are produced per annum, mainly by Thailand, Vietnam and Taiwan (Lee and Wickins, 1992).

According to Food and Agricultural Organisation fishery statistics (F.A.O., 1989) production of freshwater crayfish from the wild and from aquaculture (astaciculture) during the period 1986-1989 was between 42-56 000 t/annum, originating mainly from the USA, Australia, Kenya, Turkey and Europe (*table* 1). The wild harvest is not truly represented in these figures and, if in addition, production from Russia and Lithuania are included then the figure could well be over 100 000 t/annum in some years, of which at least half may be produced by astaciculture. The Chinese harvest, which is based on the Louisiana red swamp crayfish, *Procambarus clarkii* (Girard), is underexploited at present and could yield in the region of 40 000 t/annum (Huner, pers. comm.). As much of the global crayfish harvest comes from ponds, lakes, swamps and marshes it is very dependent on the amount of water available. Due to the ravages of crayfish plague, much of the crayfish harvest in Europe is based on North American species which are most resistant to the disease and have been introduced to supplement native stocks (Holdich, 1988; Lowery and Holdich, 1988).

Aquaculture implies some form of intervention in the rearing process of aquatic organisms to

Table 1. – Nominal catches (tonnes) of freshwater crayfish from all sources except recreational (F.A.O., 1989 and F.A.O. Fisheries Circular No. 815, Rev. 3, Aquacultural Production (1986-1989)).

Sources	Species	1986	1987	1988	1989
USA	other*	6 433	7 810	8 010	9 613
USA	red swamp *Procambarus clarkii*	44 318	43 182	29 931	30 000
Kenya	red swamp *Procambarus clarkii*	36	92	14	94
Spain	red swamp *Procambarus clarkii*	-	3 100	2 689	2 690
Turkey	narrow-claw *Astacus leptodactylus*	1 585	1 565	1 813**	1 642**
Europe***	Astacids	36	114	10	14****
Australia	Murray River cray	20**	20**	20**	204**
Australia	marron *Cherax tenuimanus*	8	10	3	7
Australia	yabbie *C. destructor*	1	3	9	31
Australia	red claw *C. quadricarinatus*	–	–	7	166
Total		52 437	55 896	42 506	44 461

* Astacids and cambarids.
** Estimated. The figure of 206 tonnes for the Murray River crayfish in 1989 cannot be considered as realistic.
*** Mainly France, Sweden, Poland, Romania, Britain.
**** A considerable underestimate - see text.

enhance production, such as regular stocking, feeding, protection from predators, etc., as well as individual or corporate ownership of the stock being cultivated. Some of these conditions can be applied to astaciculture in the USA, Australia and N.W. Europe, but much of the culture is of an extensive nature, and is often based on a "stock and forget" policy, particularly in Europe.

Much has been written about astaciculture and the present review touches only on particular aspects. This paper is based on a plenary lecture given at the 1st European Crustacean Conference in Paris (1992). For more details about astaciculture readers are directed to Mancini (1986), Holdich and Lowery (1988), Huner, 1989, Skurdal *et al.* (1989), Westman *et al.* (1990), Arrignon (1991), Huner and Barr (1991), and Lee Wickins (1992). The International Association of Astacology (P.O. Box 44 650, University of S.W. Louisiana, Lafayette, LA 70 504, USA) acts as a forum for all matters concerning crayfish. It holds regular symposia, papers from which are published as "Freshwater Crayfish – A Journal of Astacology", a list of those in volumes I-VII appears in Holdich (1991), and two more volumes are in preparation.

CRAYFISH DISTRIBUTION, SPECIES USED IN AQUACULTURE, AND TRANSLOCATIONS

There are in the region of 500 species of crayfish inhabiting fresh-water, and sometimes brackish- water, environments (Hobbs, 1988; Holdich and Lowery, 1988). The peak of adaptive radiation has been reached in North America where there are over 300 species, and Australia with over 100 species. Europe by comparison has only five endemic species. Out of these 500 species only seven are currently of commercial importance (*table* 2).

There are three families of crayfish: Astacidae, Cambaridae and Parastacidae (Hobbs, 1988). The Parastacidae is mainly restricted to the Southern Hemisphere. The Cambaridae is mainly represented in North America but also in eastern Asia. The Astacidae occur mainly in Eurasia but also in the western USA. Crayfish are do not naturally occur in Africa, India and most of Asia.

Superimposed on this natural distribution is one due to translocations within and between continents, mainly for aquacultural purposes. In many cases such translocations have escaped or been deliberately introduced into the wild where they have formed naturally breeding populations, as for example in Britain (Holdich and Reeve, 1991) and Spain (Huner, 1988, 1989).

The only continent which has not received introduced crayfish species is Australia, although species with aquaculture potential have been moved round within Australia (Horwitz, 1990). Species of *Cherax* have been translocated to the USA, Central America, Europe, Israel, New Zealand and South Africa for aquacultural trials, but it is not thought that this species has escaped into the wild yet. The danger of this happening with marron (*C. tenuimanus*) introduced into New Zealand (where they do not naturally occur) has been curtailed by the Government ordering the destruction of stock and compensating the farmer (Jones, pers. comm.).

