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NEW ZEALAND FRESHWATER FISHERIES MISCELLANEOUS REPORT NO. 113

RESEARCH REQUIREMENTS FOR
ENVIRONMENTAL IMPACT STUDIES ON MARRON
(*Cherax tenuimanus*) IN NEW ZEALAND

by

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1. INTRODUCTION

1.1 The start of marron farming in New Zealand

European fisheries for crayfish have collapsed in recent years, and there is now a growing demand for cultured freshwater crayfish in Europe (Merrick and Lambert 1991). This demand is largely responsible for the increasing global interest in crayfish aquaculture, and the corresponding search for a suitable species for aquaculture. Marron (*Cherax tenuimanus*) is an Australian species of freshwater crayfish. It has fast growth, a high meat yield and is better tasting than other Australian crayfish (Decker 1990). It is therefore a good candidate for aquaculture, and marron farming is now being attempted in a number of countries throughout the world.

Marron farms were initially established within its natural range, in southwestern Australia. Subsequently marron were introduced to Queensland and, since 1980, they have been introduced to South Africa, Zimbabwe, Egypt, Japan, China, France, the United States, and the Dominican Republic in the Caribbean. In 1987 marron were introduced to New Zealand.

They were placed in quarantine at the Koru Aquaculture Ltd. (KAL) farm site at Warkworth, near Auckland. In July 1989 they were released from quarantine and KAL was issued with a licence to farm them. The marron reproduced successfully in ponds at Warkworth, and in 1990 were being distributed and sold within New Zealand. KAL intended to assist the development of a New Zealand marron industry by supplying juveniles for on-growing in other farms throughout New Zealand.

There is clearly a strong interest and demand for this type of aquaculture in New Zealand. To date MAF Fisheries has received 11 applications to licence marron farms in New Zealand, and an additional 57 enquiries have been received about marron farming (pers. comm., B. Swale).

1.2 Development of a New Zealand marron farming industry halted

Approvals to transfer marron from the KAL farm site at Warkworth to other farm sites have not been given. This is primarily because of concerns over the effect of this species on the New Zealand environment. The introduction of a new species to any new site, is covered by the Conservation Law Reform Act (1990). Section 26ZM of this Act requires the approval of the Minister for Conservation before a new species of freshwater life can be introduced to a new location. However, the impact assessments for the transfers of marron were heavily criticised (e.g., Barrett Fuller and Partners 1990), mainly because of the lack of information on the biology, and on the ecological requirements of marron. This lack of information means that concerns over the potential impact of marron on native flora and fauna cannot be resolved. The Department of Conservation was therefore unable to authorise their transfer to new locations. A situation was created in which marron were being legally farmed at

the Warkworth site, and could be sold alive throughout the country, but could not be transferred to farm sites elsewhere in New Zealand.

To resolve this impasse, Cabinet decided in December 1990 to purchase the farm at Warkworth. The Ministry of Agriculture and Fisheries (MAF Fisheries) was directed to conduct studies at the farm site over the next 3 years to determine the ecological requirements of marron and their interactions with other freshwater species in New Zealand. It was anticipated that a decision would then be made to either allow marron to be introduced to other farm sites, or to destroy the stocks, depending on the results of the studies.

1.3 Purpose of this report

The Cabinet decision to buy the farm and to have MAF Fisheries conduct studies on the environmental consequences of marron implied that such research would resolve the impasse. It created the impression that by November 1993, the scientific data would clearly establish whether marron could cause unacceptable impacts in this country, allowing a clear objective decision to be made on their future.

Although scientific research based on tank studies would provide answers to a number of questions, and could be expected to clarify the debate, it would not be able to provide irrefutable proof of impact or lack of it. Thus a defensible decision on the future of marron could not be based wholly on the results of research. Because of this difference between expectation and reality, this report has been prepared to explain the major issues to be faced, and to identify the priority areas for research into marron. The extent to which the issues could be practically resolved by research is discussed so that the limits to scientific studies can be appreciated.

To begin with the report firstly reviews some of the problems that have occurred with crayfish introductions in other countries. Experience with crayfish introductions overseas may provide lessons relevant to the introduction of marron, or other crayfish species into New Zealand. In addition, problems encountered with overseas introductions of crayfish species can be expected to provide a generalised ecological model of the types of impact that can be anticipated. Such a model would provide a useful framework for identifying the types of impact that might be expected from marron in New Zealand.

The report then identifies the main ecological and biological factors that would influence the establishment of breeding populations of marron in New Zealand. This is the most important and first issue to resolve as any long-term, sustainable impacts would be limited primarily to locations where marron can establish self-recruiting feral populations. If they cannot naturalise in New Zealand waters, or would be restricted to very few places, they are unlikely to become a serious pest species in this country.

However, if they can become widely established, then concerns over the effect of

marron on components of New Zealand's aquatic flora and fauna, fisheries and aquatic environments need to be addressed. The potential problem areas are discussed in relation to the existing literature on the biology and ecology of marron. Unfortunately much of this information is observational or anecdotal and has limited predictive value. However, some of it serves to reinforce some of the concerns, whereas others can be discounted. As a result, secondary priorities for research are established.

Finally, the three main methods for determining potential impacts of marron on the New Zealand flora and fauna are identified. The advantages and disadvantages of these approaches are discussed in relation to their practicality and the limitations imposed on this study.

2. PROBLEMS WITH CRAYFISH INTRODUCTIONS OVERSEAS

Freshwater crayfish species have been introduced to many countries. Although these introductions have often resulted in useful fisheries, some introductions have also caused unexpected problems (Holdich 1988, 1990). These problems highlight the fact that there are dangers involved with releasing exotic species of freshwater crayfish into new waters.

2.1 The red swamp crayfish (*Procambarus clarkii*)

The red swamp crayfish is a native of southern U.S.A, and was introduced into Japan in 1918 as a food for bullfrogs. The introduced crayfish became a serious agricultural pest in rice fields west of Honshu, eating rice shoots and weakening dykes by their burrowing activities (Bardach *et al.* 1972, Holdich 1988). A similar situation occurred after this species was introduced to Hawaii. Here it became a pest in taro fields (Bardach *et al.* 1972). Following its introduction to Lake Naivasha, Kenya, the red swamp crayfish proliferated and is now destroying marginal vegetation and eating fish eggs (Lowery and Mendes 1977). It is apparently causing problems wherever it is introduced (Holdich 1988).

2.2 The signal crayfish (*Pacifastacus leniusculus*)

The signal crayfish is another North American species and has caused problems for other native crayfish species when introduced to North American waters outside its natural range. In California, its introduction led to the creation of valued, exploitable populations (Lowery and Holdich 1988) but the native crayfish (*Pacifastacus fortis*) is now threatened (Eng and Daniels 1982). In addition, introductions of the signal crayfish are thought to have contributed to the extinction of *Pacifastacus nigrescens*. Momot and Leering (1984) showed that in tank studies *P. leniusculus* dominated the Eastern Canadian native crayfish *Orconectes virilis* despite the fact that *O. virilis* always initiated aggressive interactions.

In Europe, native crayfish stocks (*Astacus* and *Austropotamobius sp*) were depleted by the *Aphanomyces* plague in the later half of the 19th century and never recovered (Holdich 1988). Although the initial vector for the crayfish plague is unknown, earlier introductions of North American fish or crayfish species are probable candidates. Introductions of the signal crayfish have since occurred to provide a plague-resistant replacement species. As a result of these introductions the signal crayfish is now widespread in Europe (Holdich 1990).

Although it is generally believed that introductions of the signal crayfish have had no effect on the native crayfish species of Europe (Westman and Pursiainen 1984, Holdich 1990) this may be because of limited information on the effects of crayfish introductions. Abrahamsson (1969) considered that the signal crayfish would displace the native species because of its aggressive nature and its higher fecundity and

growth rate. Westman and Pursiainen (1984) noted that interspecific competition was likely to occur between the native and introduced crayfish species as they share similar habitats, foods, and life histories. More recently Soderback (1991) demonstrated that the signal crayfish clearly dominated *Astacus astacus* in tank studies.

The signal crayfish was introduced into the United Kingdom for aquaculture in the mid 1970s. Subsequently, outbreaks of the crayfish plague (*Aphanomyces astaci*) occurred within the native crayfish (*Austropotamobius pallipes*) stocks. These outbreaks occurred in regions where the signal crayfish was being cultured (Thompson 1990) and some populations of the native species were devastated by the plague. The introduction of the signal crayfish for aquaculture has been blamed for the introduction of the crayfish plague to the United Kingdom (Holdich 1990), however, proponents of signal crayfish dispute this.

