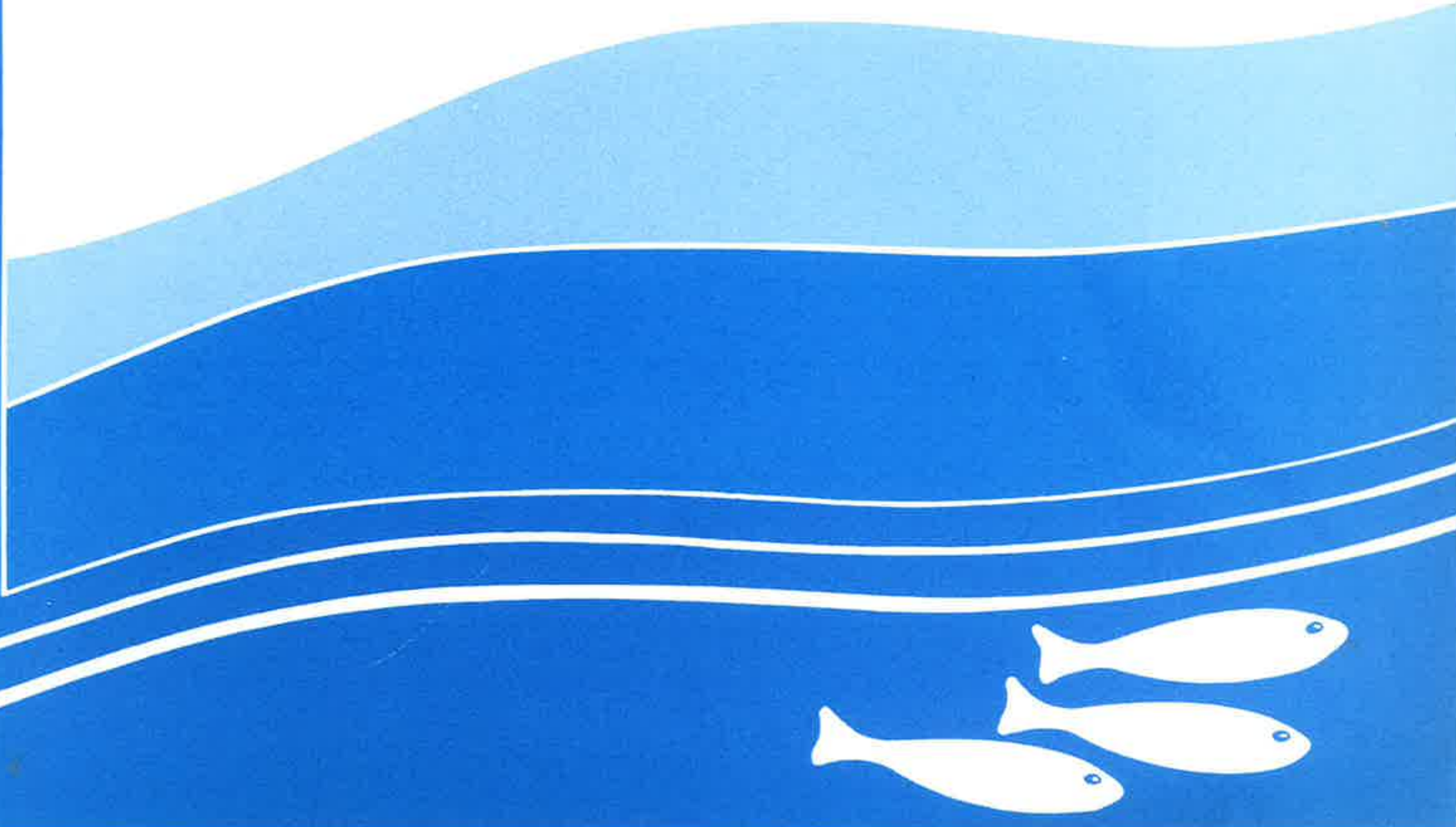
No. 117

NEW ZEALAND FRESHWATER FISHERIES REPORT

MAF

The Effects of Koi Carp on New Zealand's Aquatic Ecosystems



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New Zealand Freshwater Fisheries Report No. 117

The Effects of Koi Carp on New Zealand's Aquatic Ecosystems

by
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Report to: Department of Conservation

Freshwater Fisheries Centre
MAF Fisheries
Rotorua

Servicing freshwater fisheries and aquaculture

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NEW ZEALAND FRESHWATER FISHERIES REPORTS

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1. INTRODUCTION

In October 1987, MAF Fisheries was approached by the Department of Conservation to carry out an assessment of the potential impacts of koi carp on New Zealand's aquatic environment. Koi carp, also known as "Japanese" or "Singapore" carp, are probably an ornamental strain of the common carp (*Cyprinus carpio* L) (see Section 2), which have been bred for many years by the Japanese for their colourful markings. Because of their bright colours - often including white, yellow, orange, red, and blue - koi have become very popular amongst fish breeders and water garden enthusiasts, and in some countries champion fish have a value of US$50,000 (Marx 1980).

The introduction of koi into New Zealand waters is undocumented, but they were probably brought into the country in a consignment of goldfish (*Carassius auratus*), from which they are difficult to distinguish as juveniles (McDowall 1979). Since koi arrived in New Zealand, they have been bred and introduced into many farm ponds and dams, mainly in the north of the North Island. The present known distribution of koi in New Zealand is shown in Figure 1. (A list of these records including dates, location, map reference, and contact name is given in Appendix I.) Fish also have been kept in zoos, public aquaria, and a variety of ornamental pools and water gardens. Wild populations were first reported from the Waikato River system (Whangamarino River) in November 1983 (Pullan 1984a). Since then they have been reported from the Waikato mainstem, the Mangatawhiri and Opuatia Streams, and Lakes Waikare, Whangape, and Waahi (Fig. 2). Spawning has been observed in a number of different locations in the Waikato catchment and it is accepted that this population is self- maintaining. Although isolated records exist for koi in streams outside the Waikato system (e.g., the Waimapu River in Tauranga, and many streams in the North Auckland area), it is not known whether these are self-maintaining populations. The full extent of their distribution is presently unknown.

In parts of Australia, Canada, and the United States, carp have been accused of having detrimental effects on vegetation, water quality, fish, and waterfowl because of their feeding and spawning behaviour (e.g., McCrimmon 1968; Sigler 1958; Butcher 1962). In the United States, concerns about carp were first expressed in the early 1900s. Since then there has been a deluge of scientific papers and unpublished departmental reports attributing declining fisheries and waterfowl values to the abundance of carp (e.g., Cole 1905; Cahn 1929; Ricker and Gottschalk1941; Black 1946; Anderson 1950; Cahoon 1953; Sigler 1958; Jessen and Kuehn 1960a,b; Moyle and Kuehn 1964; King and Hunt 1967; Taylor *et al.* 1984).

The potential for carp to have detrimental effects on the environment has received less attention in the other 47 countries to which carp have been introduced. In Australia, populations of carp have existed since the 1880s but little information was available on them until 1960, when a more virulent strain was introduced. Since then, there have been a number of unpublished reports concerning their potential impacts in Australia, culminating in a large report by Hume *et al.* (1983a), and a publication by Fletcher *et al.* (1985). In Canada, the scanty literature referring to carp was summarised by McCrimmon (1968) and little work has been done since then (Crossman 1984). In Europe, where the carp is widespread and often abundant, detrimental effects have not been reported (Crivelli 1983).

In some states and provinces carp have been considered a pest, and methods have been implemented to control them. Because of fears that koi could become a problem in the aquatic environment in New Zealand, it was declared a noxious fish in 1980, making it illegal to possess, transport, or breed the fish. Despite this status, releases of koi into many farm ponds and dams have continued to occur.

The objectives of this report are to bring together, and summarise, the voluminous overseas literature on common carp and the information on New Zealand koi, so that an evaluation of the potential impacts of koi on the New Zealand aquatic environment can be made, and recommendations for future policies on koi can be assessed. In Section 2, the various races, strains, and taxonomic status of carp are considered. In Section 3, the reproduction, growth, feeding, and behaviour of common carp are summarised and compared to New Zealand koi. Section 4 examines the impacts of common carp overseas in some detail, while Section 5 discusses the potential impacts of koi in New Zealand. In subsequent sections, groups interested in koi, control methods, and research needs are outlined and recommendations made.