In North America there has been a lot of internal translocation of crayfish species for aquacultural purposes and for bait by fishermen (Hobbs *et al.*, 1989). In some cases, e.g. *Orconectes rusticus*, this has caused environmental problems, due to displacement of other freshwater animals and destruction of weed beds. It is from the USA that the two main crayfish species used in astaciculture have been translocated to many parts of the world, i.e. *Pacifastacus leniusculus*, the signal crayfish, and *Procambarus clarkii*, the red swamp crayfish.

The signal crayfish, originally a native to Washington State, was introduced to California, mainly as a fish food in sub-alpine lakes, but now supports an industry based on wild populations in the Sacramento River. From populations in Lake Tahoe exports were made to Sweden in the 1960s where a hatchery was set up (Brinck, 1983). The original aim was to introduce into Sweden a crayfish species which was resistant to crayfish plague, a fungal disease which had, and still is, devastated populations of indigenous crayfish in

Table 2. – Crayfish species of aquacultural importance*.

Genus	Species	Authority	Common name	Origin
Pacifastacus	*leniusculus*	(Dana, 1852)	signal	W. USA
Procambarus	*clarkii*	(Girard, 1852)	red swamp	S. USA
Procambarus	spp.		**	S. USA
Astacus	*astacus*	(Linnaeus, 1758)	noble	Europe
Astacus	*leptodactylus*	Eschscholtz, 1823	narrow-clawed	Turkey
Cherax	*tenuimanus*	(Smith, 1912)	marron	W. Australia
Cherax	*destructor*	(Clarke, 1936)	yabbie	S. Australia
Cherax	*quadricarinatus*	(von Martens, 1868)	red claw	N. Australia

* For comments on uniformity of nomenclature see Holdich (1993).

** Species contained under this heading include the white river crayfish complex comprising *Procambarus acutus* (Girard, 1852), *P. zonangulus* Hobbs and Hobbs, 1991, and *Procambarus* sp. No real effort is made to distinguish between the commerical species although *P. clarkii* makes up the bulk.

Table 3. – Countries into which *Procambarus clarkii* has been introduced.

AFRICA
South Africa, Kenya, Zimbabwe, Uganda, Sudan, Zambia, Egypt.
CENTRAL and SOUTH AMERICA
Mexico, Belize, Costa Rica, Dominican Republic, Nicaragua, Guatemala, Brazil, Guyana, Venezuela, Columbia, Ecuador
INDO- PACIFIC
Hawaii, Taiwan, China, Japan, Hong-Kong, Singapore, Malaysia, Thailand, Philippines
EUROPE
Spain, Majorca, Portugal, France, Netherlands, Germany, England, Sweden, Italy, Cyprus

Europe (Holdich, 1988; Lowery and Holdich, 1988). The signal crayfish has proved very popular and has been exported from Sweden, or directly from the USA to most European countries, with the exception of Norway, the Netherlands and Ireland, for aquacultural purposes. In many cases it has escaped into the wild but, more to the point, it acts as a vector of crayfish plague, and has helped to increase the spread of the disease in Europe (Alderman and Polglase, 1988; Alderman *et al.*, 1991).

The most widely-introduced crayfish species is the red swamp crayfish. Like signals it is a vector of crayfish plague. Outside of North America it is now present in many countries due to man-made introductions (Huner, pers. comm.) (*table* 3).

The red swamp crayfish is a very adaptable species and when it escapes into the wild, as it frequently does, it undergoes a population explosion in suitable habitats, and is subsequently impossible to get rid of. Although this can have serious environmental consequences, as this species is a prolific burrower, it can also bring benefits. Red swamps introduced into southern Spain in the 1970s (Huner, 1988), have colonised much of the rice growing areas and moved into many waterways in central Spain and southern Portugal. An industry has been built up which has brought benefit to economically depressed areas. An export industry has been developed, particularly to France and Scandinavia, where demand for crayfish outstrips supply. Red swamps were introduced into Japan in the 1930s and soon after from there to China. They have gradually colonised large areas of marsh and fish ponds (Shu, 1988). Although they have been served in restaurants for a number of years, it is only recently that the export potential has been realised and, ironically, it may not be long before China matches the production levels in Louisiana itself but from the wild harvest as there is currently little aquaculture of crayfish in China (Huner, pers. comm.). Red swamps have also been introduced into Lake Naivasha, Kenya in 1970. There they underwent a population explosion subsequently causing some adverse alteration to the trophic dynamics of the lake. A fishery opened in 1975 and several tonnes were exported annually to Europe up until 1983. Less than 100 t/annum are now produced, mainly for local, in particular tourist, consumption (Harper *et al.*, 1990).