Recently, Holdich (1990) expressed concern that competition between the native species (*A. pallipes*) and the signal crayfish may be further depressing native stocks in the United Kingdom. In England the signal crayfish grow faster, are more aggressive, feed on a wider trophic spectrum, have a higher reproductive potential, and have a higher juvenile survival rate than the native species (Holdich 1988, Thompson 1990). In this sense they have the classic life history profile of successful invader species. In laboratory experiments, adult signal crayfish out-competed and displaced the more specialised native species (Holdich 1990).

Biologists now believe that competition between the signal crayfish and the native species of North America, Europe and the United Kingdom will occur where distributions overlap and where resources (e.g., food or shelter) are limiting. Unfortunately it is difficult to measure the outcome of such interactions in the wild because such effects may take many years to occur. For example, in a Swedish lake, the signal crayfish and the native species were equally abundant after 10 years. But now, 18 years after their introduction, signal crayfish dominate by 5:1 (Soderback 1990).

P. leniusculus controlled aquatic weeds in a weed-choked water body in France (Laurent and Vey 1986). This was probably regarded as beneficial, however, in some circumstances a reduction in aquatic macrophytes may be undesirable.

2.3 *Orconectes* sp.

Introductions of North American crayfish species of the genus *Orconectes* have also caused problems. In North American waters outside its natural range *O. rusticus* destroyed weed beds, consumed fish eggs and invertebrates, and replaced fish as the top predator (Hobbs III *et al.* 1988 cited by Holdich 1988, Lodge and Lorman 1987). *O. rusticus* has also been responsible for the decline of native crayfish species. It replaced *O. sanborni* in some American waters because males of both species mated preferentially with female *O. rusticus* (Butler and Stein 1985). As a consequence

recruitment of both species was reduced, but the more fecund *O. rusticus* was less affected and so eventually dominated *O. sanborni*. Size-selective predation by fish restricted habitat use by crayfish and so may have increased competition between *O. sanborni* by *O. rusticus* (Stein and Magnuson 1976, Mather and Stein 1990).

In Trout Lake, Wisconsin, the introduced crayfish, *O. propinquus*, replaced the native *O. virilis* as the dominant species (Lodge *et al.* 1986). However, *O. rusticus* subsequently invaded Trout Lake and, because it had dominated other species elsewhere, was expected to dominate *O. propinquus*. Instead densities of the native species, *O. virilis*, increased. This result shows that population dynamics between crayfish species are complex and not explained by simple dominance hierarchies.

In Newcastle Reservoir, Utah, the introduced *O. virilis* suppressed the growth of rainbow trout by altering the food web and diverting benthic production away from the trout (Hepworth & Duffield 1987). *O. virilis* have also significantly reduced macrophytes in lakes where they have been introduced (Chambers *et al.* 1990).

O. limosus displaced native crayfish species in many waters to which it was introduced in Europe (Laurent 1990).

2.4 The marron (*Cherax tenuimanus*)

The crayfish species discussed above are all Northern Hemisphere species, belonging to the Astacidae or Cambaridae families. All are native to North America. In comparison there are no reports of any European or southern hemisphere species causing problems. However, this may be because these species have not been introduced to new waters as widely or frequently as the North American species.

Marron belong to the Parastacidae, which includes a number of crayfish species found only in the southern hemisphere. Although there is concern over the spread of both the yabbie (*Cherax destructor*) and the marron in Australia, there is little evidence for any problems due to introductions of these species.

Marron have now been introduced to farm ponds throughout southwestern Australia. They have also been introduced to Queensland, but no feral populations are known to have become established in this state. A population of marron became established on Kangaroo Island in Flinders Chase National Park, South Australia (Jones 1988). Expansion of the colony was reported as rapid and extensive (Jones 1988), however, it is not known yet what impact, if any, this has had on the native crayfish, the yabbie (*C. destructor*).

In a report on yabbies, Mills (1989) stated that marron could be expected to outcompete other Australian *Cherax* species where their ranges overlapped. However he provided no evidence for this assertion. Later he noted that koonacs (*C. plebejus*, *C. glaber*) stunted the growth and reproduction of marron in farm ponds. This later statement probably refers to Morrissy's (1970) conclusion that koonacs could have

been a factor in the failure of marron to breed in some ponds. If so the evidence that marron compete successfully with koonacs is hypothetical. It is not known whether marron would out-compete the yabbie (*C. destructor*) or vica versa.

Zeidler (1982) indicated that species in the genus *Cherax* were the most successful and widespread in Australia and probably out-competed species of the genus *Geocharax*. He noted that where *Cherax* and *Geocharax* species co-existed *Cherax* was always the most abundant species and *Geocharax* was rare. In comparison, when *Geocharax* species occurred on their own they were very abundant. Zeidler (1982) was probably referring primarily to the yabbie, nevertheless, such comments may reflect a generic rather than a species-specific trait.

Marron have now been introduced to eight countries, including New Zealand (Decker 1990), but there are no known feral populations in any of these. An accidental release of marron into the Buffalo River in South Africa has been reported, but their fate is unknown. The marron probably failed to establish (Decker 1990). The introductions have occurred relatively recently (since 1980) and so it may be too early to determine whether feral populations will become established, or whether these will create any problems for native faunas.

Shireman (1973) documented the introduction of marron into Louisiana for experimental evaluation of its aquaculture potential and conducted tank trials to determine impacts on the native *Procambarus* crayfish species. Marron were restricted to the corners of the tanks while the native species roamed freely. Marron would not compete for food. They were harassed by the smaller *Procambarus* and usually died within a few weeks.

These results suggest that marron cannot compete with *Procambarus*, but their poor reactions may have been due to difficulties in acclimatising, and not to the aggressive behaviour of *Procambarus*. Rubino *et al.* (1990) reported problems with acclimatising marron to new waters, but once these problems were overcome, there were no apparent interactions when marron were placed in tanks with *Procambarus clarkii*.

2.5 Conclusions

It is apparent that many crayfish introductions to other countries have resulted in useful new fisheries. However, most introductions have also resulted in unexpected problems, indicating that care needs to be taken with crayfish introductions. The preliminary interaction experiments between marron and the native crayfish species in North America (Shireman 1973, Rubino *et al.* 1990) reflect the growing awareness that crayfish introductions need to be carefully evaluated. Fears over the possible effects of marron in New Zealand waters are therefore justified and there is a need for a careful evaluation of this species.

The main impact that can be expected from the introduction of an exotic crayfish

species is a reduction in stocks of the native crayfish species. In this respect it is important to note the long time scale (10-18 years) that may be needed before species interactions result in measurable changes to native crayfish populations in the wild. Very little is known about the mechanisms for such changes. Competition for food and/or cover is possible and is resolved primarily by aggressive behaviour and fighting. Interspecific or intergeneric breeding has also resulted in the decline of native species. However, predation and interference competition are also possible. Because of the few studies of mechanisms there is no theory that allows prediction of where or when such interactions can be expected, and what outcomes may occur.

There are fewer reports of taxa other than native crayfish being adversely affected by introduced crayfish. However, this does not indicate that impacts to other taxa are unlikely or minimal, only that they are encountered less frequently than impacts to native crayfish species. In particular, introduced crayfish may cause problems by destroying aquatic macrophyte beds, eating fish eggs, and preying on invertebrates, including small crustacea. They can significantly alter the food webs of aquatic systems, thereby affecting the production of top predators such as fish.

Reports of adverse effects of crayfish introductions on the physical features of aquatic environments are also scarce and relate mainly to the burrowing habits of crayfish.

3. FACTORS AFFECTING THE ESTABLISHMENT OF MARRON IN NZ

If marron can establish breeding populations in waters throughout New Zealand then any impacts they may have can be expected to be widespread and irreversible. If they cannot establish breeding populations in New Zealand waters, or will be limited to very few waters, then any impacts will be correspondingly restricted. Determining the waters where marron can establish breeding populations is therefore a key issue.

At present it is not known whether marron could survive in many New Zealand waters. They appear to require waters with a relatively high alkalinity (Decker 1990). If this is confirmed then their potential distribution in New Zealand waters may be limited. However, there are other factors to consider in the establishment of breeding populations. Firstly marron would have to escape from a farm environment in sufficient numbers to establish a breeding population. Secondly they would have to be able to disperse to streams in the farm catchment. They must then be able to survive in the stream water. Although tolerance to water chemistry may be an important factor determining survival in streams, predators also need to be considered as they will influence densities of marron. If marron can survive and cope with predators, they must be able to find suitable foods and grow in New Zealand waters. Finally they must be able to reproduce. If a feral population can become established in the river adjacent to or below a farm site, then the potential for marron to spread to new catchments needs to be considered.