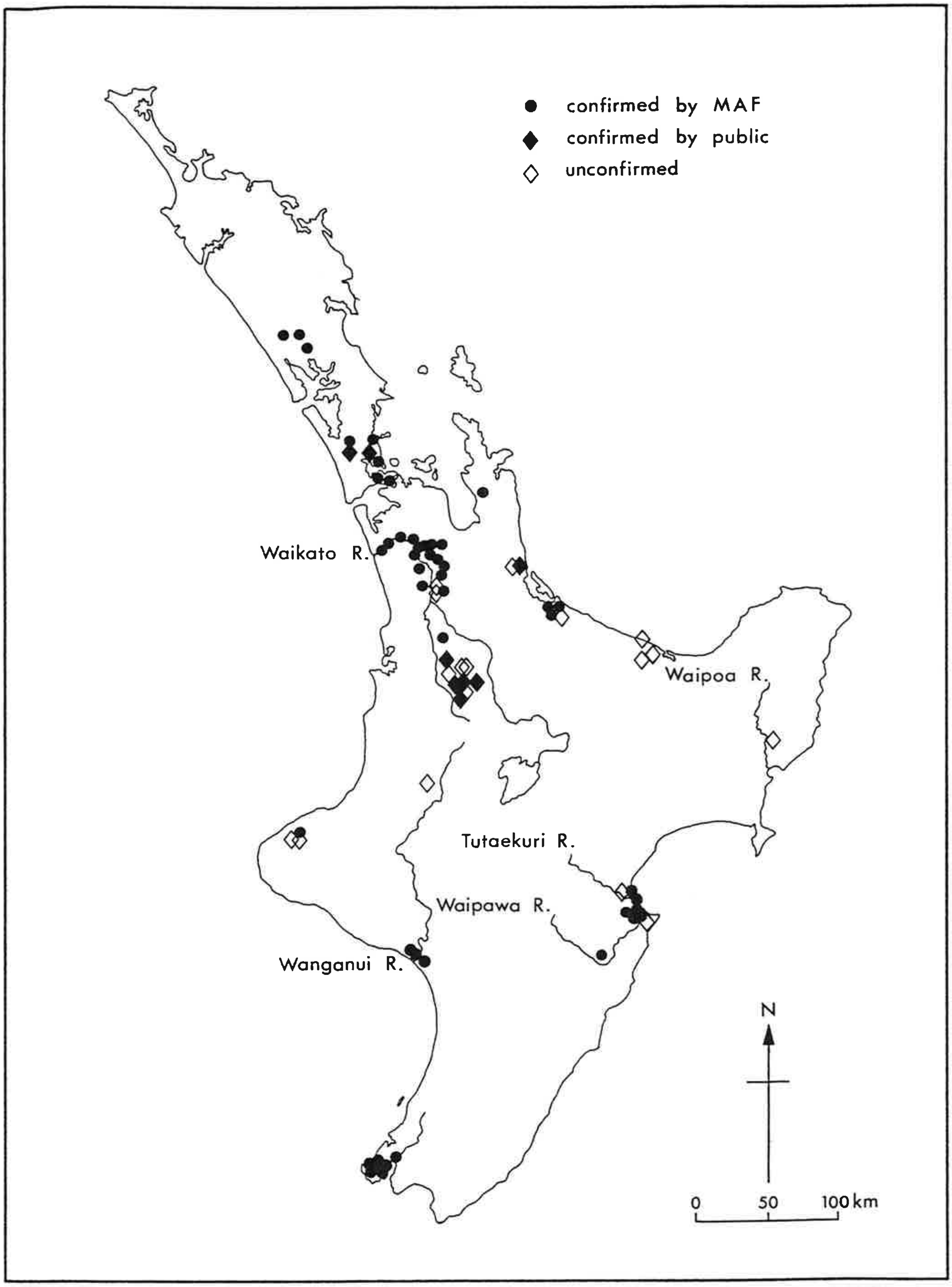

FIGURE 1. Distribution of koi carp in New Zealand (after Pullan 1984b).

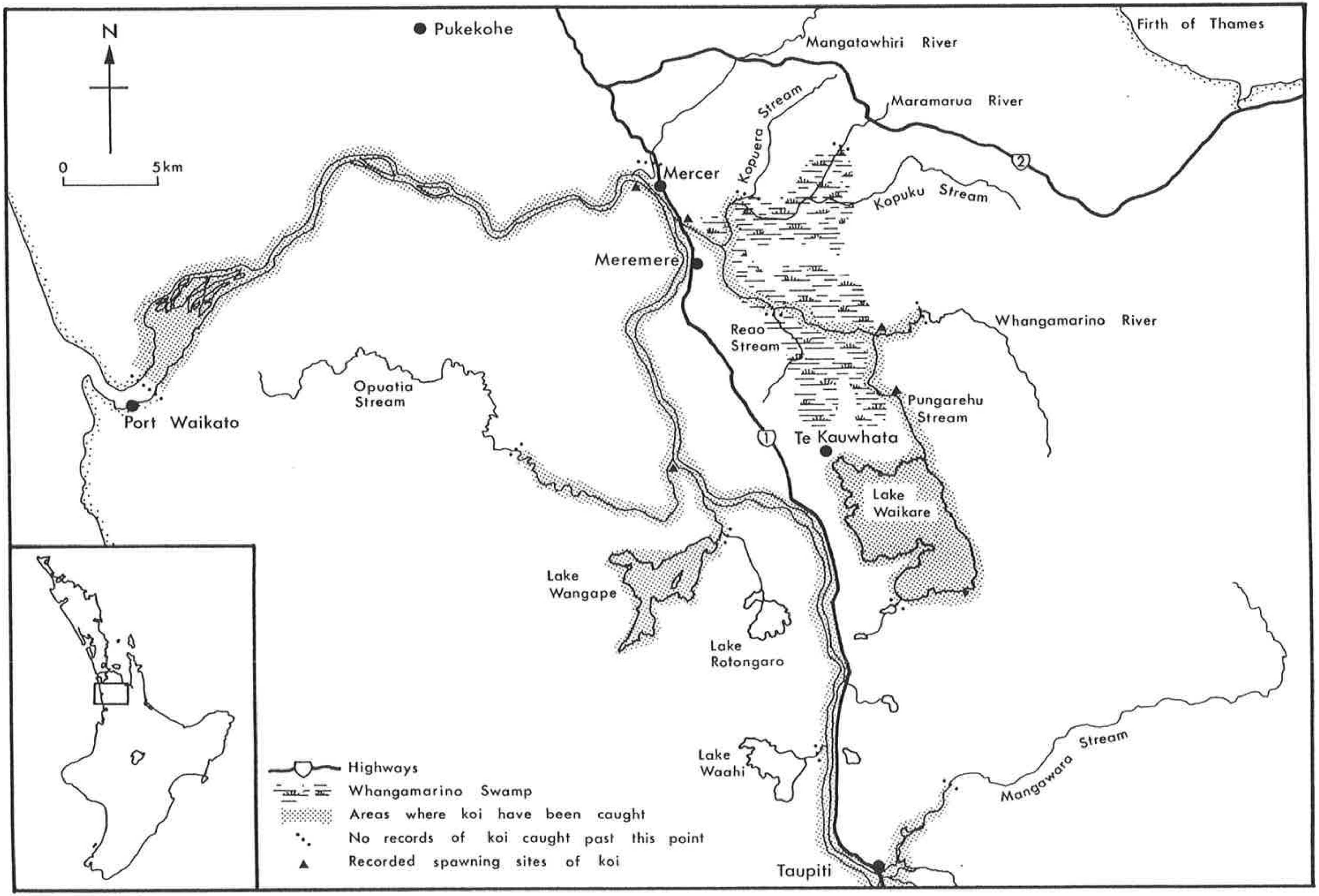

FIGURE 2. Areas where koi carp have been caught in the Waikato system (after Pullan 1984b).

2. TAXONOMY

The common carp (*Cyprinus carpio* Linnaeus 1758) is believed to have originated in a region of eastern Asia (McCrimmon 1968). It was introduced to Europe over 2000 years ago, and has been liberated in a total of 47 countries, reaching Australia, the United States of America, and Canada in 1872, 1842, and 1880, respectively. Early records of carp introductions to New Zealand during 1860-1880 probably refer to goldfish (*Carassius auratus*) (McDowall 1979).

As a result of intensive cultivation in Europe and Asia, a number of varieties or races of carp have arisen which are reasonably stable; these include the scaled carp, the mirror carp (partly-scaled), and the leather carp ("scaleless") (McCrimmon 1968). Further strains of scaled carp also have been bred, and amongst these are the European carp, the Israeli carp, and the Japanese carp or "koi" (koi means carp in Japanese). Whilst some authors have suggested that koi are a complex hybrid between carp and goldfish (probably both Prussian carp (*Carassius auratus*) and the Crucian carp (*C. carassius*) (Vanderplank 1972; Walker 1973)), other authors have suggested that koi are simply a domesticated form or colour strain of common carp (Anon. 1972; Axelrod 1973). Pullan (1984a) concluded that, apart from their colouration and a small difference in the number of lateral line scales, there is little difference taxonomically between koi and European carp.

It is important to note that some strains and races of common carp may have a greater potential for expansion of their range than others. For example, in Australia three strains of common carp are known to occur - "Yanco", "Prospect", and "Boolara" (Shearer and Mulley 1978). Carp have been present in Australia since the 1870s, but it was not until the early 1960s that they underwent a dramatic population explosion and became widespread through south-east Australia. Using gel electrophoresis, Shearer and Mulley (1978) showed that only the "Boolara" strain had increased its range, whilst the distributions of the "Yanco" and "Prospect" strains had remained unchanged since before 1960. Hume *et al.* (1983a) considered that the "Boolara" strain was a hybrid of an imported variety of mirror carp and a variety of scaled carp of unknown origin. The "Prospect" strain is possibly a scaled carp of Prussian origin (Shearer and Mulley 1978). The "Yanco" strain is brightly coloured (red-orange on the dorsal surface and yellow on the ventral surface) and, according to the Australian Carp Programme staff, is a koi carp. Furthermore, electrophoretic work has shown that the New Zealand koi and the "Boolara" strain are quite different (S. Pullan, pers. comm.). No electrophoretic comparison has been made yet between the New Zealand koi and the "Yanco" strain. It is recommended that this work be carried out in the near future.

Apart from the Australian experience, little has been documented on the varying impacts of the different strains of common carp, or its hybrids, on the environment.

The genetic make-up of these strains of carp and of goldfish (*Carassius* spp.) are sufficiently similar to allow intra-specific strains and inter-specific hybrids to be fairly commonplace. Hybrids have been recorded in North America and Canada (McCrimmon 1968; Taylor and Mahon 1977), in Australia (Shearer and Mulley 1978, Mulley and Shearer 1980; Hume *et al.* 1983b) and recently in New Zealand (Pullan and Smith 1986; Kilford 1988). Apart from Taylor and Mahon (1977), all authors considered the hybrids to be fertile.

Since virtually no published information is available on koi, the remainder of this report deals with the general biology and ecological impacts of the common carp, but it should be remembered that the potential impacts of koi could be quite different. Future references to carp relate to common carp (*Cyprinus carpio*) unless otherwise stated.

3. LIFE HISTORY

The purpose of this section is to review the general features of the life history of common carp, with reference to the New Zealand koi carp where available. Much of the New Zealand material comes from the results of a monitoring survey of koi carp carried out by S. Pullan (MAF Fisheries, Auckland) between 1984 and 1987, and has either been presented in internal reports or is from personal communication with him.

3.1 Reproduction

3.1.1 Maturity

Age and size at maturity varies with location and growth rates. For example, male carp may reach maturity in 3 months in Java (Sarig 1966), but not until 4 years in some areas of Europe (Hume and Pribble 1980); for females the times are 12 months and 5 years respectively. In Australia, males usually mature at between 20-30 cm, aged 2-4 years; females mature at a size greater than 30 cm, aged 3-5 years (Hume *et al.* 1983a). In New Zealand, it seems likely that koi mature at a similar size and age to common carp in Australia (Pullan 1984b).