CRAYFISH CHARACTERISTICS

Crayfish have a number of positive characters which make them ideal aquacultural organisms but they also have a number of negative attributes. *Table* 8 lists some of these characteristics for three Australian crayfish.

As with other decapod crustaceans the major part of the meat yield is derived from the abdominal muscle ("tail meat"). Additional meat can be obtained from the claws, but this is usually only done when crayfish are served whole. In Louisiana, small crayfish are hand-peeled for their tail meat in processing plants, and it is not considered economically worthwhile to extract claw meat. Meat yields vary depending on species from 10-40% on a body weight basis (Huner, 1989; Lee and Wickins, 1992). In general, meat yield from crayfish is slightly less than from other decapods (Jones, 1990; Lee and Wickins, 1992).

Crayfish are unique amongst decapod crustaceans in not having larvae (Holdich, 1993). Shrimps and prawns typically have 11-12 larval stages which have different dietary requirements from the juveniles and adults. What hatches out from the crayfish egg already resembles a crayfish and by the time they leave the mother they can feed on most animal and plant foods. Consequently, it is much easier to culture crayfish than prawns and shrimps. However, fecundity is very much lower. *Penaeus japonicus* may produce between 200 000-1 000 000 eggs and *Macrobrachium rosenbergii* 80 000 eggs, whilst for cultivated crayfish it varies between 100-1 000 depending on the species (Lee and Wickins, 1992).

In temperate regions crayfish mating usually occurs in the autumn when the male deposits a spermatophore on the female (Holdich and Reeve, 1988). The eggs are then laid into a chamber formed by the abdomen which contains a fluid that partially dissolves the spermatophore. The fertilised eggs are then attached by a cement to the abdominal appendages of the female where they are overwintered. In spring the eggs hatch into juveniles which remain attached to the mother. After one moult they become active and in astacid crayfish they leave the mother after a few days to become independent even though their appendages are not fully developed (Holdich, 1993). Initially, the juveniles are attracted back to the mother by a pheromonal bond but once this wears off the mother regards the juveniles as food! Consequently, in hatcheries the juveniles are either shaken off the mother and separated from her, or the brooding females are placed in cages which allow the juveniles to escape through the mesh. In some hatcheries the eggs are stripped from the berried female and grown in their thousands in special chambers (Cukerzis, 1988; Skurdal *et al.*, 1989). In cambarid and parastacid crayfish the second stage juveniles remain with the

Table 4. – Estimated USA and Canadian crayfish production (derived from Huner *et al.*, 1989).

Region	Wild (tonnes)	Astaciculture (tonnes)	Genus	Wholesale value (kg)
Southern USA	5 000-25 000	up to 60 000	*Procambarus*	$1.00-2.25
Mid-west USA	100	150	*Procambarus* *Orconectes*	$4.50
Far-west USA	300 +	—	*Pacifastacus* *Procambarus*	$2.00-2.75
Ontario-Canada*	10 +	?	*Orconectes* *Cambarus*	$5.00 Can.

* See Momot (1991).

mother and it is not until the third stage that they are released.

Growth rates are temperature and species dependent (Lowery, 1988). Most crayfish species cannot match the growth rates of tropical shrimps and prawns under aquaculture conditions, but warm-water species such as *Procambarus clarkii* and *Cherax quadricarinatus*, are able to reach a marketable size in less than 12 months (Wickins, 1982; Jones, 1990; Lee and Wickins, 1992).

Cannibalism is often a problem amongst decapod crustaceans grown communally (Lee and Wickins, 1992). In crayfish it is particularly prevalent at times of moulting and the sight of gastroliths on a tank floor is usually a sign of cannibalism. These calcium stores are used by the crayfish to harden particularly important parts of the body in the immediate post-moult period (Lowery, 1988). Crayfish with their large mobile claws frequently attack other crayfish and this can lead to death or loss of limbs. Crayfish such as *Pacifastacus leniusculus* have a lot of meat in their claws, consequently their loss can make them unmarketable. There is some evidence that the large males in a population depress the growth of younger cohorts. Their regular removal can therefore lead to an increase in growth and biomass of the population (Momot, 1991). If populations are not subject to harvesting then stunting of individuals may occur.

METHODS OF ASTACICULTURE

Many different methods are employed in growing crayfish. The majority of these are extensive or semi-intensive systems, although hatchery-produced juveniles may be used to stock them. There are many technical problems involved with intensifying crayfish culture (Skurdal *et al.*, 1989), and consequently very few intensive crayfish farms are in operation which involve the whole-cycle.

North America

Crayfish production in North America is centred on the southern states of the USA, mainly Louisiana and Texas, although there is some potential in more northern states and in Canada, particularly with *Pacifastacus leniusculus* and *Orconectes* species. (Lowery and Holdich, 1988; Huner, 1989; Huner *et al.*, 1989; Momot, 1991) (*table* 4).