3.1 Ability to disperse

Dispersal mechanisms for marron are likely to be similar to those for the closely related yabbie (*Cherax destructor*). Passive dispersal of yabbies occurs during floods (Mills 1989). However, yabbies are also capable of leaving the water on wet nights and travelling overland to new water courses (Mills 1989).

Marron can also leave the water and travel overland. They are known to forage on crops adjacent to stream banks (Shipway 1951a, Jones 1988), and Morrissy (Western Australian Marine Research Laboratory, pers. comm.) indicated that they are good climbers, capable of travelling long distances overland to reach water courses.

3.2 Escape from farms to natural water courses

Although adult marron could be theoretically confined to farms by walls, electric fences, and screens on outflows, confinement of juveniles is more difficult. In North America, the escape of cultured crayfish into the wild is almost certain (Hobbs III *et al.* 1988, cited by Holdich 1988). With reference to marron farms, N. Morrissy (pers. comm.) stated that "it is very unlikely that any practical form of security could prevent their escape in significant numbers over the long term". Individual exceptions to these statements will undoubtedly occur. But it may only take one escape during a dam burst, an unexpected flood, or when outflows block and water

spills over the screens to produce a feral population in a downstream water course.

Marron are capable of colonizing most waters within a river catchment after escape from a farm. When reaching a watercourse they can move upstream by walking, or climbing when instream obstacles (eg., rapids, logjams etc.) block the way. They may be able to bypass waterfalls by walking and climbing overland. They can also move downstream, either by active walking and swimming, or by passive transport during flood flows. Once established in a natural water below a farm, it would be very difficult, if not impossible, to eradicate marron.

3.3 Survival in New Zealand waters

Accepting that some marron will eventually escape and can disperse to natural water courses, they must be able to survive if they are to grow and eventually reproduce. Marron have failed to survive when introduced to natural waters in a number of countries, and the cause of this mortality is thought to be unsuitable water chemistry conditions (Morrissy 1988). Morrissy (1972) indicated that successful introductions to dams in southwestern Australia were associated with high levels of calcium. In New Zealand Decker (1990) found that marron could only survive in waters with alkalinities greater than 20ppm CaCO_3 . Low alkalinity, reflecting low calcium levels, could therefore limit marron survival in many New Zealand rivers as this country's rivers are relatively dilute by world standards (Close and Davies-Colley 1990). However, on the basis of minimum lethal alkalinity levels reported by Decker (1990), their survival in most lakes could be expected. Stout (1975) summarized data for a number of North and South Island lakes. Alkalinities over 20ppm were common except in the Waitaki hydro lakes and some Westland lakes.

One of the difficulties in using low alkalinities to determine the survival and hence the potential distribution of marron in New Zealand is that low alkalinity *per se* is unlikely to be lethal to crustacea (Brown *et al.* 1991). Low calcium or magnesium ion content, or low ionic content in general, are often correlated with low alkalinity and are more likely to be the cause of crayfish mortality in hard waters. Thus alkalinity itself is not a useful criteria for predicting marron survival in natural waters.

Low calcium levels have been associated with the absence of several aquatic animals, particularly crustaceans in freshwater ecosystems. But there is little evidence that low calcium affects crustacea directly (Macan 1963). Marron have a relatively high requirement for calcium (it provides rigidity in the exoskeleton). Nevertheless, they can survive in natural waters with calcium concentrations as low as 1.2 ppm (Morrissy 1976, 1988). Low calcium levels are therefore unlikely to be limiting marron survival. It is more likely that low calcium concentrations limit biological production, and that this subsequently limits marron production (Morrissy 1988).

If calcium concentrations are not limiting other ions may be. For example, the inability of crayfish to take up calcium during postmoult has been linked with low sodium and low bicarbonate concentrations (Wheatly 1990).

Furthermore, the low ionic content of low alkalinity waters could also exacerbate osmoregulatory problems. Freshwater crayfish species have evolved from marine ancestors and have varying abilities to penetrate freshwater. Marron in particular are likely to be less evolved from their marine ancestor than other *Cherax* species. They can tolerate higher salinities than other *Cherax* species (Goodsell 1984), but their relatively high haemolymph concentration suggests that they are correspondingly less adapted to pure freshwater. Tank experiments reinforce this contention. Osmoregulation of marron failed below 2.5 ppt salinity (Goodsell 1984, cited by Morrissy 1988), and Rubino *et al.* (1990) showed that survival of marron in aquaria with no salt was 0%, compared with 90% for aquaria with 50-100ppm NaCl. The concentration of sodium cations in freshwater is thus likely to be a critical factor determining the effects of dilute or low alkalinity waters on marron survival.

However, the above results on the osmoregulatory ability of marron were obtained in tank experiments, where the marron were probably stressed and/or starved. In farm ponds there was no difference in growth or survival for marron in salinity ranges of 0.05 up to 2.5ppt (Morrissy, pers. comm.). Osmoregulation in low salinity waters is therefore apparently possible if other factors such as food, lack of stress and adequate water temperatures for growth are provided. In this respect Goodsell (1984) concluded that the only site for ion uptake in marron was the gills. However, he did not consider uptake across the gut wall. O'Brien (1990) found significantly lower levels of sodium and chloride in the hindgut fluid of marron compared with the foregut. As there is a direct haemolymph supply to this organ (O'Brien 1990), it could be another site of ion uptake, in addition to the gills. If so feeding may be necessary for marron survival in dilute waters.

In summary the cause of marron mortality in waters of low ionic strength is unresolved. However it is a critical, if complex, issue and needs to be resolved before their potential distribution in New Zealand waters can be predicted.

Other environmental factors will also influence the survival of marron but will be less important than water chemistry in determining potential geographical distribution.

Water temperatures in New Zealand rivers range from a mean of 5.1°C to 22.8°C (Mosely 1982). Marron are inactive at water temperatures below 10°C (Morrissy 1976) and the maximum lethal temperature for marron is 30°C (Morrissy 1990). Thus it can be concluded that water temperature *per se* will not limit marron survival or distribution in New Zealand. However, it is interesting to note that marron died at temperatures over 27°C in New Zealand (Decker 1990). This lower maximum lethal temperature in New Zealand water maybe due to the compounding effects of lower salt concentrations. Salt regulating mechanisms work best at high temperatures and low water temperatures limit the penetration of some crustaceans into freshwater (Hutchinson 1967). Conversely, low salt concentrations could increase the susceptibility of crayfish to high temperatures. If so then marron would be expected to have a lower tolerance of high water temperatures in hard waters.

Marron require oxygen levels over 6 ppm, and have a comparatively narrow range of tolerances to pH and other water quality characteristics (Semple *et al.* 1990). Although these other water quality conditions will limit marron survival in some waters, low concentrations of ions in hard water will be the most general and critical variable determining where marron can and cannot live in New Zealand.

3.4 Foods, feeding, and growth

Marron can be expected to eat a wide range of living and dead, animal and plant foods (Shipway 1951a, b, Morrissy 1974a, Mills 1989). Although they are thought to be mainly detritivores (Mills 1989), they readily consume rooted plants (except *Characans*), and will also eat insect larvae, molluscs, other smaller freshwater crustacea, carrion and crayfish eggs. Marron are able to use their large chelipeds to roll over small stones and capture insect larvae (Shipway 1951a). They also have a limited ability to leave the water and forage on river banks, feeding on vegetable crops. It is apparent that they have a wider trophic spectrum than the native *Paranephrops* sp., and will adopt the role of herbivore, carnivore, scavenger, or detritivore as the opportunity presents. Marron can therefore be expected to find suitable foods and to grow in all waters where they can survive.

Although marron could feed on a wide range of foods in New Zealand, growth will probably be slower in most parts of New Zealand than in Australia because of this country's somewhat colder climate (N. Morrissy, pers. comm.). The optimum temperature for growth of marron is 24°C (Morrissy 1990) and growth ceases below 12°C (Hecht 1985). As a consequence the growing season lasts for eight months in southwestern Australia (N. Morrissy, pers. comm.).

In New Zealand, water temperatures between 12-24°C occur most frequently north of Auckland and in coastal regions of the Bay of Plenty, East Cape, and Hawkes Bay (Mosely 1982). Nevertheless, water temperatures exceed the 12°C threshold for growth in most New Zealand waters during summer months. Consequently, growth will be possible throughout the country, but will only approach that recorded in southwestern Australia in certain regions of the North Island. Increased water temperatures due to climate change would improve the thermal habitat for marron in New Zealand.

Where water temperatures are favourable for marron growth in New Zealand, they can be expected to grow to a size of 40-45 g in their first year, and to 100-120 g by age two. The maximum size for marron in Australia is 2.5-2.7 kg (Merrick and Lambert 1991).