3.1.2 Fecundity

Carp show a direct relationship between fecundity and fish weight or length (Swee and McCrimmon 1966; Hume *et al.* 1983a). In Canada, fecundity ranged from 36 000 eggs in a 4-year-old fish to 2.2 million eggs in a 10 kg, 16-year-old fish (Swee and McCrimmon 1966). In Australia, the maximum fecundity recorded was 1.6 million eggs for a fish of 6.5 kg. The most fecund koi so far caught in New Zealand contained an estimated 880,000 eggs and weighed 8 kg (Pullan 1984a), which is considerably fewer eggs than found in equivalent-sized carp overseas. Larger samples are required to determine whether New Zealand koi are usually less fecund than other strains of common carp. Mature hybrids have not yet been caught (Kilford 1988).

3.1.3 Spawning

The spawning requirements of carp have been well documented overseas (Sarig 1966; Swee and McCrimmon 1966; Hume *et al.* 1983a). Typically, spawning of carp involves groups of fish swimming together in warm, still, shallow waters, with the eggs being scattered over freshly-inundated vegetation, and is accompanied by much splashing and slapping of their tails in the water (McCrimmon 1968). Temperature is the most critical factor affecting spawning. In Lake St. Lawrence, Ontario, Swee and McCrimmon (1966) found that spawning activity was absent below 16°C, was low from 16-18°C, was optimal at 19-23°C, decreased after 26°C, and ceased at 28°C. In Australia, spawning occurred within a similar range of 17-25°C (Hume *et al.* 1983a).

Spawning usually takes place in the spring, but activity may extend throughout the summer, with some fish spawning on more than one occasion (Swee and McCrimmon 1966). In Australia, some carp were ripe or spent during most of the year, but successful spawning occurred between mid September and mid December. Water depth is also important. Preferred spawning beds are in water of less than 0.45 m depth, although spawning has been observed near the surface over submerged aquatic vegetation in depths of 1.7 - 1.8 m (McCrimmon 1968). Carp often begin spawning as water levels rise and inundate grass margins. Although carp show a preference for spawning over vegetation such as grasses, pondweed, or rushes and reeds (Swee and McCrimmon 1966), they have been known to spawn on walls of concrete tanks, or on coarse debris, which were devoid of vegetation (Mraz and Cooper 1957; Shields 1958).

Egg mortality is usually low (<10%), but if the temperature drops to below 11°C, or if the eggs are exposed to the air for several hours as a result of a drop in water level, then egg mortality can be 100% (Swee and McCrimmon 1966; McCrimmon 1968). Hume *et al.* (1983a) suggested that spawning success in the Murray River may be controlled by flooding, because of the effect of fluctuating water levels on the survival of eggs. Eggs may be fairly tolerant of turbid water, since Secchi disc visibilities of 7.6 cm and turbidities of 200 NTU are not uncommon where carp spawn (Jester 1974).

Incubation times vary according to water temperature. Under laboratory conditions, eggs hatch in 4-8 days at 16.7 - 18.4°C, and in less than 4 days at 22°C (Hume and Pribble 1980). In Lake St Lawrence Canada, eggs typically hatched 3-6 days after fertilisation (Swee and McCrimmon 1966). Incubation times in New Zealand are also likely to be within this range.

In New Zealand, koi have been observed spawning by members of the public on several occasions (S. Pullan, pers. comm.) A trout fisherman, Mr Alan Roddick, reported seeing hundreds of koi in flooded paddocks near the mouth of the Opuatia Stream on 27 October 1986 (see Figs. 1 and 2). He was awakened by the splashing and slapping sounds made by the fish, which were presumably spawning. However, no eggs were found subsequently (S. Pullan, pers. comm.).

Koi also have been reported spawning in the Waikato River at map reference S12 912341, and in swampy areas off the Whangamarino River at map references S12 940317; S13 040230; and S13 034263 (Fig. 2). At the time of writing (December 1988), no carp eggs had been found in any of these reported spawning sites (S. Pullan, pers. comm.).

Successful spawning of koi in New Zealand probably occurred in 1983 (possibly 1982) as evidenced by a strong year class of 1-year-old (or possibly 2-year-old) fish in the Waikato River catchment in 1984 (Pullan 1984b). Subsequent sampling in the Waikato has produced few 1-year-old fish, possibly because of fluctuating water levels in the Whangamarino River (S. Pullan, pers. comm.). The occurrence of several year classes in several ponds examined in the Auckland area suggests that successful spawning also can occur in farm ponds and lakes (see Section 5.1).

3.2 Age and Growth

Newly-hatched fry, averaging 5.0-5.5 mm in total length, immediately settle to the bottom. Fish of 6 mm are able to attach themselves to aquatic vegetation by means of adhesive glands. By the time fish reach a length of 8 mm, after about 7 days, the yolk sac has normally disappeared, the fish are feeding actively on plankton, and can swim with well co-ordinated movements (McCrimmon 1968). When about 20 mm long, after about 21 days, the fins are fully formed, and the fingerlings resemble adult carp in appearance, feeding, and schooling behaviour (Hume and Pribble 1980).

Differences in individual growth, which are influenced by water temperature, stocking density, and the availability of food, become pronounced by the 12th week of life (McCrimmon 1968). Growthrates during the first summer may be up to 2.5 mm/day for wild populations (Carlander 1969), although in Australia they were typically 0.5-0.8 mm/day (max. 1.5 mm/day) (Hume *et al.* 1983a). By the end of their first year, carp vary between 120 mm and 300 mm in length, and by age 2 vary between 180 mm and 420 mm in length (Rehder 1959; Carlander 1969; Lubinski *et al.* 1986). Growth rate probably decreases after maturity to between 20 mm and 80 mm per year, although ageing of older fish by scales and opercular bones is difficult and probably unreliable (Hume *et al.* 1983a; Weber and Otis 1984). The longevity of carp in the wild probably seldom exceeds 20 years in North America, although they have been reported to live for over 140 years in artificial conditions (McCrimmon 1968). They are reported to occasionally reach over 18 kg in North America, and the record in that country is 27.9 kg (McCrimmon 1968).

In New Zealand, koi caught in the Waikato River system in late April 1984 were between 16.5 cm and 27.9 cm long (mean 22.2 cm), and were probably spawned in 1983 (Pullan 1984b). If these fish were spawned in mid October 1983, they would have grown between 165 mm and 280 mm in about 190 days, or at a rate of 0.7-1.5 mm/day. These rates are considerably higher than the typical Australian values, although not greater than their maximum values. Pullan (1984a) reported that the growth of koi in a farm pond was between 25 cm and 50 cm in only eight months (i.e., 1.1-2.2 mm/day). It would therefore seem that New Zealand koi have similar, if not slightly higher, growth rates than are typically recorded for carp overseas. The capture of fish of up to 8-9 kg, and sightings of fish of up to 12 kg, suggest that New Zealand koi will approach the sizes of carp caught in North America.

3.3 Food and Feeding

Food of larval carp varies, but consists mainly of chironomid larvae, crustaceans, and phytoplankton. During their first summer, fingerling carp prefer crustaceans, but when these are not abundant they will take bottom fauna, mainly chironomid larvae (Hume and Pribble 1980). By the end of the first summer, young-of-the-year carp eat a variety of invertebrates including the larvae and pupae of chironomids, caddisflies, and other hexapods, and small molluscs, ostracods, and crustaceans (McCrimmon 1968).

The diet of adult carp is more omnivorous and opportunistic. Typically, the diet includes 30% benthic invertebrates (e.g., chironomids and oligochaetes), 30% micro-crustacea (e.g., *Daphnia* spp.), 30% organic detritus, with the remaining 10% being a mixture of molluscs and swimming and terrestrial insects (Sigler 1958; Sarig 1966; Hume *et al.* 1983a). However, this diet may vary considerably, both temporally and spatially. Some authors have indicated a seasonal feeding cycle including benthos in spring, plankton in summer, and plant matter/detritus in late summer/autumn (see Hume *et al.* 1983a). In other situations, carp have shown high selection for molluscs (Stein *et al.* 1975; Leventer 1981), for insect material (Harrison 1950), for seeds (Crivelli 1981,1983; Hume *et al.* 1983a), and for organic detritus (Wahlburg and Nelson 1966). In Australia, Hume *et al.* (1983a) showed that carp had a preference for chironomids, and this conclusion seems borne out by many other authors (e.g., Sigler 1958; Hruska 1961; Schroeder 1975; Forester and Lawrence 1978). Hume *et al.* (1983a) considered that micro-crustaceans (mainly *Daphnia* spp., chydorids, and copepods) were the second-most important constituents in the carp diet.

It is generally considered that detritus, algae, and seeds are taken only when animal food is unavailable, and a diet containing a high proportion of these food items is believed to result in poor growth and poor condition of carp (Sigler 1958; Wahlburg and Nelson 1966; McCrimmon 1968; Crivelli 1981,1983). Many authors have suggested that carp feed on plants, or cite the presence of vegetation in the stomach contents (see Crivelli 1983). However, few have distinguished between the presence of green or dead vegetation.

After studying the operation and morphology of the feeding apparatus of carp for a number of years, Sibbing *et al.* (1986) concluded that the lack of cutting and shearing processes, the absence of cellulase from the intestinal juices of carp, and the inefficiency with which carp handle vegetable matter compared to animal prey indicate that herbivory is doubtful.

Sibbing *et al.* (1986) also noted a whole sequence of events in the feeding process of carp, including intake of food by gulping and particulate feeding; rinsing, selective retention, and spitting for selection; gathering from the branchial sieve, crushing and grinding; all of which suit an omnivorous feeding habit and are specialisations for polyphagy. Due to their relatively small mouth, and their selective retention, carp are restricted mainly to food items larger than 0.25 mm, but less than 9% of the length of the fish. During the rinsing and spitting processes, unwanted particles (including unpalatable food, heavily soiled mouthfuls, and unmanageable large lumps) may be spat out into the water column. In the process of sucking and gulping food particles from the bottom, they may produce the 4-7 cm wide, deep pockmarks which have been recorded in the sediments of waterbodies occupied by carp (Cahn 1929; Avault *et al.* 1968; McCrimmon 1968).