Louisiana is the largest producer of farm raised crayfish in the world. In 1990, 1 600 crayfish farmers produced 27 600 t of *Procambarus* with a value of US $ 34 million in 49 000 hectares of shallow ponds (Hymel, pers. comm.). The amount of production varies from year to year, mainly in relation to the area of ponds which are flooded, and can be higher (*table* 4). In 1990 crayfish were second only to freshwater catfish in USA aquacultural production (Anon., 1992*a*).

Table 5. – Method used to set up a traditional*, permanent crayfish pond with a self- perpetuating population in Louisiana.

April/May	- stock adult crayfish at 60 kg/ha
May/June	- slowly drain pond over 3-4 weeks
June-Sept.	- plant and grow rice. Harvest or leave
October	- re-flood pond. Rice or stubble provides forage for crayfish
November-May	- harvest crayfish
May	- slowly drain pond but normally do not need to restock as young are usually present in sufficient numbers for next season

* There are many other variations of this scheme involving different forages, see Huner and Barr (1992).

In Louisiana ponds containing mature crayfish are drained in May and June which stimulates the crayfish to burrow (*table* 5). During the summer vegetation is grown in the dry ponds. This is either natural or a crop such as rice. If it is a crop then it may or may not be harvested and the crop or stubble is left as crayfish fodder as is any other vegetation. The ponds are reflooded in September and November and the crayfish emerge and release juveniles into the vegetation where they forage and grow. The crayfish are harvested from November to June. Four particular problems which concern the farmers are predators (particularly birds and fish), lack of food, stunting and oxygen levels. The latter is mainly due to the decomposing organic matter and can be remedied by circulating water round the ponds by means of pumps or paddle wheel aerators (Huner and Barr, 1991). Stunting is usually due to a high density of crayfish

and can be remedied by removing small crayfish to new ponds, a process known as relaying (McClain *et al.*, 1993). Supplemental feeding can be used when forage is depleted. Yields as high as 3 t/ha/y have been recorded, but are more often 1-1.7 t/ha/y in a well managed farm on a year-to-year basis (Huner, 1988; Huner and Barr, 1991).

Table 6. – Products derived from crayfish in Louisiana (modified from Lee and Wickins, 1992).

1. Live	2. Live and purged
3. Frozen whole and raw	4. Frozen whole, seasoned
5. Cooked or blanched:	6. Soft shelled
a. Frozen whole and seasoned	a. Live
b. Peeled	b. Frozen, raw, with or
– fresh meat with or without fat*	without gastroliths removed
– frozen meat with or without fat*	c. Frozen, processed with
– speciality products (e.g. paté)	breading and/or stuffing

* Fat refers to the hepatopancreas, most of which is in the front part (head) of the crayfish. It is common practice in Louisiana, when eating whole cooked crayfish, to suck out the fat in the head before consuming the tail meat.

In the USA a far wider range of products are derived from crayfish (*table* 6) than in Australia or Europe, where they tend to be served as whole, cooked specimens. In Louisiana crayfish are graded into small-size (15-18 g) which are hand peeled for their tail meat, medium-size (19-29 g), which go whole to the restaurants, and large-size (30-40 g), which are usually exported frozen to Western Europe. Of particular interest is the soft-shelled crayfish industry (Lee and Wickins, 1992). Although small, newly-moulted crayfish have long been used for bait, it is only recently that production of larger soft- shelled crayfish for the gourmet food market has been considered. Such crayfish command a price 15-20 times higher than hard-shelled crayfish, and demand has been estimated to be 1 500 t. In intensive systems, crayfish are caught in the wild and then held in shallow-trays of circulating water until they moult. They are then transferred to chilled water to slow down the hardening process before being processed. The gastroliths may then be removed and the whole crayfish frozen or vacuum-packed, or they may be sold live. Since 1986, 300 soft-shelled crayfish plants had been initiated in Louisiana, however, in the 1991-92 season only 20 t were produced because many have not survived.

Momot (1991) has reviewed the aquaculture potential of coolwater crayfish. Because of their longevity, slow to moderate growth, low fecundity, and low juvenile survival rates, he considers them to be poor aquacultural candidates. In addition, the catch per unit effort in high-latitude waterbodies does not match the yields of those from low latitudes, e.g. Louisiana, although the area of pristine water is much higher at higher latitudes, e.g. Canada and Scandinavia. He states that none of the crayfish found in coolwaters are cultured to a size acceptable for human consumption, i.e. 9 cm in total length and at least 25 g weight, and that the most efficient method of utilising coolwater crayfish is probably through the harvest of wild stocks. Such stocks contain many individuals of commercial size (*table* 7). However, in Western Europe, *Pacifastacus leniusculus* grows to a larger size than Momot (1991) indicates (*table* 7), and is being cultured extensively and semi-intensively throughout its whole life-cycle in a number of countries. Indeed, most individuals caught by trapping are in the 10-12 cm body length and 50-70 g wet weight range. From many years of study on Canadian crayfish Momot (1991) is of the opinion that the most desirable harvesting tactic is a fishing effort regulation that removes 50-60% of the exploitable stock without size or sex restrictions, as long as it takes place after females have released their juveniles. He considers that the various minimum size limits and closed season regulations employed in some European countries to maintain brood stock and avoid recruitment overfishing are counter productive. In his experience coolwater crayfish populations respond to an increase in harvesting rates mainly through an alteration of age-specific mortality rates. Momot (1991) suggests that size limits imposed to

Table 7. – Some life history characteristics of coolwater crayfish (after Momot, 1991).