3.5 Reproduction

Marron have bred successfully in the farm ponds at Warkworth and are not known to have any special environmental requirements for spawning other than they usually need to be two to three years old before they mature (Mills 1989, Merrick and

Lambert 1991).

Once mature they mate once a year during spring months when water temperatures and light levels are increasing (Mills 1989). In the yabbie (*Cherax destructor*), increasing photoperiod is the major cue for mating, but in marron rising water temperature is believed to be more important (Mills 1989). For example, marron can be induced to mate in aquaria during winter by increasing water temperatures up to 18-20°C under a constant photoperiod of 12:12 light-dark (Mills 1989). Water temperatures of 18-20°C are common in most New Zealand waters during mid-September (Mosely 1982). At this time daylength is 12 hours and increasing. Marron can therefore be expected to breed in virtually all North Island waters from mid-September onwards.

Although marron can have a large number of fertilized embryos (200-600 depending on size) only a small proportion of these survive and hatch (Morrissy 1975). Decker (1990) indicated that this may be because there is a lack of space for the attachment of so many eggs on the setae of the abdominal pleopods. Nevertheless, Mills (1989) stated that the number of hatched juveniles can range from 50-1200 depending on female size.

This relatively large number of juveniles means that marron will probably prove to be more fecund than the New Zealand crayfish species. *Paranephrops planifrons* only carries 20-240 eggs depending on size (Hopkins 1967a, Devcich 1974).

3.6 Predators

A lack of natural predators is a common cause of problems with introduced animals in New Zealand. Populations of introduced species have often increased to high levels because of a lack of natural predators. The high densities of animals are then responsible for the introduced species becoming a pest. Predators may be an important factor limiting population densities of marron in waters where breeding populations can become established. Therefore aquatic and terrestrial predators of marron in Australia are identified and compared with those present in New Zealand.

In southwest Australia the main aquatic predators of adult marron are the cormorant (shag) species, water rats, and herons (N. Morrissy, pers. comm.). However, Decker (1990) indicated that tortoises, introduced fish (trout and perch), kingfishers, dabchicks, and musk ducks also preyed on marron. Eels do not occur in southwestern Australian waters where marron occur, but in Queensland they are a major predator of marron in aquaculture ponds (N. Morrissy, pers. comm.).

Some of these animals occur in New Zealand, where they are already important predators on the native crayfish. Several species of shag (genus *Phalacrocorax*) eat koura (Duncan 1968, Potts 1972) and would undoubtedly take similar-sized marron. Trout (rainbow and brown) and eels are also present in many New Zealand waters and prey on koura (Burnet 1952, Smith 1959, Rowe 1984a, Jellyman 1989). They too can be expected to be predators of marron. Kingfishers may take koura in small streams

(Fordham *et al.* 1979).

The main terrestrial predators of marron in Australia are the eastern water rat, kookaburras, the introduced fox, dingos and tortoises (Mills 1989). None of these are present in New Zealand. The only known terrestrial predator of freshwater crayfish in New Zealand is the introduced stoat. Gibb and Flux (1973) reported on the diets of feral stoats, ferrets and cats in New Zealand. They found that stoats ate koura in significant quantities. Even so, these were probably all taken from small shallow streams as koura are not known to leave the water. Nevertheless, stoats could be expected to take marron on land in New Zealand. Overall, there are fewer land based predators of marron in New Zealand than in Australia.

Marron are carnivorous, and adults can readily prey on other adults when they are vulnerable (i.e. moulting), or on their young (Morrissy 1975, 1976). In the wild, juvenile marron tend to frequent the shallow margins of streams or ponds. Such a shallow distribution could allow juveniles to avoid predation by the deeper-living adult marron, but they would still be vulnerable to other predators such as aquatic insects and birds. Aquatic invertebrates (e.g., dragonfly larvae) are major predators of newly hatched marron in Australia (Decker 1990).

3.7 The spread of marron in New Zealand

Movement of marron between catchments via the sea is not possible as sea water is lethal to marron (Morrissy 1974a, 1988, Goodsell 1984). However, overland movement is possible and could theoretically result in the spread of marron to new catchments in much the same way as eels penetrate new waters by overland movement on wet nights.

Nevertheless, natural dispersal by this means may be quite limited. Marron have a very restricted geographical distribution in southwestern Australia (Mills 1989). Artificial stocking was needed to extend their range northwards. Desiccation in the dry climate, and predation on land are probably the main factors limiting the extent of land-based forays by marron in southwest Australia. If so, the comparatively wetter climate and fewer land-based predators in New Zealand may allow relatively greater overland movement here than in Australia.

Another means of dispersal is by deliberate stocking. The relatively large size and high value of marron as a food source can be expected to lead to their transfer to both private and public waters throughout the country. Amateur aquarists may also release marron into new waters. Marron are readily caught in traps, and can be easily transferred to new locations in a moist environment. Human intervention is likely to be the main means of spread to new catchments once a feral population is established.

4. MAIN CONCERNS AND ISSUES WITH MARRON IN NEW ZEALAND

Some marron can be expected to escape from farms and to find their way to nearby streams. If water chemistry permits their survival, they will be able to establish a feral population in that stream. From there they may be spread to other catchments. It is therefore critical to determine the limits to survival of marron set by water chemistry. If the potential range for marron in New Zealand waters is very restricted, they will not become a serious pest species, at least not on a par with deer, possums, goats rabbits etc. In this case, impact assessment would be best approached on a site specific basis for the waters where they could survive.

However, if marron can survive in a wide range of natural waters in New Zealand then there is scope for widespread environmental impacts. The main areas of potential interaction with the New Zealand flora and fauna have been identified (Section 2.5). The specific information needed to determine the probable outcome of such interactions is identified below so that research can be focused on the more important issues.

4.1 The native crayfish (*Paranephrops* sp.)

If marron are able to survive in New Zealand waters, then I consider the major concern is the potential impact on the native crayfish species, commonly called koura. The literature on impacts of crayfish introductions overseas indicates that displacement of the native freshwater crayfish is the most likely impact to expect (See Section 2.5).

There are two species of freshwater crayfish in New Zealand. *Paranephrops planifrons* occurs in the North Island and along the west coast of the South Island. *Paranephrops zealandicus* occurs east of the Southern Alps in the South Island (Hopkins 1970). Distributions do not overlap. Archey (1915) described some aspects of the biology of these species. The growth and breeding of *P. planifrons* was reported for a river population by Hopkins (1966, 1967a, 1967b) and for a lake population by Devcich (1974). Jones (1981) reported on growth rates of both species in streams and aquaria. Wong & Freeman (1976a, 1976b, 1976c) studied some aspects of osmoregulation in both species. Despite these studies, there is little known about the ecology of either species in New Zealand.

Some generalisations are possible, however, and help to identify areas where interactions between marron and the native species can be expected, and where research needs to be directed. Both marron and koura in rivers can be expected to feed on similar foods, and occur where the substrate provides refuges in the form of woody debris, rocks and holes in the soft bottoms of stream beds (Archey 1915, Shipway 1951a, b). If distributions overlap, and if food or shelter are in limited supply, competition may occur and favour one of the two species.

Interspecific aggression can be expected to determine the outcome of competition

for food and shelter in crayfish and can result in the displacement, or even replacement of one of the species (Soderback 1991). If marron dominate then koura may well be displaced to suboptimal habitats, and/or their density may decline. But, even if marron proved to be less aggressive than koura, an increased level of behavioral interaction (interference competition) would be energetically demanding and so could reduce production of the native species.

A reduction or displacement of koura could also occur through interspecific predation. Marron are cannibalistic (Morrissy 1976, Mills 1989), and are significant predators of their own offspring (Morrissy 1975). Juvenile marron frequent the shallow banks of rivers, streams and ponds and are found in the fringing grass and litter (Morrissy 1972). It is possible that this shallow, littoral distribution allows juveniles to avoid predation by the deeper-living adult marron. The distribution of juvenile koura in rivers and lakes is not known and they may prove to be more vulnerable to predation by marron than juvenile marron.

Overlap in distribution and habitat of one or more life history stages of marron and koura is essential for competitive or predatory interactions to occur. Although little is known about factors determining habitats for either species, water temperature is likely to be an important factor determining preferred habitat and in mediating interactions.