Stomach contents of 26 New Zealand koi caught in the Whangamarino River have been examined by J. Boubee (MAF Fisheries scientist, Hamilton, pers. comm.). In 40% of these fish the stomach was at least half full, in the remainder the stomachs were empty or contained only traces of food. Detritus or slime was either the dominant or the subdominant item in nearly every fish. Benthic invertebrates (including chironomids and oligochaetes) occurred in 22 fish, terrestrial insects in 17, molluscs in five, and aquatic insects and crustacea in four fish each. Superficially, the diet of koi in New Zealand resembles that of overseas carp.

3.4 Behaviour

Young-of-the-year carp are often difficult to catch, but it seems that they usually remain in weedy shallow areas (0.15-0.30 m deep) during their first summer and autumn until they reach a size of 7.5 - 10.0 cm (Sigler 1958; McCrimmon 1968; Weber and Otis 1984; Lubinski *et al.* 1986). Larvae and young carp (<4 cm) are caught best by making random plunges into dense vegetation with fine-mesh dip nets, larger juveniles are caught best by electrofishing (Weber and Otis 1984).

After they reach a size of 10 cm, juveniles move into slightly deeper water (1.0-1.5 m) where they remain with adult fish during the rest of the summer and autumn. Once the temperature in the shallows drops below about 11°C, carp in North America characteristically move into deeper and warmer waters where they reside during the winter months (Sigler 1958; McCrimmon 1968; Johnsen and Hasler 1977). Carp activity during winter is much reduced, with their home range diminished by as much as one third (Otis and Weber 1982), and the fish forming quite large aggregations (Johnson and Hasler 1977). As water temperatures increase in spring (to above 11°C in Canada), carp typically move into shallow water. Pre-spawning aggregations of carp swim leisurely about the more open areas, or near the surface of deeper water (McCrimmon 1968). As water temperatures increase to 16°C, carp may begin spawning, at which time they lose much of their natural wariness and can be seen or heard splashing about in shallow water, often with their backs and dorsal fins exposed. Although aquatic vegetation may be temporarily flattened, it does not seem to be permanently damaged or uprooted by this behaviour (Swee and McCrimmon 1966; Fletcher *et al.* 1985). Otis and Weber (1982) found that, in Wisconsin, carp of all sizes spent the rest of spring and summer in the shallows (1.0-1.5 m), occupying areas with vegetation cover for over 90% of the time.

Carp tend to remain in the same locality during much of their adult life, possibly as defined stocks or sub-populations (Lubinski *et al.* 1986), and may show homing tendencies when displaced (Otis and Weber 1982; Reynolds 1983). However, juveniles (possibly 0+ and 1+ fish) may move out of established populations, which could help the species to colonise new areas (Reynolds 1983). One juvenile carp measuring 26 cm was tagged and released in the Missouri River, Missouri, and was recaptured in South Dakota, 1085 km away and 28 months later (Sigler 1958).

Little is known of the behaviour of koi in New Zealand. Pullan (1984a,b) has documented their occurrence in the tributaries and mainstem of the lower Waikato River, although their original release point is unknown. During spring, summer, and autumn, koi were caught regularly during a monitoring programme and often were observed feeding in the shallows of Lake Whangape (J.W. Hayes, MAF Fisheries, Christchurch, pers. comm.). However, they were seldom seen or caught during the winter months, suggesting either that they were less active at that time, or that they had migrated out of the area, possibly into deeper water.

3.5 Tolerances

Carp are a hardy species occupying a wide range of freshwater habitats (Sigler 1958), and often extending into brackish or saline waters (Soller *et al.* 1965; McCrimmon 1968). McCrimmon postulated that carp had moved between river catchments via saline waters on both coasts of Canada. This hypothesis was supported by Barraclough and Robinson (1971), who caught juvenile carp (26-41 mm long) in sea water of up to 13.9% in the Strait of Georgia. They concluded that this was a natural environmental route by which carp could become established in Vancouver Island.

Carp also are very tolerant of high turbidities, pollution, and contaminated waters in general (Sigler 1958; McCrimmon 1968). Adults can survive oxygen concentrations down to 3 mg/l, temperatures as low as 0.7°C or as high as 34°C, and acid waters to pH 5.0 (Hume and Pribble 1980). Because of this high tolerance, carp are able to survive in polluted waters where many other species, except perhaps eels, would die.

4. IMPACTS OF CARP OVERSEAS

Since the late 1800s, common carp have caused a great deal of concern amongst North American fisheries and waterfowl managers regarding their potential impacts on water quality, aquatic vegetation, waterbirds, invertebrates, and fish life. Whilst in many instances carp have been a convenient scapegoat for a variety of either natural or human-induced changes, e.g., lake level fluctuations, sedimentation caused by earthworks or mining, eutrophication from sewage or land run-off, and industrial or domestic pollution (Jessen and Kuehn 1960b; Robel 1961; McCrimmon 1968), there do appear to be certain situations where carp have had an impact on the aquatic environment.

The conflicting reports on the impacts of carp are due, in part, to the differing perspectives of the authors writing about them. Many reports are extremely one-sided (in either direction), and a major problem in this review has been to gain a balanced view of the real impact of carp on the environment. A further reason for these conflicting reports is that the scale of the impact of carp depends on the waterbody concerned. Important factors include: carp biomass, water depth, type of waterbody, type of substrate, and the density and species of aquatic vegetation, fish, and waterbirds living in, or around, the waterbody.

Lentic environments (i.e., standing waterbodies such as pools, ponds, lakes, etc.) are finely balanced systems which are extremely prone to disruption. Perhaps the most sensitive aspect of a lentic environment is the turbidity/phytoplankton: macrophyte equilibrium. Nutrients entering a lentic habitat are taken up by plants living in the lake. These plants may be either the phytoplankton suspended in the water column, or macrophytes growing on the bottom or around the fringes of the lake. In addition to nutrients, plants need sunlight to photosynthesise. In a natural system, there are usually low amounts of inorganic turbidity and phytoplankton in the water column and macrophytes are able to photosynthesise. However, if the waters of the lake become turbid through pollution, or if the phytoplankton population becomes too high, then the macrophytes will not get enough light to photosynthesise and will die. With the resultant increase in nutrients, both from decomposition of the plants and from the available nutrients now not utilised by plants, the phytoplankton population can explode.

Furthermore, macrophyte roots usually help to stabilise the lake substrate, thereby reducing the turbidity. When macrophytes die, sediment can more easily be re-suspended by wave action, and the lake rapidly becomes permanently turbid. Several shallow lakes in the lower Waikato (e.g., Lakes Waahi and Waikare) have recently lost their macrophytes, and these lakes now have dense phytoplankton populations and are extremely turbid. The problem in these lakes has probably been accentuated by the very fine clay particles in the catchment, which can remain in suspension for long periods of time.

Alterations in the macrophyte:phytoplankton equilibrium may have significant consequences for fish, as well as for other components of aquatic communities (Fig. 3). Macrophytes provide suitable habitat for a diverse invertebrate community, and refuge for the early life history

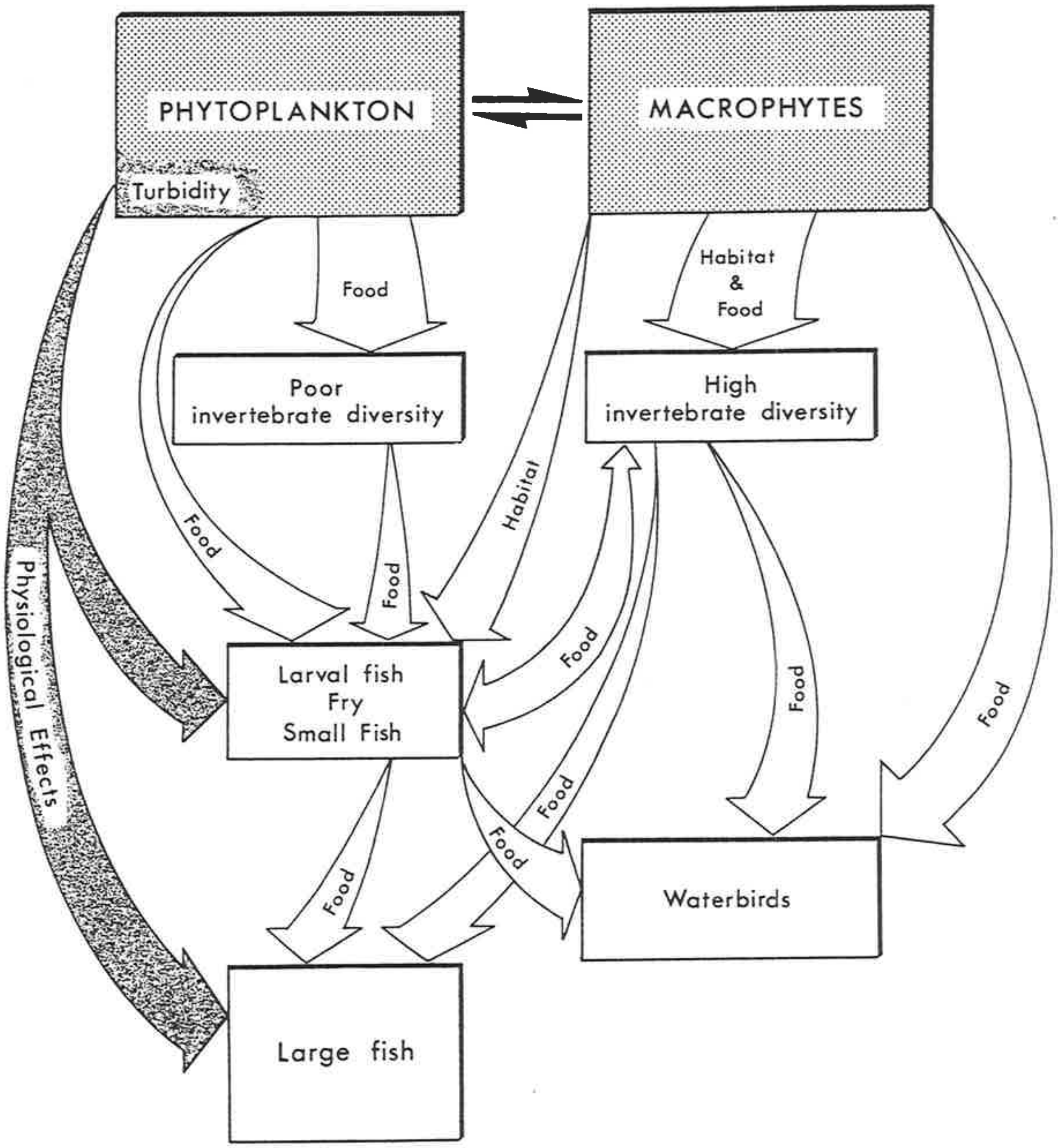

FIGURE 3. Trophic inter-relationships and potential changes arising from a shift in the macrophyte: phytoplankton equilibrium in shallow waterbodies.

stages of fish, which in turn provide important food resources for larger fish. Macrophytes also provide food and foraging habitat for waterfowl. Partial or total losses of aquatic vegetation, accompanied by increasing inorganic turbidity and/or phytoplankton blooms, result in low species diversity of invertebrates and fish, and reduced usage by waterbirds. The associated low aesthetic qualities also often reduce recreational use.