Crayfish	No. of eggs (range of means)	Max. carapace length (mm) ♂	♀	Carapace length at maturity	Life span (months)
Astacus astacus	103-242	75	65	40-65	42
Austropotamobius pallipes	20-135	56	47**	25-47	72-168
Pacifastacus leniusculus	110-180**	65	60**	30-47	48-132
Orconectes virilis	86-415	54	69	19-26	36- 40
Orconectes limosus	163	50	54	20-25	36- 48
Orconectes immunis	80-574	40		25-32	36
Cambarus robustus	186	60	65	36	36
Orconectes rusticus	80-574	51		17-23	36

* May be over 250 eggs in large individuals (Lowery, 1988).

** In a mixed population of *P. leniusculus* and *A. pallipes* being studied by the author the maximum carapace length so far recorded for males and females for each species has been 77 and 76, and 54 and 55 mm respectively, although larger (and heavier) individuals of both species have been recorded for other sites in England. The respective weights were 198 and 132, and 61 and 39 g respectively.

protect maturing males may cause the population to decline since it is the maturing males that regulate the population by suppressing recruitment of young crayfish. He suggests that there is a self-regulatory process in coolwater crayfish populations which is a result of dynamic intra-life stage interactions within food-limiting systems, and that biotic interactions between maturing males and younger stages are increased by setting harvestable sizes on males, as this suppresses recruitment, production and yield.

Australia

Australian aquaculture is in its infancy compared with the rest of the world. Production is dominated by salmonids, edible oysters and pearl oysters which between them made up 90% of production between 1988 and 1990 (O'Sullivan, 1991). Freshwater crayfish play a small but increasing part in total production and income (*table* 8).

There are estimated to be over 100 species of crayfish in Australia, but only three are of any consequence from a commercial point of view, i.e. the yabbie, *Cherax destructor*, the marron, *Cherax tenuimanus*, and the red claw, *Cherax quadricarinatus*, although koonacs, *Cherax plebejus* and gilgies, *C. glaber*, are also caught in some areas. Yabbies, marron and red claw possess excellent aquacultural characteristics (*table* 9), although meat yields are often exaggerated by including exoskeleton weight (Morrissy *et al.*, 1990).

The majority of the 405 licence holders in 1988/89 (*table* 8) farmed extensively in farm dams/lakes which are used as drinking water stores for sheep and cattle in dry areas (O'Sullivan, 1991). This method is mainly used for yabbie culture (Sokol, 1988). A number of farms were involved in contract growout of juveniles. Farms set up to produce yabbies in New South Wales have attracted considerable investment from entrepreneurs. One site of 243 ha in New South Wales comprises hundreds of concrete tanks, growout ponds, and a hatchery and processing plant. Another site is geared up to produce 15 million juveniles per annum. Production of marketable yabbies from one farm alone has been predicted to be in the region of 1 200 t/annum (Blue Cray Project-Prospectus 1990). As well as the domestic market there is considerable export potential, particularly to Asia, for the product, especially as it can be exported live, surviving for up to 7 days if chilled.

Marron and red claw tend to be cultured in ponds. Although marron culture in Western Australia has been successful, attempts to grow this species in

Table 8. – Estimates of value (farm gate) in A$million and crayfish farm production (tonnes) by state (derived from O'Sullivan, 1991).

Australia	1988	1988-1989	1989-1990
Total aquaculture	150.9	155.1	206.2
Crayfish	0.4	2.5	2.6 (0.8 hatchery 1.8 market)

State 1989-1990	No. of farms	Production (tonnes)
Queensland	80	31.24+
New South Wales	38	8
Victoria	100*	20
South Australia	120	13.77++
Western Australia	60	39.74+++
Northern Territory	7	experimental
Total	405	94.75**

* 24 active. +31.2 tonnes of red claw (*Cherax quadricarinatus*), 0.06 t of marron (*C. tenuimanus*). ++11.65 t of yabbies (*C. destructor*), 2.11 t of marron (*C. tenuimanus*. +++27.87 t of yabbies/koonacs (*C. destructor* and *C. plebejus*) 1.88 t of marron (*C. tenuimanus*).
** Note that this figure differs from that of the F.A.O. (*table* 1).

Table 9. – Characteristics of Australian crayfish used in astaciculture (modified from O'Sullivan, 1990). For additional characteristics and comparison with other species see Lee and Wickins (1992) and *table* 7.