Adult marron prefer water temperatures close to 24°C (Morrissy 1990). Such temperatures are relatively high for New Zealand rivers, even in summer (Mosely 1982). Consequently marron will probably prefer the warmest regions of rivers, such as the margins of large pools that occur in the more exposed, lower, coastal reaches of rivers. This would be consistent with their reported distribution in Australian rivers. If so, overlap with koura may be minimal in rivers as I have rarely seen koura in such habitats. Furthermore, any competitive advantage of marron over koura may be limited to summer months. Marron stop feeding at temperatures below 12°C, and become inactive at temperatures below 10°C (Morrissy 1976, 1990). In comparison, koura, particularly *P. zealandicus*, are likely to be still active at temperatures below 12°C. For example Jones (1981) found that a feral population of *P. zealandicus* grew in a stream where summer water temperatures only averaged 12°C, and *P. planifrons* were found living in a subalpine stream at altitudes of 1260m (Fordham *et al.* 1979). Differences in activity levels between marron and koura during winter months could therefore be expected to favour koura. Conversely, comparatively greater activity during summer months could favour marron.

A reduction in marron feeding at low water temperatures could also reduce any predation on young-of-the-year koura. Koura hatchlings appear mainly in September (Hopkins 1967a, Devcich 1974), when water temperatures are generally less than 13°C. As adult marron do not start feeding until temperatures exceed 12°C (Morrissy 1990) they may prove to be relatively inactive and hence poor predators of juvenile koura during the vulnerable post-hatch period, when koura hatchlings leave their mothers and become free ranging.

In lakes and reservoirs the depth distribution of adult marron is thought to be controlled by daytime avoidance of shag predation and nocturnal feeding in the shallow littoral zone (pers. comm., N. Morrissy). In comparison, the daytime depth distribution of koura in lakes is believed to be related to light levels (Devcich 1974). Light levels determine feeding activity in marron (Merrick and Lambert 1991) and may serve as an environmental cue to restrict feeding to periods when predation risk is minimised. However, there have been no studies into the factors controlling crayfish or marron depth distribution in lakes. Because of this it is not possible to determine whether overlap would occur and whether competition or predation is likely.

A reduction in the production of koura, or the displacement/replacement of koura by marron may have effects on major predators such as eels, trout and shags. Koura are a major food source for longfinned eels over 50 cm TL in lakes and streams (Burnet 1952, Jellyman 1989), for large (FL > 50 cm) trout in lakes (Smith 1959, Rowe 1984a), and for shags (Duncan 1968, Potts 1972). Reduced production of koura could affect the growth of these predators.

It could be argued that marron would simply replace the native species in the diet of predators. However, this may not occur. Predation on invertebrates is usually size dependent, with a particular size range of individuals being more vulnerable than larger or smaller individuals. The marron may not be a suitable replacement prey species if they prove to grow faster, and are generally larger than the koura. For example, large marron (> 0.5 kg) are known to be relatively immune to predation by shags in Australia.

Interspecific matings have been reported for freshwater crayfish (Capelli and Capelli 1980, Smith 1981) and intergeneric matings have occurred as well (Holdich 1988). It is not known whether marron could hybridise with *P. planifrons*, or whether any hybrids would be viable. Nor is it known whether preferential mating of female marron or koura would occur. A reduction in intraspecific matings for females of *O. sanborni* caused by preferential mating of *O. rusticus* females resulted in the replacement of *O. sanborni* by *O. rusticus* (Butler and Stein 1985). The mating season for koura and marron is spring (Devcich 1974, Mills 1989) so the opportunity for reproductive interference exists, provided distributions of sympatric populations overlapped.

At present the New Zealand freshwater crayfish, or koura, forms the basis for an exclusive Maori fishery in the Central North Island lakes. It would be difficult to police the exclusive right for Maori people to harvest crayfish in these lakes if marron were also present and could be legally caught.

4.2 Animal health risks

Screening for introduced pathogens was carried out by MAFQual while marron were in quarantine. In Australia marron are host to two commensal temnocephalid flatworms (*Temnocephala minor* and *Craspidella spenceri*), which deposit eggs on

both swimmerets (Shipway 1951b) and gills. At high densities *T. minor*, the larger (6-7mm long) of the two species, can become a nuisance, affecting the marketability of crayfish (Herbert 1987). Both these flatworms were found in marron introduced to New Zealand (Decker 1990).

The New Zealand crayfish are host to a different, native species of flatworm (*Temnocephala novaezelandiae*). There was no cross infection, and the New Zealand flatworm species, which is cannibalistic, may not be affected by *T. minor*. However, *T. minor* and possibly *T. novaezelandiae* may pose problems for marron farming in New Zealand.

Spores of the fungus *Psorospermium* were also found in the New Zealand stocks of marron but could not be transmitted to the native crayfish. This genus is common in many parts of the world. Herbert (1987) regards it as an innocuous species at low densities.

Thelohania, the microsporidian protozoan which causes porcelain disease in Europe, has been found in other *Cherax* species in Australia (Mills 1989). MAF Qual found no sign of it in the marron introduced to New Zealand (Decker 1990). Another protozoan, *Vavraia* sp., has been recently found in marron in Australia. It can cause crayfish mortalities but was not detected in marron in New Zealand.

4.3 Aquatic macrophytes

Marron will eat *Elodea*, *Hydrilla*, and *Vallisneria*, but not Characeans (Shipway 1951a). Marron are efficient shredders and rooted macrophyte plants are frequently absent where marron occur in Australia (pers. comm. N. Morrissy). They can "cut" the rooted, flowering macrophytes close to the ground and can "chop" leaves into small pieces (Shipway 1951a). Marron are clearly effective herbivores when the opportunity presents itself. However, they do not prefer macrophytes. Shireman (1973) found that they preferred crayfish tails, fresh fish, and catfish pellets, in that order, over beef liver and *Elodea*. They only consumed certain parts of the *Elodea* plants, but this may have been because of the other food present. The general scarcity of macrophytes in South Australian waters occupied by marron may reflect heavy browsing pressure by this crayfish (Shipway 1951a) at times when other foods are scarce.

Chambers *et al.* (1990) noted that the introduction of crayfish into lakes where they don't occur can have major effects on the structure and composition of macrophytes. It is clear that marron have the capability to be significant herbivores in New Zealand lakes and so may affect lake ecosystems through their effects on macrophytes.

Rare species of native aquatic plants occur in a number of northern New Zealand waters (Given 1981) and may be vulnerable to browsing by marron. The shallow-growing Characean species such as *Nitella flexilis* and *Chara braunsi* are rare but, as

marron apparently do not eat charophytes, these plants may not be endangered. However, the palatability of these charophytes needs to be checked. In comparison, *Hydatella inconspicua* and *Myriophyllum robustum*, which are also rare in some New Zealand waters, could be browsed by marron.

Although marron may not browse characeans, they could still damage such plants if their diurnal migrations traversed the characean meadows. In New Zealand, Coffey and Clayton (1988) demonstrated that koura could damage characean meadows in lakes by both browsing and trampling. They attributed the reduced depth range for characeans in lakes with koura to high densities of crayfish created by abundant exotic macrophytes (*Elodea*, *Egeria*, *Lagarosiphon*). The relatively larger size of marron compared with koura may increase the extent of any mechanical damage.

4.4 Invertebrates

Parastacid crayfish are predators of *Halicarcinus* in Australian waters (Walker 1969). As marron are members of the Parastacidae, and are known to consume other small crustaceans (Mills 1989), the New Zealand freshwater crab (*Halicarcinus lacustris*) may be susceptible to predation by marron. Little is known about the distribution and habitats of the freshwater crab, however, it has been found in some lakes in the top half of the North Island, and in the lower reaches of the Waikato River (Chapman and Lewis 1976). These are waters where marron may well be able to survive. The freshwater shrimp (*Paratya curvirostris*) is more widespread than the freshwater crab and inhabits the lower coastal reaches of rivers (Chapman and Lewis 1976). It too could prove vulnerable to predation by marron.

Marron can prey on molluscs and aquatic insect larvae (Mills 1989), but there is virtually no data on the extent to which this occurs. Shipway (1951a) indicated that they use their large chelipeds to turn over small stones and to catch insect larvae. Morrissy (pers. comm.) indicated that marron at high densities had a noticeable impact on the benthic invertebrates in farm dams. The extent of predation on invertebrates probably depends on the quantity and quality of other foods present. Despite Shireman's (1973) preliminary experiments on food preferences, it is not known whether detritus is preferred to live foods, or carrion.

4.5 Fish stocks and fisheries

The only native fish of appreciable size found in southwestern Australian streams inhabited by marron is an eel-tailed *plotosid* catfish. Shipway (1951a) noted that, although stocked populations of fish such as perch, Murray cod, carp, and trout could be maintained in some of these streams and rivers, breeding populations failed to become established. He attributed this to the ability of marron to outcompete these fish for insect larvae. Such comments are not supported by any data. These fish may have failed to establish for completely different reasons, unrelated to the presence of marron. For example the reversed longitudinal salinity profiles of such rivers (Morrissy 1974b) may have prevented the establishment of breeding populations of

some freshwater fish. Nevertheless such comments show the need to consider such issues and to determine mechanisms by which marron could affect fish.