The ability for carp to affect the macrophyte:phytoplankton equilibrium, and/or other aspects of the ecosystem are examined in the following section. Although these values are interrelated (Fig. 3), the effect of carp on each one has been evaluated separately. The information refers mainly to the effects of the European strain of the scaled carp on the aquatic environment; the effects of other strains are largely undocumented.

4.1 Effects on Turbidity and Water Quality

Many authors have accused carp of increasing turbidity in a number of lakes and waterbodies (e.g., Ricker and Gottschalk 1941; Anderson 1950; Cahoon 1953; Sigler 1958; Miller *et al.* 1959; Jessen and Kuehn 1960a,b; Moyle and Kuehn 1964; King and Hunt 1967; Avault *et al.* 1968; McCrimmon 1968; Leventer 1981), but there is surprisingly little hard evidence to support their claims.

Indeed, several experiments have shown that carp did not significantly increase water turbidity (Threinen and Helm 1954; Tryon 1954; Robel 1961), whilst many others have either no quantitative data, or have not analysed their data statistically (Crivelli 1983). Studies which have demonstrated a significant deterioration in water quality due to carp (Buck 1956; Avault *et al.* 1968; Forester and Lawrence 1978), were carried out in small (≤ 0.1 ha) experimental ponds, often lacking vegetation, which may be very atypical of the situation in larger, weedy lakes. Fletcher *et al.* (1985) studied a number of Australian waterbodies where carp were present - both lotic (running water) and lentic (standing water) - and concluded that, at carp densities of up to 690 kg/ha, there was no significant effect on turbidity. They suggested that, in lotic situations, floods were the main cause of turbidity, whereas in lentic situations, water level fluctuations (caused by floods or high evaporation rates) and wind-induced turbulence were the main causes of increased turbidity.

While carp are unlikely to increase turbidity directly, except when biomass is very high, they may increase turbidity indirectly by causing a reduction in macrophytes (see Section 4.2). Without the stability provided by plants, fine sediments may be re-suspended by wave action, or by the feeding activity of carp, resulting in increased turbidity. The particle size and nature of the sediment is therefore of considerable importance (Jessen and Kuehn 1960a). For example, Mraz and Cooper (1957) stocked carp at 230 kg/ha in two experimental ponds in two successive summer periods. In the first pond, where the bottom was composed predominantly of fibrous plant materials, the water remained clear, whereas in the second pond, where the bottom was a mixture of loam and plant fibres, the water rapidly became turbid in both years. In addition to turbidity, carp could affect water quality by accelerating eutrophication, caused by the re-suspension of nutrients from sediments and by the release of nutrients from decaying plants (Taylor *et al.* 1984). However, little evidence is available for this.

In summary, low densities of carp (<100 kg/ha) are unlikely to have a direct effect on turbidity, except in small, weed-free, shallow, silty ponds. Even at higher densities (up to 700 kg/ha), carp will not necessarily increase turbidity if waterbodies are more than 1 m deep, and/or contain vegetation (Robel 1961; Fletcher *et al.* 1985).

4.2 Effects on Aquatic Vegetation

The effects of carp on aquatic vegetation (macrophytes) have been reviewed by Smith and Pribble (1979) and Taylor *et al.* (1984). Most authors have concluded that carp can cause a significant decrease in vegetation. Indirect evidence comes from the loss of vegetation when carp have been introduced to a waterbody (Black 1946; Moyle and Kuehn 1964; McCrimmon 1968; McLaury *et al.* 1975), and also from the recovery of vegetation once carp and other coarse fish have been removed by rotenone or seining (e.g., Cahn 1929; Ricker and Gottschalk 1940; Anderson 1950; Gerking 1950; Rose and Moen 1953; Cahoon 1953; Jessen and Kuehn 1960a,b; Moyle and Kuehn 1964; McLaury *et al.* 1975).

More direct evidence of damage has come from cage experiments. When carp were placed in cages in vegetated lakes, they were shown to cause a significant decline in weed biomass within the cage (Black 1946; Robel 1961, 1963; Crivelli 1983). Similarly, when cages have been set up to exclude carp from areas within a lake, significantly more vegetation has grown within the cage than outside (Tryon 1954; King and Hunt 1967), although, in a similar experiment, Threinen and Helm (1954) found inconsistent results. In contrast, McCrimmon (1968) reported that, in Ontario and Quebec, initial vegetation destruction by recently introduced carp was superseded by luxuriant and sometimes excessive weed growth - although not necessarily of pristine species composition.

Carp could affect vegetation in at least three ways: by increasing turbidity and hence decreasing light transmission for photosynthesis, by direct consumption, or by physically uprooting plants during feeding or spawning activity (Taylor *et al.* 1984). It is evident from Sections 3.3 and 4.1 that carp are unlikely to have a significant effect on weeds, either from direct consumption or from light attenuation, except in localised areas of high biomass and/or a lack of other prey items. Since spawning carp have not been observed to uproot vegetation (Swee and McCrimmon 1966; Fletcher *et al.* 1985), it seems most likely that physical disturbance during feeding is the major factor affecting vegetation.

Many authors have remarked on the occurrence of uprooted plants in the vicinity of feeding grounds, floating on enclosures, or washed up on shores of lakes (Moyle and Kuehn 1964; King and Hunt 1967; Avault *et al.* 1968; McCrimmon 1968; Crivelli 1983). Because of differences in plant rooting systems, carp selectively remove certain species (Moyle and Kuehn 1964; King and Hunt 1967; Avault *et al.* 1968; Smith and Pribble 1979; Crivelli 1983; Hume *et al.* 1983a; Fletcher *et al.* 1985), often resulting in reduced species diversity (King and Hunt 1967). These authors have concluded that the most sensitive plants are those submerged species with poorly developed root systems (particularly *Chara* spp., some species of *Myriophyllum*, and *Potamogeton foliosus*). Submerged species with well developed or robust root systems (e.g., *Potamogeton* spp. and some *Myriophyllum* spp.), are less sensitive to carp. Submerged species with no root system (e.g., *Ceratophyllum demersum)*, or those which form dense masses (e.g., *Myriophyllum propinquum*, *Elodea* spp., and some *Potamogeton* spp.), are somewhat more resistant to carp. Emergent species (e.g., *Carex* spp., *Typha* spp., *Paspalum distichum*, *Juncus* spp.) appear to be largely unaffected by carp.

The extent to which carp affect vegetation is related primarily to carp biomass, although size of carp, coarseness and type of substrate, plant species (see above), and water depth also are important. In short-term enclosure experiments, Robel (1961, 1963) and Crivelli (1983) demonstrated inverse relationships between carp biomass and vegetation (mainly *Chara* spp. and *Potamogeton pectinatus*). At biomass densities of about 100 kg/ha, less than 10% of the vegetation was destroyed, but, at densities of 450 kg/ha, between 30% and 50% was destroyed. These values contrast with the figures of Hume *et al.* (1983a), who concluded that, at densities of less than 450 kg/ha, carp had no significant effect on aquatic vegetation. In reaching their conclusions, Hume et al. (1983a) had cited Robel (1961, 1962) as stating that carp had eliminated 25% of the vegetation cover at densities of 450 kg/ha. However, Robel's data clearly show that at this density, 35% and 50% of the vegetation, respectively, was removed in 1959 and 1960 (also see Crivelli 1983). Field evidence, provided by Buck *et al.* (1960) from two adjacent shallow lakes in Illinois, corroborated this. The smaller lake (0.6 ha) was turbid, with no weeds, and had a biomass of 460 kg/ha, whereas a larger lake (1.7 ha) was clear, with dense *Myriophyllum* spp., and had a biomass of 275 kg/ha.

Crivelli (1983) also showed that larger carp destroyed significantly more vegetation than smaller carp. Since strength and surface area of the mouth for sucking are a function of body size, uprooting would be more extensive in larger fish. Several authors have shown that waterbodies with fine sediments in the littoral zone, as opposed to those with firm, sandy bottoms, are particularly susceptible to vegetation damage (Cahn 1929; Threinen and Helm 1954; Jessen and Kuehn 1960a,b; McCrimmon 1968). Although most waterbodies affected by carp have been small (<50 ha), there are several instances where large lakes (>1000 ha) have been impacted (Moyle and Kuehn 1964; McLaury *et al.* 1975; Otis and Weber 1982; Hume *et al.* 1983a). Finally, because feeding activity is confined mainly to shallow areas, water depth is also important, with plants in water greater than about 10 m being relatively unaffected (Gerking 1950; Crivelli 1983; Johnsen and Hasler 1977).

In summary, carp in shallow, silty waterbodies can significantly reduce the abundance and species diversity of aquatic vegetation. At low biomass densities (<100 kg/ha), plant species composition may be affected, but at higher densities, particularly above 450 kg/ha, partial or total removal of most submerged species could occur.