	Cherax destructor (Marron)	*Cherax tenuimanus* (Yabbie)	*Cherax quadricarinatus* (Red claw)
Max. wt. (g)	2 000	320+	400+
Common adult wt.	100-200	50-100	100-150
Meat yield (% body weight)*	50-60*	50*	50-60*
Breeding age (months)	20+	<12	<12
Spawning/year	1	Multiple	3-5
Fecundity	Moderate	High	Very high
Burrows	No	Yes	No
Survival at high density	Good	Very good	Very good
Hardiness	Good	Very good	Very good
Water temperature	Cool	Hot	Hot
Cannibalistic	Yes	(?)	Moderate
Aggressive	No	Yes	No
1990 wholesale price	A$25-35/kg	A$10-25/kg	A$20-30/kg
1990 export price (not incl. freight)	A$40+	A$20-25	A$20-40+
Aquaculture potential	High	High	High

* Meat yields are exaggerated by including the exoskeleton and may be much less than this value (Morrissy *et al.*, 1990).

other states have been thwarted by unfavourable climatic conditions (Rogers, 1992). Many farmers in Queensland after first trying marron, turned to red claw, as this species is considered to have considerable potential (Jones, 1990*a*, *b*), and in fact now forms a good part of what is produced by aquacultural means (*table*, 1, 8). However, the economic recession in Australia has meant that many crayfish enterprises which relied on outside capital have ceased trading (Rogers, 1992).

Crayfish cultured for the restaurant trade are usually harvested at 50+grams, at about 1 year old. Price per kg ranges from A$10-35 depending upon species. Production levels vary with species from 200 kg/ha/y for yabbies in unmanaged farm dams to 5 t/ha/y for well-managed red claw ponds (*table* 10) (O'Sullivan, 1990; Jones, 1990*b*).

Table 10. – Notional production statistics for red claw *Cherax quadricarinatus* (from Jones, 1990*b*).

Statistic	Value	Statistic	Value
Stocking density	10/m^2	Mean harvest weight	70-100 g
Stocking size	0.5-2.0 g	Survival	50-80%
Growout period	6-18 months	Production	3-5t/ha/y
			300-500 g/m^2

Europe

There are five species of crayfish indigenous to Europe (Holdich, 1988, 1993; Lowery and Holdich, 1988), i.e. the noble crayfish, *Astacus astacus*, which is widespread in eastern, central and northern areas; the narrow-clawed crayfish, *Astacus leptodactylus*, which occurs mainly in western Asia and Eastern Europe, but which has been introduced into many other European countries; *Astacus pachypus* Rathke, a species confined to areas of the Caspian and Aral Seas; the stone crayfish, *Austropotamobius torrentium* (Schrank); and the white-clawed crayfish, *Austropotamobius pallipes* (Lereboullet), which occurs mainly in southern, and western parts, including the British Isles, where it reaches the limits of its northerly distribution and is the only native species (Holdich and Reeve, 1991). All native European crayfish have been affected by increasing industrialisation, resulting in pollution of waterways, and changes in land use, to varying degrees (Westman, 1985; Hogger, 1988).

In addition, there are three introduced species which have a widespread distribution (Holdich, 1988, 1993; Lowery and Holdich, 1988), i.e. the spiny-cheek crayfish, *Orconectes limosus* (Rafinesque), a North American species originally introduced into Germany in 1890, but which now has a widespread distribution in mainland Europe; the North American signal crayfish, *Pacifastacus leniusculus*, originally introduced into Sweden in the 1960s (Brinck, 1983), but which has now been spread to most European countries; and the Louisiana red swamp crayfish, *Procambarus clarkii*, introduced into Spain in the 1970s and which is currently expanding its range into Portugal and France, as well as being present as isolated populations in other European countries (*table* 3).

It is said that the market for crayfish in Europe could be in the region of 10 000 t per year, with Scandinavia and France (see below) being the main consumers. Current production on the other hand is only about 5 000 t per annum, most of that being based on *P. clarkii* from Spain (Huner *et al.*, 1989). In N.W. Europe, at least, prices are high, particularly early in the season (*table* 11). Before the onset of crayfish plague in the mid 1800s Western Europe was self sufficient in crayfish, the harvest being based mainly on *A. astacus* and *A. pallipes*, and countries such as Finland (Westman, 1991) and Sweden (Gydemo, 1989) were exporters. After the demise of much of the native stock, attention was turned to *A. leptodactylus* from Turkey and Russia, from where it was introduced and also regularly imported. However, like other European astacid crayfish it is susceptible to crayfish plague and many introductions were not successful. As the disease did not reach Turkey until 1985, that country remained the main supplier of crayfish to Western Europe until the disease struck. At its peak in 1984 nearly 8 000 t were produced, the majority being exported (Köksal, 1988). Due to overfishing and plague production dropped dramatically (*table* 1) in 1986. This caused crayfish prices to rise in Western Europe and stimulated the export trade from the USA and Spain, particularly to Sweden where over 2 000-3 000 t are consumed annually (Gydemo, 1989).