Marron, particularly males, will eat eggs shed by females (Shipway 1951a). They can therefore be expected to prey on the similar-sized fish eggs deposited on stream or lake bottoms. Several native species of fish (e.g., *Gobiomorphus sp.*, *Galaxias sp.*, *Retropinna retropinna*) inhabit the lower reaches of rivers that would probably be inhabited by marron. These fish deposit eggs on the under-surfaces of rocks, or on river banks, or on sandy bottoms. Such eggs could be particularly vulnerable to the foraging habits of marron.

Anglers have expressed concerns that marron may consume trout eggs and thus reduce trout stocks. This is not a major concern for three reasons. Firstly, marron are uncommon in the small feeder streams in southwestern Australian rivers, preferring the larger pools in the lower reaches of rivers (Shipway 1951a). They are therefore unlikely to inhabit the smaller tributary streams of New Zealand rivers used by salmonids for spawning. Secondly, although marron can turn over small stones on the stream bed, they are unlikely to be able to excavate gravels to a depth of 10-20cm below the surface, where trout eggs are deposited. Thirdly, even if marron were present in spawning streams they are unlikely to feed on trout eggs because water temperatures will be too cold. Feeding in marron ceases below 12°C (Morrissy 1976, 1990) and trout generally prefer colder water for spawning and egg incubation. For example mortality of brown trout eggs increases above 11°C (pers. comm. D. Scott, University of Otago).

However, marron may be significant competitors with both trout and native fish for benthic invertebrates. Marron are significant predators of invertebrates in both streams (Shipway 1951a) and farm ponds (Morrissy pers. comm.). Koura are not known to roll stones over while foraging, and this ability may provide marron with a relatively greater foraging capacity for invertebrates. Crayfish have been shown to reduce trout production in lakes by reducing densities of invertebrates available to trout (Hepworth & Duffield 1987). As marron are capable of reducing invertebrates in still and flowing waters, they could affect fish production by reducing the food base for fish. However, competition for food between marron and trout may be reduced in rivers as marron prefer significantly warmer waters than trout and are more likely to occupy regions of rivers where trout are uncommon. Although trout production in Central North Island lakes is likely to be based primarily on limnetic food webs, trout production in other lakes is more dependent on benthic foods and so could be affected by marron. Native fish species in the lower reaches of rivers and in lakes could be affected if marron removed more invertebrate production than koura.

Shipway (1951a) speculated that the ammocoete larvae of the lamprey (*Geotria sp.*) would be taken by marron because they inhabit the terrigenous silt found in pools and preferred as habitat by marron.

4.6 Water quality and the physical environment

The burrowing habits of some species of crayfish can cause problems. Such activity is minimal in the marron (Mills 1989, Decker 1990, Morrissy pers. comm.) and no greater than that reported for koura (Archey 1915). This is therefore not a significant concern with marron.

If marron proved to be effective herbivores of aquatic macrophytes in New Zealand waters, they may have an influence on water quality in some lakes. For example, Lake Pupuke (Auckland) is eutrophic and contains large beds of *Vallisneria* around the littoral zone. This macrophyte species is eaten by marron. Destruction of such macrophyte beds by marron could lead to a deterioration in water quality and an increased frequency of algal blooms. If marron are able to reproduce in lakes, removal of macrophytes, and the creation of any resulting environmental problems, could be sustained indefinitely. Marron may also be effective browsers of marginal vegetation on stream banks.

5. POSSIBLE APPROACHES TO IMPACT STUDIES IN NEW ZEALAND

Debate concerning the introduction of marron is hindered by inadequate information on the potential impact of this species on the New Zealand environment. Research to clarify the debate needs to be focused initially on the limits to marron survival set by water chemistry, and later, on interactions between marron and the native flora and fauna. Such research can be approached in New Zealand in two ways; by tank or aquarium experiments, and by field studies. However, other useful information may also be available from studies of marron interactions overseas.

5.1 Aquarium or tank studies

Aquarium or tank studies can be used to predict some of the basic ecological requirements of marron. For example, it will be feasible to determine the factors limiting marron survival in low alkalinity waters. If the results showed that marron would be restricted to a few New Zealand waters, then there would little need for further investigation.

However, if marron can survive in a wide range of New Zealand waters, further experiments would be needed to determine the outcome of interactions with the native fauna. For example, it would be possible to determine whether marron or koura would be dominant should competition for food or shelter occur. The potential for marron predation on juvenile koura and intergeneric matings could also be confirmed. Aquarium studies could also be used to determine whether marron would eat New Zealand invertebrates, macrophyte species, or the eggs of native fish. There would be reason for concern if marron proved to be more effective predators than koura in tank environments.

However, results from tank studies can only support hypotheses about species interactions in the wild. Results cannot be used to predict what will occur in lakes or rivers because we do not know whether distributions will overlap, and/or whether food or shelter will be limiting. Fundamental ecological data is lacking for many of New Zealand's aquatic species, including the freshwater crayfish. For example, we do not know what determines the food or habitats of koura in rivers and lakes despite studies by Hopkins (1966, 1967b) and Devcich (1974). There is even less information on the feeding and habitats of freshwater shrimps, and the spawning sites for native fish. The habitats of marron in streams and lakes are also unknown. Such basic information is needed before behavioural traits observed in aquaria can be translated into hypotheses about interactions in the wild.

5.2 Field trials

In the absence of reliable information on distributions, habitats and food requirements of key species, field trials will be needed to provide tangible evidence of impacts, or lack of them, by marron in New Zealand. Trials with a stocked

population of marron in landlocked lakes would be theoretically possible. To obviate the risk of marron escaping into the wild and establishing feral populations, such trials would need to be conducted with all-male populations. Afterwards, eradication of crayfish would be possible without harming fish life (Laurent 1990).

Such trials would also provide useful results as this approach is tried and tested. Field trials with grass carp in New Zealand revealed important ecological information, useful in predicting impacts on a more general scale (Mitchell *et al.* 1984, 1986, Rowe 1984b). Later a similar, but much larger field trial of grass carp was conducted in Lake Conroe in Florida (Klussmann *et al.* 1988). It produced very similar results to those obtained in New Zealand.

However, such trials would prove to be time consuming and expensive. Before and after monitoring would be needed over several years. In addition a number of factors can mediate the outcome of behavioral interactions in the wild. D. Holdich (University of Nottingham, pers. comm.) found that density was a critical factor in field trials between alien and native crayfish in wire mesh cages in streams. He also found that results were influenced by season, and hence water temperatures. The long time scale (10 to 18 years) that may be needed for crayfish interactions to be resolved has already been noted (Section 2.5).

5.3 Overseas experience of marron introductions

Overseas experience of the environmental consequences of marron introductions is limited. Environmental impact studies have been conducted, in the USA, in South Africa, and possibly in other countries where marron have been recently introduced. Studies are now being conducted into the impact of the feral population of marron on the yabbies of Kangaroo Island, South Australia, by staff of the Western Australian Department of Fisheries. The results of such studies need to be obtained when completed.

However, favourable results may need to be treated with caution because introductions of marron to other countries are relatively recent. It may be too early to determine whether feral populations have or will become established, let alone whether these will create problems. Such changes can take many years. It took 10 to 18 years for signal crayfish to become dominant over the native species in a Swedish Lake (Soderback 1990), and it is still not clear which crayfish species will prove dominant in Trout Lake, Wisconsin, some 10 or more years after it was invaded by two introduced species (Lodge *et al.* 1986).