4.3 Effects on Invertebrates

Fletcher and Pribble (1979) reviewed the effects of carp on invertebrate communities. They suggested that the fish may alter the abundance and diversity of invertebrates, both directly through predation, and indirectly through alteration of the environment - in particular, through destruction or alteration of aquatic vegetation. As stated earlier (Section 3.3), the principal food items of carp are benthic organisms (e.g., chironomids and oligochaetes) and zooplankton (e.g., *Daphnia* spp.). Several pond experiments have shown that, at densities of 175 kg/ha, carp can significantly decrease the standing crop of chironomids, oligochaetes, and nematodes (e.g., Hruska 1961; Schroeder 1975; Forester and Lawrence 1978). Other experiments have shown that carp decrease the standing crop of zooplankton (Straskraba 1965; Schroeder 1975). (However, most of these studies were carried out in the absence of pondweed, so the change in biomass could be attributed mainly to direct predation.)

It is well known that the presence of aquatic vegetation provides for a diverse and abundant invertebrate community (Moss 1980). Plants provide invertebrates with food, as well as shelter from predation, and greatly increase the area available as substrate. Many invertebrates eat the periphyton on plants, which comprises a rich diet of epiphytic algae, bacteria, protozoa, and detritus. "Periphyton feeders include freshwater shrimps, snails, mayfly and caddisfly larvae, whilst clinging on to stems and leaves are a much greater variety of small crustacea (cladocerans, copepods and ostracods) than is ever found in the open water of a lake or river" (Moss 1980). Feeding on both these groups are carnivorous insects such as dragonfly, damselfly, and beetle larvae. Loss of weedbeds, therefore, profoundly changes the invertebrate communities found in waterbodies, producing a less diverse fauna, often of reduced biomass.

In summary, low densities of carp may reduce the abundance of certain invertebrate species (e.g., chironomids or micro-crustaceans) which are actively preferred by carp (Hume *et al.* 1983a). However, they are unlikely to have a major impact on invertebrate diversity or overall standing crop. At higher densities of carp, the destruction of weed beds would radically reduce the diversity and, usually, the abundance of invertebrates - although in New Zealand the latter may not necessarily be the case (see Section 5).

4.4 Effects on Waterbirds

In North America, common carp have been held responsible for the reduction in waterfowl usage of many wetland habitats (Moyle and Kuehn 1964; McCrimmon 1968; McLaury *et al.* 1975). However, in a recent study in Australia, Hume *et al.* (1983a) found no evidence to suggest that carp adversely affected, either directly or indirectly, waterbird populations of the billabongs. To evaluate the possible effects of carp on waterfowl, the requirements of waterfowl need to be considered.

Wetland habitat must provide the nesting, protection, open-water, and feeding requirements of waterfowl species. For nesting and protection, most waterfowl require cover in the form of large stands of trees, shrubs, tall reeds, emergent sedges, or rushes (Smith and Pribble 1979). Since even high densities of carp have little impact on emergent vegetation, carp are unlikely to affect these nesting or protection requirements. Furthermore, many waterbirds (such as grebes, ducks, swans, gulls, and terns), require open water for resting, whereas others (such as swans, some species of ducks, shags, and coots), require open water for feeding. By restraining the natural succession of vegetation, carp may increase habitat diversity and enhance usage of some waterbodies (Robel 1963; Smith and Pribble 1979). On the other hand, a decline in both the amount and diversity of aquatic vegetation, consistent with a high carp biomass (Section 4.2), could have a marked effect on waterbirds.

Waterbirds have diverse and often opportunistic diets, ranging from wholly animal food (shags, herons, rails, and crakes) to wholly plant food (black swans and coots). In addition, many species of duck and teal take varying proportions of plant and animal matter, both temporally and spatially.

When the plant species destroyed by carp are also those preferred by browsing waterbirds, the reduction or loss in food supply would cause those birds to go elsewhere. In North America, the loss of large areas of waterbird feeding grounds has been attributed to the destruction, by carp, of the preferred beds of wild rice (*Zizania aquatica)*, wild celery *(Vallisneria americana)*, *Chara* spp., *Myriophyllum* spp., and *Potamogeton* spp. (Moyle and Kuehn 1964; McCrimmon 1968). Although this loss of food is potentially serious for herbivores such as black swan, other birds can feed on aquatic invertebrates, or terrestrial grains and seeds.

Carp also can reduce invertebrate diversity and abundance, both directly through feeding (Section 3.3), or indirectly by destroying the plants which provide refuge for many invertebrates (Section 4.2). Loss of invertebrate groups (such as aquatic insect larvae, crustaceans, and small molluscs) from wetlands may result in those habitats becoming less attractive to many waterbirds for breeding or feeding purposes (Smith and Pribble 1979). On the other hand, piscivorous species (such as pelicans, shags, and herons) are known to eat small carp, and may benefit from the presence of carp (Smith and Pribble 1979). Lastly, the presence of seeds of several aquatic plants (including *Scirpus* spp., *Potamogeton* spp., and *Chara oogonia*) in carp stomachs have prompted authors to suggest there may be competition between carp and waterbirds for seeds (Crivelli 1981).

In summary, in situations where carp are present in low densities (<100 kg/ha), they are unlikely to be detrimental to waterbirds. However, where carp have significantly reduced the submerged vegetation, utilisation of the area by some species of waterbird would probably be reduced - mainly as a result of a reduction in aquatic plants for the more herbivorous species, but also because of a reduction in the abundance and diversity of invertebrates.

4.5 Effects on Fish

Common carp have been widely accused of having a detrimental effect on native fish in North America (see Taylor *et al.* 1984). There are several studies where removal of carp, and other coarse fish (e.g., suckers (*Carpiodes* spp.), buffalofish (*Ictiobus* spp.), and catfish (probably *Ictalurus* spp.)), have resulted in the recovery of native and game fish populations (Ricker and Gottschalk1941; Cahoon 1953; Rose and Moen 1953; Miller *et al.* 1959). However, the removal of coarse fish has not always been successful (Ricker and Gottschalk 1941) and, furthermore, the results of pond experiments have not always shown carp to have a detrimental effect on fish.

The effects of carp on other fish will depend to a large extent on the biomass of carp present, the conditions of the waterbody, and the fish species concerned. McCrimmon (1968) cited many instances where carp co-exist with populations of warmwater species in Canada, and concluded that, in moderate numbers, carp seem to have no effect on the size of game fish populations, e.g., bass (*Micropterus* spp.) (also see Miller 1952).

Several pond experiments have been carried out to examine the effects of carp on largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*), and several other species in the United States. Buck (1956) used carp in high enough densities to keep the waters turbid (biomass values not given); whereas Mraz and Cooper (1957) and Forester and Lawrence (1978) used densities of between 170 kg/ha and 220 kg/ha. Buck was concerned mainly with the effects of turbidity, and showed that bluegills in clear ponds had higher growth rates and standing crops than bluegills in muddy pools. Furthermore, lower growth rates, but higher recruitment and standing crops, of bluegills occurred in muddy pools containing carp than in muddy pools without carp. Mraz and Cooper (1957) also concluded that the recruitment of bluegills was enhanced in the presence of carp. Although Forester and Lawrence (1978) recorded no inhibition of spawning by bluegills in the presence of carp, they did record a reduction in the recruitment and standing crop of bluegills. Similar, contrasting, effects on growth rates, recruitment, and standing crops of largemouth bass were recorded in the same experiments, although there was some suggestion that spawning inhibition occurred in each case.

There is little doubt that, when present in high densities, carp can have a significant impact on other fish. The density at which this impact occurs will depend on the fish concerned, and on the nature of the waterbody. There may be direct effects (e.g., competition for food or space, predation, forage supplementation), or indirect effects (e.g., removal of vegetation, degradation of water quality (Fletcher and Pribble 1979; Taylor *et al.* 1984)). The potentially detrimental effects of vegetation removal on water quality and invertebrates have already been considered (see Section 4.2). A reduction in invertebrate diversity and abundance reduces the amount and variety of food for fish. Specialist feeders would be affected to a greater degree than opportunistic feeders, but many species might be expected to show reduced growth rates, standing crops, or reproductive success. Vegetation also provides protection for the early life history stages of many fish, so that its loss may leave juvenile game fish vulnerable to predation (Savino and Stein 1982). Lastly, vegetation provides egg deposition sites for many species.

Alabaster and Lloyd (1980) reviewed the effects of differing concentrations of suspended solids on fish, and provided the following tentative criteria regarding the maintenance of freshwater fisheries:

(a) there is no evidence that concentrations of suspended solids less than 25 mg/litre have any harmful effects on fisheries;

(b) it should usually be possible to maintain good or moderate fisheries in waters which normally contain 25-80 mg/litre suspended solids;

(c) waters normally containing 80-400 mg/litre suspended solids are unlikely to support good freshwater fisheries, although fisheries may sometimes be found at lower concentrations within this range;

(d) at best, only poor fisheries are likely to be found in waters which normally contain more than 400 mg/litre suspended solids.

There are several reasons for the detrimental effects of suspended solids on fish. Schooling behaviour may be disrupted, both in larval and in adult fish, making them more susceptible to predation; visual feeders will be disadvantaged, thereby reducing growth rates and probably standing crops; and reproduction may be disrupted (e.g., desertion of nests, inhibition of spawning, and increased egg mortality). At high turbidities, fish may show physiological stress, whereas at lower turbidities they often show avoidance behaviour, and, like waterfowl, will go elsewhere if possible. Lastly, carp feeding and spawning behaviour also may be detrimental to spawning by other species in shallow water areas (Taylor *et al.* 1984). However, experimental attempts to demonstrate direct behavioural interference in spawning have given largely inconsistent results (see earlier).

The direct effects of carp on fish may be less pronounced than indirect effects. Despite many studies on the diet of carp (see Section 3.3), direct predation on any stage of the life cycle of fish does not usually occur. One notable exception was recorded by Jonez and Sumner (1954), who observed large groups of carp foraging in spawning areas of the razorback sucker *(Xyrauchen texanus)*. Gutanalysis of the carp verified that egg predation had occurred, and this was cited as a key factor in the decline of suckers in the Colorado basin (Taylor *et al.* 1984). Earlier reports of carp foraging on the eggs and young of game and pan fish last century seem to be groundless (McCrimmon 1968; Taylor *et al.* 1984).

Owing to the preference of carp for zooplankton and benthic organisms, there must be potential for them to compete directly with a large number of fish species that have the same diet during some stage of their life cycle (Reynolds 1976; Cadwallader 1978; Taylor *et al.* 1984). In the Murray River, in south-east Australia, Reynolds (1976) considered that the decline in catches of tench (another exotic species) was a direct result of competition for food with carp, since both had the same trophic status. He suggested that carp also could have been instrumental in the decline of catfish, golden carp, bream, and yabbies (freshwater crayfish) for similar reasons.