Reliable data on the crayfish harvest in Eurasia is very difficult to obtain. *Table* 1 of FAO statistics shows that in 1989 some 2 690 t of *P. clarkii* (from Spain) and 1 642 t of *A. leptodactylus* (from Turkey) were harvested. These relatively large catches were entirely from wild populations. Much of the Spanish production is consumed within the country but some is exported. Not included in the figures is any production from Russia and Lithuania. By contrast, according to FAO statistics, only 14 t of astacid crayfish were produced by European countries. This is a considerable under-estimate and the figure is likely to be closer to 1 000 t for both *A. astacus* and *P. leniusculus* combined. Finland produces over 100 t (Westman, 1991), and Sweden at least 400 t (Gydemo, 1989; Brinck, pers. comm. 1992, puts the figure at 600 t). The low FAO figures are probably due to the fact that much of the production in N.W. Europe is sold at the farm gate and consequently does not appear in fishery statistics. How much of that volume is produced from astaciculture is difficult to determine. Lindqvist (1989) has put the figure as low as 2%, but that again would appear to be something of an under-estimate if extensive culture is taken into consideration.

Westman *et al.* (1990) have listed Austria, Britain, Denmark, Finland, France, Germany, Ireland, Italy, Lithuania, Norway, Russia Spain, and Sweden as farming crayfish. Sweden is the most advanced with over 400 farms involved in culturing *A. astacus* (54) and *P. leniusculus* (351), either for consumption or as juveniles for re-stocking or stocking into extensive systems or the wild (Gydemo, 1989). Live crayfish, particularly *A. astacus*, fetch a high price in the markets early in the season in Sweden (Gydemo, 1989), but can be obtained at much lower prices directly from trappers or farmers (Brinck, pers. comm.). The high prices in Sweden and Finland reflect the high labour costs, compared with Spain and Louisiana (*table* 11). In Finland, astaciculture as such also tends to be confined to the production of young noble and signal crayfish for stocking (Westman, 1991). In 1990 there were 39 government and private crayfish rearing institutions in central and southern areas which produced 88 000 noble and 47 000 signal summerlings, together with 13 000 older juveniles. The most advanced form of culture involves stripping eggs from brood crayfish and transferring them to warm incubators in which hatching takes place under controlled conditions. By this method juveniles can be produced some two months ahead of those in the wild (Pursiainen *et al.*, 1989). Similar methods have been used in Lithuania to produce large numbers of noble crayfish for stocking purposes (Cukerzis, 1988). Although the number of semi- professional and professional trappers has decrased since the height of Finnish crayfish production in 1900, when 15.5 million noble crayfish were exported to Russia, Sweden and Denmark, there are currently estimated to be 100 000 recreational trappers. The current catch of crayfish in Finland, however, is only about 110 t (3.5 million individuals) (Westman, 1991). Köksal (1988) has described the methods used in Turkey for producing juvenile *A. leptodactylus* for stocking and adults by pond culture, and the methods used by many European countries are summarised in Holdich and Lowery (1988), Skurdal *et al.* (1989) and Westman *et al.* (1990).

Table 11. – Comparative prices of crayfish.

Sweden (Gydemo, 1989):	
Astacus astacus (live from Sweden)	US$100/kg
Pacifastacus leniusculus (live from Sweden)	US$70/kg
Astacus leptodactylus (live from Turkey)	US$20/kg
Procambarus clarkii (frozen from USA)	US$11/kg
Louisiana (Huner *et al.*, 1989):	
Procambarus spp. in Louisiana	US$1.00-2.25/kg
Britain (1992):	
Procambarus (live)	US$23/kg
Pacifastacus (live, top grade)	US$23/kg
France (Laurent, 1992):	
Astacus astacus (live)	US$16/kg
Pacifastacus (live)	US$7/kg
Procambarus (frozen from USA/Spain)	US$3.6/kg
Finland (1991 pers. obs.):	
Astacus astacus (live)	US$4/individual
Astacus leptodactylus (cooked from Turkey)	US$2/individual
Procambarus (cooked from Louisiana)	US$1/individual

The French are said to consume large quantities of crayfish (Huner *et al.*, 1989), and indeed nearly 2 000 t were imported in 1981, but this amount steadily declined and by 1986 it had dropped to 600 t (Laurent, 1992). Up until 1988 all imported crayfish were live, but a ban on the importation of non-native crayfish has meant that most *P. clarkii*, for example, are now imported frozen. In 1991, 650 t were imported, of which 355 t were frozen; 98.5% of the frozen product coming from Spain. China exported 21 t of *P. clarkii* to France and Turkey 192 t of *A. leptodactylus*. Besides Spain, Yugoslavia (*A. astacus* and *A. leptodactylus*), Britain (*P. leniusculus*), and Greece (*A. astacus*) were the main European suppliers of crayfish to France in 1991. France exported just over 60 t of crayfish in 1984, but less than 10 t in 1991 (Laurent, 1992). Very little astaciculture appears to be going on in France at present, except for the production of noble juveniles for stocking, although this was not the case in the past (Arrignon, 1991). Indeed, the largest crayfish farm ever built in Europe, consisting of 12 km of canals on 12 hectares of land, was built by the Marquis de Selve in the Essonne valley in the mid-1800s. In 1869 some 350 000 *A. astacus* were produced but soon after crayfish plague and a war put an end to the enterprise (Arrignon, 1991).