6. CONCLUSIONS

- (a) There is clearly a need to determine the potential impact of marron in New Zealand waters.
- (b) The most important priority is to determine whether low alkalinity, or some other chemical factor, limits marron survival in hard waters. Once the cause of mortality in hard waters is identified then the limiting level needs to be determined. This can be used to determine the potential distribution of marron in New Zealand. If marron will only survive in very few New Zealand waters the scope for impacts is greatly reduced, and impact assessments can be site specific.
- (c) If marron can survive in a wide range of environments then it can be concluded that they will grow and breed in these environments. Their potential impact on a correspondingly wide range of species would then need to be considered. The first priority would be to determine the effects of marron on the native crayfish species. However, predation on aquatic macrophytes, eggs of native fish, and other macro-invertebrate crustaceans is also possible and needs to be investigated.
- (d) The literature on marron in their natural habitat, and on the distribution and habitats of New Zealand native crayfish species in rivers and lakes is limited. If such data cannot be obtained (by additional studies) it will not be possible to predict whether overlap will occur in the wild. Information on distributions and habitats of other key New Zealand species is also lacking.
- (e) If studies of species interactions are limited to tank and aquarium experiments, results will not determine whether impacts will occur in the wild. At best they can turn speculation into hypothesis and lead to a more informed debate about potential impacts. Field trials are needed to provide a realistic test of hypotheses for species interactions. Such trials would be technically feasible, using monosex populations, but cannot be contemplated within the three-year time frame permitted for this evaluation.
- (f) If field trials are not permitted then the option of insufficient information, which was available to the review team considering the release of channel catfish (Townsend and Winterbourn 1990), is probable. Therefore, if scientific studies are to be limited to tanks and aquaria and are to be useful, then it will be necessary to recognise their limits, and to link decision-making to an agreed set of indicator results, which may fall well short of proof of impacts.
- (g) Results of impact assessment studies of marron in other countries may be useful if results are available. For example the conclusion that channel catfish would be more likely than not to cause significant problems in New Zealand was based largely on results from overseas. Results of such studies should be obtained if available.

REFERENCES

- Abrahamsson, S. A. 1966. Dynamics of an isolated population of the crayfish *Astacus astacus* L. *Oikos* 17: 96-107.
- Archev, G. 1915. The freshwater crayfish of New Zealand. *Transactions and Proceedings of the New Zealand Institute* 47: 295-315.
- Bardach, J. E., Ryther, J. H., W. O. McLarney. 1972. Aquaculture, the farming and husbandry of freshwater and marine organisms. Wiley-Interscience, New York. 868 pp.
- Barratt, Fuller and Partners. 1990. Audit of the Environmental Impact Assessment. Introduction of Marron freshwater crayfish *Cherax tenuimanus* (Smith 1912) into Knights Road, West Melton, Christchurch.
- Brown, J. H., Wickins, J. F., MacLean, M. H. 1991. The effect of water hardness on growth and carapace mineralization of juvenile freshwater prawns *Macrobrachium rosenbergii* de Mann. *Aquaculture* 95: 329-345.
- Burnet, A. M. R. 1952. Studies on the ecology of the New Zealand longfinned eel, *Anguilla dieffenbachii* Gray. *Australian Journal of Marine and Freshwater Research* 3: 32-63.
- Butler, M. J. and Stein, R. A. 1985. An analysis of the mechanism governing species replacements in crayfish. *Oecologia* 66: 168-177.
- Capelli, G. M. and Capelli J. F. 1980. Hybridization between crayfish of the genus *Orconectes*: morphological evidence (Decapoda: Cambaridae). *Crustaceana* 39: 121-132.
- Chambers, P.A., Hanson, J.M., Burke, J.M., Pripas, E. 1990. The impact of the crayfish *Orconectes virilis* on aquatic macrophytes. *Freshwater Biology* 24: 81-91.
- Chapman, M. A. and Lewis M. A. 1976. An introduction to the freshwater crustacea of New Zealand. Collins, Auckland. 261 pp.
- Coffey, B. T. and Clayton, J. S. 1988. Contrasting deep-water macrophyte communities in two highly transparent New Zealand lakes and their possible association with freshwater crayfish, *Paranephrops* spp. *New Zealand Journal of Marine and Freshwater Research* 22: 225-230.
- Decker, P. J. 1990. Marron (*Cherax tenuimanus* Smith 1912). Decker Consultants Ltd. Warkworth, New Zealand. 39 pp.

- Devcich, A. 1974. Aspects of the biology of the freshwater crayfish *Paranephrops planifrons* (White) in Lake Rotoiti. Unpublished B. Phil. Thesis. University of Waikato.
- Duncan, K. W. 1968. The food of the black shag (*Phalacrocorax carbo novaehollandiae*) in Otago inland waters. *Transactions of the Royal Society of New Zealand* 11: 2-23.
- Eng, L. L. and Daniels, R. A. 1982. Life history, distribution and status of *Pacifastacus fortis* (Decapod: Astacidae). *California Fish and Game* 68: 197-212.
- Fordham, R. A., Kelton, S. D., Leersnyder, H., Lo, P. L. 1979. *New Zealand Journal of Marine and Freshwater Research* 13: 443-446.
- Gibb, J. A., and Flux, J. E. C. 1973. Mammals. In Williams, G.R (ed.), *The Natural History of New Zealand, An Ecological Survey*. A.H. & A.W. Reed, Wellington.
- Given, D. R. 1981. *Rare and endangered plants of New Zealand*. A.H.W. Reed, Wellington. 150p.
- Goodsell, J. T. 1984. A comparison of haemolymph osmoregulation in three Australian freshwater crayfish *Cherax destructor/albidus*, *C. tenuimanus*, *C. Plebejus* (Decapoda: Parastacidae). *Proceedings of the Annual Workshop of the Marron Growers Association of Western Australia, October 1984*. p 17-46.
- Hecht, T. 1985. Characteristics of the Australian freshwater crayfish *Cherax tenuimanus*. Unpublished manuscript. Department of Fisheries Science, Rhodes University, South Africa.
- Hepworth, D.K. and Duffield, D.J. 1987. Interactions between an exotic crayfish and stocked rainbow trout in Newcastle Reservoir, Utah. *North American Journal of Fisheries Management* 7: 554-561.
- Herbert, B. 1987. Notes on diseases and epibionts of *Cherax quadricarinatus* and *Cherax tenuimanus* (Decapoda: Parastacidae). D.P.O. South. Fish. Queensland, Australia. p 165-173.
- Hobbs, H. H. III, Jass, J. P. and Huner, J. V. 1988. A review of global introductions with particular emphasis on two North American species (Decapoda: Cambaridae). *Crustaceana* (In press).
- Holdich, D. M. 1988. The dangers of introducing alien animals with particular reference to crayfish. *Freshwater Crayfish* 7: 15-30.

- Holdich, D. M. 1990. Crayfish farming and the House of Commons Report. *Fish Farmer 13*: 41-42.
- Hopkins, C. L. 1966. Growth in the freshwater crayfish *Paranephrops planifrons* White. *New Zealand Journal of Science 9*: 50-56.
- Hopkins, C. L. 1967a. Breeding in the freshwater crayfish *Paranephrops planifrons* White. *New Zealand Journal of Marine and Freshwater Research 1*: 51-58.
- Hopkins, C. L. 1967b. Growth rate in a population of the freshwater crayfish *Paranephrops planifrons* White. *New Zealand Journal of Marine and Freshwater Research 1*: 464-474.
- Hopkins, C. L. 1970. Systematics of the New Zealand freshwater crayfish *Paranephrops* (Crustacea: Decapoda: Parastacidae). *New Zealand Journal of Marine and Freshwater Research 4*: 278-291.
- Hutchinson, G. E. 1967. A Treatise on Limnology. Vol 1 Geography, physics and chemistry. John Wiley & Sons, New York.
- Jellyman, D. J. 1989. Diet of two species of freshwater eel (*Anguilla* spp.) in Lake Pounui, New Zealand. *New Zealand Journal of Marine and Freshwater Research 23*: 1-10.
- Jones, J. B. 1981. Growth of two species of freshwater crayfish (*Paranephrops* spp.) in New Zealand. *New Zealand Journal of Marine and Freshwater Research 15*: 15-20.
- Jones, J. B. 1988. Environmental Impact Summary, Marron. Internal report. MAF Fisheries, Christchurch. 5 pp.
- Klussmann, W. G., Noble, R. L., Martyn, R. D., Clark, W. J., Betsill, R. K., Bettoli P.W., Cichra, M.F., Campbell, J.M. 1988. Control of aquatic macrophytes by grass carp in Lake Conroe, Texas, and the effects on the reservoir ecosystem. *Miscellaneous Publication*. Texas Agricultural Experiment Station, Department of Wildlife and Fisheries Sciences, Texas A & M University. 61 pp.
- Laurent, P. J. 1990. Eradication of unwanted crayfish species for astacological management purposes. 8th International Symposium of the International Association of Astacology. Baton Rouge, Louisiana, April 22-26, 1990. (abstract).
- Laurent, P. J. and Vey, A. 1986. The acclimation of *Pacifastacus leniusculus* in Lake Divonne. *Freshwater Crayfish 6*: 146-155.