Hybridisation, and the introduction of parasites and diseases, are other potentially detrimental effects of exotic fish on native species (Taylor *et al.* 1984). Hybridisation of carp, which may occur with other members of the Family Cyprinidae, has not been a problem in North America or Australia because native cyprinids do not exist in those countries. Some potential parasites and diseases of carp are listed by Shotts and Gratzek (1984) and Hoffman and Schubert (1984), but their impact on other fish is largely unknown.

Despite many references to the detrimental effects of carp on game fish, there is little mention of impacts on trout. Sigler (1958) reported anecdotal information from Utah anglers, who claimed that trout fishing (possibly for *Salmo clarki*) at twilight progressed satisfactorily until carp moved into the area, after which no more trout were caught. Fletcher and Pribble (1979) cited a BSc thesis by Malcolm (1971), who noted an increased condition factor in carp, compared to a decrease in the condition of brown trout (*S. trutta*), in populations that were sympatric in farm dams in south-east Australia. Lastly, the loss of a fine trout fishery in Yallourn Dam, in south-east Australia, was attributed to the dominance of European carp (Anon. 1971). It is difficult to draw conclusions about the effect of carp on trout on this evidence alone, especially since no data on habitat or carp biomass accompanied the reports. As outlined earlier in this section, the main impacts of carp seem confined to warm, shallow (<10 m), silty, and often eutrophic, marshes, lakes, and ponds, where carp can reach a high biomass. Populations of carp may exist in lotic habitats or in large, deep, cool, clear lakes, but only in low numbers (Sigler 1958; McCrimmon 1968). From environmental considerations, therefore, it would seem that carp only pose a threat to trout in shallow, warm, weedy lakes or ponds.

Lastly, carp may be beneficial to other fish as forage, since predation by native piscivores has been observed on a number of occasions (see McCrimmon 1968; Fletcher and Pribble 1979;

Taylor *et al.* 1984). No rigorous efforts have been made to quantify this effect, although some pond experiments have shown poor recruitment of carp in the presence of bass and bluegills (Mraz and Cooper 1957; Avault et al. 1968; Forester and Lawrence 1978). It seems probable that predatory game fish populations usually hold the carp population in check, either through direct predation or competition (see Section 4.6).

In summary, at low biomass levels (<100 kg/ha) it seems unlikely that carp will have a detrimental effect on other fish populations. However, when conditions enable carp to reach greater densities, they are detrimental to many species of native fish. The main reason for this effect is probably due to the removal of vegetation, with a consequent reduction in cover, invertebrate diversity, and spawning sites for some species. Effects due to turbidity, and competition for food and space, may be of secondary importance for most species.

4.6 Discussion

It is evident from the preceding sections that carp have the potential to radically alter the environment. Although there are no doubt instances where carp have been the scapegoat for human-induced environmental changes, there are well documented experiments showing carp to have detrimental effects on aquatic vegetation, which usually, but not necessarily always, lead to reduced water quality, invertebrate fauna, fish life, and waterbird usage. The critical factor in these effects seems to be carp biomass. The inverse relationship between aquatic vegetation and carp biomass has been well demonstrated (Robel 1961; Crivelli 1983), and it remains only to determine which factors enable carp to reach a high biomass.

Because of their high fecundity, fast growth rate, and varied diet, carp have the potential for massive population explosions. However, some abiotic and biotic factors must usually hold carp populations in check. Successful spawning, and high egg and fry survival, hold the key to good recruitment and hence population increases. For successful spawning, carp require optimum water temperatures, optimum water levels, and suitable spawning areas (Section 3.1). Temperatures and water levels (both before, during, and after spawning) are critical to the survival of eggs and larvae (Shields 1958; Swee and McCrimmon 1966). Both these authors noted high egg mortality when water levels dropped, owing to egg desiccation. The effect of environmental conditions on survival of fry is unknown, although Shields (1958) speculated that a drawdown in water level after hatching also upset a biological condition (such as food availability) at a critical stage in the life of the tiny fry. Environmentally-induced egg mortality may be greatest in lotic (running water) habitats, where water levels and temperatures may fluctuate greatly, and this may be the reason for low carp biomasses, and lack of impacts, in these habitats.

Biotic factors limiting carp recruitment are probably more important in lentic (standing water) habitats, where predation by game fishes on fry and juvenile fish is known to occur (see Section 4.5). Furthermore, experiments by Forester and Lawrence (1978) and Mraz and Cooper (1957) showed poor carp recruitment when bass recruitment was good, suggesting possible competition between larvae. Field observations also provide evidence that biotic factors are important. When carp have been removed from, or controlled in, lakes, and game fish have been re-introduced, the balance is often restored (Section 4.5). This also has happened without human intervention in many areas of Europe, Canada, and Australia (McCrimmon 1968; Hume *et al.* 1983a; Merrick and Schmida 1984).

Reasons for the initial disruption of the balance could be many-fold. Natural decreases in aquatic vegetation, caused by water level fluctuations and/or wind-induced re-suspension of sediments, could easily affect the spawning success of other species. Carp spawning, not necessarily affected by this vegetation loss, could be highly successful and the resultant larvae would be free from competition, leading to high recruitment. Alternatively, fishing pressure or pollution could affect adult game fish numbers, relieving predatory pressure on carp fry, again allowing high recruitment of carp.

To summarise, carp populations probably usually are controlled by poor recruitment to the adult population. Both intra-specific and inter-specific competition for food and space, and predation at larval and post-larval stages, are probably the main controlling factors in lentic habitats. Abiotic factors affecting egg mortalities may be important controlling factors in lotic (still water) habitats. Removal of competition or predation, as a result of pollution, fishing pressure, or natural causes, can allow carp to become the dominant species, with consequent detrimental effects on aquatic vegetation, water quality, invertebrates, fish life, and waterbird usage.

5. POTENTIAL IMPACTS OF KOI IN NEW ZEALAND

The impacts of koi on the New Zealand aquatic environment are extremely difficult to predict. Firstly, we have little information on whether their growth, reproduction, feeding habits, and general behaviour are similar to some of the more virulent strains of carp overseas (see Section 2). For example, in Australia, the "Yanco" carp strain, which is apparently similar to koi, has remained in the same location within the Murray-Darling River system for many years, with no documented adverse impacts. Secondly, we have little information on the densities of koi attained in New Zealand, and at what densities any impacts to vegetation will eventuate. Furthermore, the effects of carp on many of our exotic plants (e.g., *Egeria densa*, *Lagarosiphon major*, and *Vallisneria gigantea*) and native plants (e.g., *Potamogeton* spp., *Myriophyllum* spp.) are unknown. Lastly, the principal, large, predatory fish in New Zealand (eels and trout) are largely absent from those areas in North America where carp have been a problem, and therefore their role in regulating koi numbers is unknown. That said, it is evident from Section 4 that carp will thrive under certain conditions, but will form only small populations under others.

In this section, the known impacts of koi in New Zealand are examined, their potential effects on aquatic vegetation, fish, invertebrates, and waterbirds are discussed, and the waterbodies which are potentially at high and low risk to koi are identified.

5.1 Known Impacts of Koi in New Zealand

In January 1988, MAF Fisheries was aware of only three waterbodies where koi apparently have had a major impact on the aquatic environment. The first waterbody, called Harrison's Pond, is on a farm north of Auckland. The pond is 440 m long by 67 m wide, is 2 ha in area, and has an average water depth of 1 m (maximum depth, 3 m). It was sampled in August 1986 by MAF Fisheries, using gill nets and fyke nets. Nineteen koi, 49 eels, seven rudd, and two goldfish were caught (S. Pullan, pers. comm.). Details of the date and number of koi originally released into the pond are unknown. The presence of several size classes of koi in the catch suggests that these fish have successfully bred there. The pond had a surface temperature of 13.7°C, a Secchi disk reading of 475 mm, a mud substrate, and very sparse aquatic vegetation (algae, watercress, and willow weed). Mr Harrison (the landowner) stated that, since koi had been introduced, there had been a reduction in aquatic vegetation (quantity and species unknown) and that the ducks previously present had disappeared. The koi caught in Harrison's Pond were in poor condition compared to koi caught in the Waikato River. This suggests that there was a shortage of food in the pond and that the density of koi was probably high. No biomass estimates are available for this pond.

The second waterbody is a small pond on a farm in Taranaki (Pullan 1982). The pond has an area of about 0.2 ha with an average water depth of 2 m. It was surveyed by S. Pullan in December 1981, and, using gelignite, a total of 22 koi was removed. Ten koi survived the blasts, but eight of these fish were later removed (Pullan 1984b.). The fish were on average 40-50 cm long, and weighed between 1.5 kg and 4.8 kg, giving an estimated density of 440 kg/ha. After the koi were removed, dense regrowth of vegetation occurred (S. Pullan, pers. comm.).

The third waterbody is also a small (0.05 ha) pond, about 1.0 - 1.5 m depth, near Ohaupo, south of Hamilton. The water has apparently become turbid, and lost its vegetation since koi were liberated (S. Pullan, pers. comm.). No attempt has been made to sample the waterbody, and so no estimate of fish density is available.

5.2 Aquatic Vegetation

The precise impacts of koi on aquatic vegetation in New Zealand are difficult to predict, because the effects of carp on many of the species here have not been studied. Many native species are endemic to New Zealand, whereas the exotic species (e.g., *Lagarosiphon major*, *Egeria densa*) are not a problem overseas. Furthermore, the degree of impact on vegetation, and the consequences in terms of water quality, are likely to differ from waterbody to waterbody.

The impacts of koi could range from loss of the more sensitive, perhaps rare, species, through to total removal of the aquatic vegetation. The loss of rare or endangered species (e.g., *Hydatella inconspicua*, *Chara braunii*, and various species of *Nitella* or *Utricularia)*, or of rare plant communities (e.g., charophytes in the dune lakes of Northland, Tanner *et al.* 1986), depends on their sensitivity to disturbance by koi. Loss of charophytes (e.g., *Chara* spp. and *Nitella* spp.) is a realistic danger, even at low koi biomass densities (perhaps as low as 50-150 kg/ha). The impact on less sensitive species (e.g., *Potamogeton* spp., *Myriophyllum* spp.) would probably become apparent at moderate koi densities (probably between 200-400 kg/ha). The densities required to remove plants which form denser masses (e.g., *Elodea canadensis, Egeria densa, L. major*), or ones which may be more resistant to koi damage (e.g., *Ceratophyllum demersum)* may be considerably higher.