Various aspects of the situation regarding crayfish in the British Isles have been dealt with by Lowery and Holdich (1988), Alderman and Wickins, (1990), Holdich and Reeve (1991), Lee and Wickins (1992), Holdich *et al.* (1993), and Holdich and Rogers (1993). Prior to the 1970s there was no crayfish-based industry and consumption was based on *Austropotamobius pallipes* (the white-clawed crayfish) at a local level, although *Astacus leptodactylus* (the narrow-clawed crayfish) from Turkey and *Procambarus clarkii* (the red swamp crayfish) from Kenya were sometimes found in fish markets in Britain (alien crayfish imports are banned in Ireland). In the mid-1970s *Pacifastacus leniusculus* (the signal crayfish) was introduced into Britain, mainly from Sweden, to test its aquaculture potential. It grew well, particularly in southern parts (Hogger, 1986), and was distributed to many potential crayfish farmers, mainly for pond culture, although some were introduced into the wild. A British Crayfish Marketing Association (B.C.M.A.) was set up which helped maintain prices and quality, and marketed crayfish for its members. However, despite many predictions being made about the ease with which signal crayfish could be cultured and the profits to be made, they are still an unfulfilled promise (Behrendt, 1992). The BCMA did not survive for long as independent crayfish growers undercut their prices, although they are still high (*table* 11). It is not possible to determine how many signal crayfish are produced annually in Britain as much is sold at the farm gate, although it is probably less than 10 t. Some 60 sites are registered with the government as crayfish farms,

but many people also produce crayfish for their own purposes. Some successful crayfish farmers in Britain consider that a greater profit per unit area can be made from crayfish than agricultural products, although this has not been the experience of the majority.

The development of crayfish farm sites falls into three categories (Holdich and Rogers, 1993): a. non-drainable lakes where extensive farming (ranching) is practised, often on a stock-and-forget principle; b. non-drainable or drainable ponds where there is some degree of management; and c. drainable, purpose-built channels, where semi-intensive or intensive culture is practised. Yields of signal crayfish equivalent to 500 kg/ha have been achieved in semi-intensive ponds but there is little evidence that this can be achieved every year. Escapes from crayfish farms and deliberate introductions into the wild have led to self-sustaining wild populations of signal crayfish. Within 5-6 years such populations can build up to many thousands of individuals, and in a number of cases these are being trapped commercially in some English rivers. Similarly, narrow-clawed crayfish which have escaped into the wild, have formed huge populations at a number of sites with relatively static water: they too are being commercially fished, but mainly in an attempt to keep their numbers down. Both signal and narrow-clawed crayfish are currently causing anglers considerable problems, and in a number of water-bodies fishing has been ruined as the crayfish take the bait before the fish!

In a belated attempt to try and control the spread of alien crayfish and crayfish plague in Britain, the government has introduced a number of laws (Alderman and Wickins, 1990; Holdich and Rogers, 1993), but still refuses to impose import restrictions as many European countries have done. Serious consideration is, however, being given to the setting up "no-go areas" where permission will not be given for any new alien crayfish farming enterprises where there are substantial populations of the native crayfish, *Austropotamobius pallipes* (Holdich and Reeve, 1991). In addition, it has recently become illegal to allow alien crayfish to escape into the wild, despite the fact that they are now ordinarily resident in Britain, i.e. there are wild breeding populations. This law not only applies to signal and narrow-clawed crayfish, but also to noble crayfish which are currently being cultured on a small scale in Britain. Their escape could have an adverse effect on native populations as they are likely to be superior competitors for resources like other alien crayfish. *Procambarus clarkii* may also be breeding in the wild in Britain, although this has yet to be proved conclusively. It has recently appeared live in one southern fish market at the same price as signal crayfish elsewhere (Foster, pers. comm.) (*table* 11). The individuals apparently originate from juveniles imported into Britain for growing-on in the summer months!

CONCLUSION

As long as demand for whole, live crayfish in N.W. Europe continues then interest in astaciculture as a means of supplementing the wild harvest is set to increase. More effort is likely to be put into trying to intensify production, increase survival, and speed up growth. The same can be said for Australia, particularly if the export markets are exploited. The supply of live crayfish has tended to be seasonal in Europe, but a year-round supply can now be guaranteed via the frozen product. At present this is largely based on *Procambarus clarkii* from Louisiana but it seems likely that an increasing amount will come from China and Spain, where labour costs are lower.

Crayfish are good aquacultural organisms as they reproduce readily in culture and do not have larvae. They are polytrophic and will feed on inexpensive feeds. Where there is a tradition for eating them then they are easily marketed, but introducing them to new markets, or as a different product, requires good promotion and marketing (Avault, 1993).

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