- Lodge, D. M., Kratz, T. K., Capelli, G. M. 1986. Long term dynamics of three crayfish species in Trout Lake, Wisconsin. *Canadian Journal of Fisheries and Aquatic Sciences* 43: 993-998.
- Lodge, D. M. and Lorman, J. G. 1987. Reductions in submersed macrophyte biomass and species richness by the crayfish *Orconectes rusticus*. *Canadian Journal of Fisheries and Aquatic Sciences* 44: 591- 597.
- Lowery, R. S. and Holdich, D. M. 1988. *Pacifastacus leniusculus* in North America and Europe with details of the distribution of introduced and native crayfish species in Europe. Pp. 283-308. *In: Freshwater crayfish: biology, management and exploitation. Eds. D. M. Holdich and R. S. Lowery. Croom Helm, Beckenham.*
- Lowery, R. S. and Mendes, A. J. 1977. The biology of *Procambarus clarkii* in Lake Naivasha, Kenya; with a note on its distribution. *Freshwater Crayfish* 3: 203-210.
- Macan, T. T. 1963. *Freshwater Ecology*. Longmans, Green and Co. London. 338 pp.
- Mather, M. E. and Stein, R. A. 1990. Habitat specific mortality and size-selective fish predation influencing the replacement of *Orconectes sanborni* by *O. rusticus*. *Bulletin of the Ecological Society of America* 71: 241 (abstract).
- Merrick, J. R. and Lambert, C. N. 1991. *The Yabbie, Marron and Red claw - production and marketing*. J. R. Merrick Publications. Artarmon New South Wales, Australia. 180 pp.
- Mills, B. J. 1989. *Australian Freshwater Crayfish-Handbook of Aquaculture. Freshwater Crayfish Aquaculture Research and Management*. Lymington, Tasmania. 116 pp.
- Mitchell, C. P., Fish, G. R., Burnet, A. M. R. 1984. Limnological changes in a small lake stocked with grass carp. *New Zealand Journal of Marine and Freshwater Research* 18: 102-114.
- Mitchell, C. P. 1986. Effects of introduced grass carp on populations of two species of small native fishes in a small lake. *New Zealand Journal of Marine and Freshwater Research* 20: 219-230.
- Momot, W. T. and Leering, G. M. 1984. Aggressive interaction between *Pacifastacus leniusculus* and *Orconectes virilis* under laboratory conditions. P 87-94. *In 6th International Symposium of Astacology, Lund, Sweden 13-15 August 1984.*

- Morrissy, N. M. 1972. Report on marron in farm dams. *Fisheries Report Western Australia* 5 (revised): 34 pp.
- Morrissy, N. M. 1974a. The ecology of marron *Cherax tenuimanus* (Smith) introduced into some farm dams near Boscabel in the Great Souther Area of the wheatbelt region of Western Australia. *Fisheries Research Bulletin of West Australia* 12: 1-55.
- Morrissy, N. M. 1974b. Reversed longitudinal salinity profile of a major river in the south-west of Western Australia. *Australian Journal of Marine and Freshwater Research*, 25: 327- 335.
- Morrissy, N. M. 1975. Spawning variation and its relationship to growth rate and density in the marron *Cherax tenuimanus* (Smith). *Fisheries Research Bulletin of West Australia* 16: 1-32.
- Morrissy, N. M. 1976. Aquaculture of marron *Cherax tenuimanus* Smith. Part I. Site selection and the potential of marron for aquaculture. *Fisheries Research Bulletin of Western Australia* 17: 1-27.
- Morrissy, N. M. 1988. Pristine characteristics of water and soil in the southwest for pond production of crayfish. *Proceedings of the Aquaculture Workshop '88*. Curtin University of Technology, 28 May 1988. 29 pp.
- Morrissy, N. M. 1990. Optimum and favourable temperatures for growth of *Cherax tenuimanus* (Smith 1912) (Decapod: Parastacidae). *Australian Journal of Marine and Freshwater Research* 41: 735-746.
- Mosely, M. P. 1982. New Zealand river temperature regimes. *Water and Soil Miscellaneous Publication No. 36*. National water and Soil Conservation Organisation. 87 pp.
- O'Brien, B. 1990. Feeding biology of marron (*Cherax tenuimanus*) (Decapoda: Parastacidae). Pp. 89-103 *In Proceedings of a National Symposium on Freshwater Crayfish*, Perth, May 1990. Published by Curtin University of Technology.
- Potts, K. J. 1972. Aspects of the ecology of shags in the Rotorua district. M. Phil. thesis, University of Waikato.
- Rowe, D. K. 1984a. Factors affecting the foods and feeding patterns of lake-dwelling rainbow trout (*Salmo gairdnerii*) in the North Island of New Zealand. *New Zealand Journal of Marine and Freshwater Research* 18: 129-141.

- Rowe, D. K. 1984b. Some effects of eutrophication and the removal of aquatic plants by grass carp (*Ctenopharyngodon idella*) on rainbow trout (*Salmo gairdnerii*) in Lake Parkinson, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 18: 115-127.
- Rubino, M., Alon, N., Wilson, C., Rouse, D. and Armstrong, J. 1990. Marron aquaculture research in the United States and the Caribbean. *Aquaculture Magazine (May/June)*: 27-44.
- Semple, G. P., Rouse, D. B., McLain, K. R. 1990. *Cherax destructor*, *C. tenuimanus* and *C. quadricarinatus* (Decapoda: Parastacidae) - A comparative review of aquaculture potential. 8th International Symposium of the International Association of Astacology. Baton Rouge, Louisiana, April 22-26, 1990. (abstract).
- Shireman, J. V. 1973. Experimental introduction of the Australian crayfish (*Cherax tenuimanus*) into Louisiana. *Progressive Fish Culturist* 35: 107-109.
- Shipway, B. 1951a. The natural history of marron and freshwater crayfishes of South Western Australia-Part 1. *Western Australian Naturalist* 3: 7-12.
- Shipway, B. 1951b. The natural history of marron and freshwater crayfishes of South Western Australia-Part 2. *Western Australian Naturalist* 3: 27-34
- Soderback, B. 1990. Noble crayfish versus signal crayfish. *International Association of Astacologists Newsletter* 12: 8.
- Soderback, B. 1991. Interspecific dominance relationship and aggressive interactions in the freshwater crayfishes *Astacus astacus* (L.) and *Pacifastacus leniusculus* (Dana). *Canadian Journal of Zoology* 69: 1321-1325.
- Smith, D. C. W. 1959. The biology of the rainbow trout (*Salmo gairdnerii*) in the lakes of the Rotorua district, North Island. *New Zealand Journal of Science* 2: 275-312.
- Smith, D. G. 1981. Evidence for hybridization between two crayfish species (Decapoda: Cambaridae: Orconectes) with a comment on the phenomenon in Cambarid crayfish. *American Midland Naturalist* 120: 405-407.
- Stein, R. A. and Magnuson, J. J. 1976. Behavioural response of crayfish to a fish predator. *Ecology* 57: 751-761.
- Stout, V. 1975. The limnology. Pp 405-458. *In Biogeography and Ecology in New Zealand*. Ed. G. Kuschel. Dr. W. Junk. The Hague.
- Thompson, A. 1990. Plague-some lessons to be learned. *Fish Farmer* 13: 54-56.

- Townsend, C.R. and Winterbourn, M.J. 1990. Assessment of the environmental risk posed by channel catfish in New Zealand (Report of the Independent Review Team, 20 July 1990). 24pp.
- Walker, K. 1969. The ecology and distribution of *Halicarcinus lacustris* (Brachyura: Hymenosomatidae) in Australian inland waters. *Australian Journal of Marine and Freshwater Research* 20: 163-173.
- Westman, K. and Pursiainen, M. 1984. Introduction of the American crayfish (*Pacifastacus leniusculus*) in Finland; impact on the native crayfish (*Astacus astacus*). *EIFAC Technical Paper 42 (Suppl. 2)*: 422-426. FAO, Rome.
- Wheatly, M. G. 1990. The physiology of moulting in the freshwater crayfish: an update on ion regulation. 8th International Symposium of the International Association of Astacology. Baton Rouge, Louisiana, April 22-26, 1990. (abstract).
- Wong, T. M. & Freeman, R. F. H. 1976a. Haemolymph concentrations of two species of New Zealand freshwater crayfish in relation to the concentration of their media *Comparative Biochemistry and Physiology* 55A: 13-16.
- Wong, T. M. & Freeman, R. F. H. 1976b. Seasonal and thermal effects on the concentration of the haemolymph in the New Zealand freshwater crayfish *Paranephrops zealandicus* White. *Comparative Biochemistry and Physiology* 55A: 17-22.
- Wong, T. M. & Freeman, R. F. H. 1976c. Osmotic and ionic regulation in different populations of the new Zealand freshwater crayfish *Paranephrops zealandicus*. *Journal of Experimental Biology* 64: 645-663.
- Zeidler, W. 1982. South Australian freshwater crayfish. *South Australian Naturalist* 56 (3): 36-43.