The ability of koi to remove all vegetation from a waterbody should be considered. With our present knowledge we can say that the aquatic vegetation in small, shallow, ponds and dams is likely to be totally destroyed by koi when they are present at densities of about 440 kg/ha (Section 5.1). The habitats under threat from koi could probably be extended to include most small, shallow, silty lakes, and most sluggish drains. However, the impacts of koi on larger shallow lakes and reservoirs, which are thickly vegetated with exotic macrophytes, or on deep waterbodies with coarse sediments, would depend on the ability of koi to attain high biomasses under such conditions. But, for the reasons stated at the beginning of this section, these abilities are presently unknown.

5.3 Fish

It was concluded in Section 4.5 that the overseas impacts of koi on fish were mediated principally through the removal of vegetation, with a consequent reduction in cover, invertebrate diversity, and spawning sites. In New Zealand, however, the results of weed removal may not be quite so detrimental to fish life. Apart from the introduced species such as rudd, tench, perch, and goldfish, only the native inanga (*Galaxias maculatus*) and possibly the dwarf inanga (*G. gracilis*) spawn on vegetation in New Zealand. Inanga spawn on very shallow, flooded vegetation in the tidal reaches of rivers, after which the eggs remain out of water for between 2-4 weeks. It is unlikely that koi could have an impact on this vegetation. Dwarf inanga, a rare, landlocked form of inanga, occur in only seven dune lakes in Northland (McDowall 1978, 1984) which are, as yet, free from koi. It is highly likely that these fish also spawn on vegetation, but their precise spawning requirements have not been identified. Vegetation loss is more likely to affect egg mortality amongst the introduced species, although evidence for this in New Zealand is lacking.

The impacts of vegetation removal on growth, standing stocks, and feeding behaviour of fish are complex. Several of the native species (e.g., eels, bullies, smelt, and inanga) are able to survive in lakes denuded of vegetation (Rowe and Schipper 1985). When weeds were removed from a small coastal dune lake (Rowe 1984; Mitchell 1986), there was a reduction in smelt numbers, no reduction in bully densities, and increased shag predation on small trout, rudd, and tench. Other changes included an increased growth rate of rudd, an increased condition factor in tench, and an increased mean size of bullies and smelt, but a reduction in the numbers of larval bullies, and an absence of larval smelt. The diet of bullies and smelt switched from small zooplankton to chironomids (Mitchell 1986).

The results of a recent study by MAF Fisheries staff on two of the lower Waikato lakes (J. Hayes, pers. comm.) is also worth documenting here. Lake Whangape had extensive macrophyte beds of *Ceratophyllum demersum* during the year of study, whereas Lake Waahi was almost devoid of aquatic vegetation, having had a macrophyte collapse during 1978/79. Hayes found species diversity was similar in the two lakes, although site diversity was higher in Lake Whangape. The only species which appeared adversely affected by the loss of the macrophytes was the lake-resident smelt (the lacustrine form of the common smelt), which had disappeared from Lake Waahi (see also Ward *et al.* 1987). Most other species (including shortfinned eels, common bullies, rudd, and large goldfish) were present in greater numbers and biomasses in Lake Waahi. Furthermore, the condition and growth of eels were also higher in Lake Waahi, but bullies were generally smaller, and small goldfish were caught infrequently. Hayes considered that the increase in biomass of most of the carnivorous species may be related to the presence of the mysid shrimp, *Tenagomysis chiltoni.* It occurred in greater abundance, and formed a greater proportion of fishes' diets, in Lake Waahi compared to Lake Whangape.

There is no documented evidence on the effect of the loss of vegetation on self-sustaining trout populations in New Zealand lakes. It is likely, however, that juvenile trout rely on vegetation for cover. Removal of vegetation from a small, shallow, dune lake may have resulted in increased shag predation on trout (Rowe 1984). It is also likely that juvenile, and sometimes adult, trout rely on invertebrates and small fish which live amongst the weedbeds. Thus, the effect of vegetation removal on their diet would depend on the abundance of alternative foods, and the ability of trout to take them efficiently. It is difficult, therefore, to make accurate predictions concerning the effects of vegetation removal on trout, but populations in small, shallow lakes would probably be affected more than populations in deep lakes. This is because food and cover would continue to be available in the deeper water of deep lakes.

The loss of aquatic vegetation, and subsequent increases in turbidity, therefore have different impacts on different species and size classes of the same species, ranging from devastating for species such as lacustrine smelt to advantageous for species such as eels.

Other possible detrimental impacts of koi include competition for food, space, and cover. On the positive side, juvenile koi may be prey to piscivorous species such as eels and trout. Diet studies have not been carried out for all New Zealand species, but, given the general opportunistic feeding habits of carp, there is likely to be dietary overlap with most other species inhabiting the same environments (e.g., eels, trout, bullies, smelt, and some galaxiids). However, the potential impact of competition on those species is difficult to assess. McDowall (1984) considered that competition with trout for food, or cover, has resulted in a decline in giant kokopu (*Galaxias argenteus*) numbers during the past century. Giant kokopu, listed as an "indeterminate" species in the New Zealand Red Data Book (Williams and Given 1981), are known from a wide range of habitats, but could conceivably suffer from interactions with koi in coastal streams, coastal lakes, and wetlands.

The role of juvenile koi as a food, both for eels and trout, is also a possibility. Beumer (1979) and M. Rutledge (Department of Conservation, Christchurch, pers. comm.) have recorded juvenile goldfish in the diet of shortfinned eels in Australia and New Zealand respectively, and goldfish also have been recorded in the diet of rainbow trout in New Zealand (Smith 1959; J. Hayes, MAF Fisheries, pers. comm.).

5.4 Waterbirds

Williams (1984) and Rowe and Schipper (1985) evaluated the potential impacts of the herbivorous grass carp on New Zealand waterfowl and other waterbirds. Both studies concluded that the major impact of grass carp would be the elimination of some or all plants favoured by waterfowl, and the loss of invertebrates which are associated with those plants. Because of the selective damage caused by koi (see Sections 4.2 and 5.2), they would be expected to have a similar impact on waterbirds to that of grass carp, but, with koi, there is also the possibility of direct competition with waterfowl for invertebrates and seeds.

As stated earlier, the degree of impact of koi depends on the sensitivity of the plant species to removal, and of the waterbody to modification, both of which ultimately depend on the density of koi. Potts (1977) reviewed present knowledge of the plant and animal species favoured by waterfowl in New Zealand. It is evident that the most sensitive species - the Characeans - are not amongst the plants most favoured by waterfowl, although they will be eaten on occasions by grey duck and mallard. Species less sensitive than characeans (e.g., *Potamogeton ochreatus, P. cheesemani*, and *Myriophyllum elatinoides*) are known to be utilised by black swan, grey duck, and mallard. During their season of abundance, these plants, and their seeds, can become important items of the diet of waterfowl. The more resistant species, such as *E. densa* and *E. canadensis* (but not *C. demersum)*, appear to be the preferred diet of black swan, particularly in the lower Waikato lakes. Other very resistant plants (e.g., *Lemna* spp.) are the preferred plant food for shoveler, whilst seeds of emergent plants (e.g., *Scirpus, Juncus*) are eaten by several species. Several other species of waterfowl (e.g., coot, scaup, and grey teal) are known to feed extensively on submergents (Falla 1975), but which plants are utilised has not been documented (Williams 1984).

The effect of the loss of aquatic vegetation on black swan (the only bird feeding entirely on aquatic plants) has been well illustrated in Lake Waahi in the lower Waikato (Ward *et al.* 1987). Black swan numbers usually ranged from 1000 - 3000 between 1974 and 1979, but have dropped to less than 100 since the collapse of the macrophyte beds. A decline in the usage of Lake Waahi by other waterfowl also has been reported over this period (A. Roxburgh, pers. comm.), although numbers have not been documented.

Competition for animal food and seeds may also occur between koi and some waterbirds. Potts (1977) stated that, in terms of volume and frequency of occurrence, snails were the dominant food item of mallard and grey ducks. Insect larvae and pupae (e.g., Hemiptera, Coleoptera, Diptera) also were common in their diet, although the relative importance of these and other invertebrates varied from place to place. Shoveler ducks feed on seeds and zooplankton, including cladocerans (e.g., *Daphnia*), copepods, and ostracods (Williams 1984). The diets of grey teal and scaup have not been studied in New Zealand, although Williams (1984) and Falla (1975) considered that they eat a wide variety of animal and plant foods. Although little is known about the diet of koi in New Zealand, carp overseas have been shown to preferentially eat chironomid larvae, followed by micro-crustacea, and occasionally large amounts of seeds, snails, and insect material (Section 3.3). Some competition for food between koi and most waterfowl species would therefore be expected.

A number of piscivorous species, including mainly shags (but also herons, bitterns, scaup, coot etc.) may benefit from macrophyte removal by koi, since juvenile and other small fish (which usually rely on the weed for cover) would become more available.

In summary, at low biomasses koi will probably not greatly affect waterbirds. However, at medium or high biomasses, partial or total removal of the preferred aquatic vegetation would reduce the availability of plant and invertebrate food. The black swan would be most affected by the direct removal of vegetation, although mallard duck, grey duck, coot, shoveler, and probably grey teal and scaup, also could be affected.

5.5 Waterbodies

New Zealand habitats which have the potential to support high densities of koi include most shallow (<10 m), silty, warm (>20°C), eutrophic waterbodies. This includes shallow lakes (e.g., Waahi, Whangape, Waikare, and others in the lower Waikato and elsewhere), most farm ponds and dams, drains, wetlands, and some of the shallower coastal dune lakes. In most of these habitats, particularly those with sensitive plants and/or silty littoral zones, koi could modify the environment, causing a decline in the aquatic vegetation and an associated decrease in waterbird usage, and, in some cases, fisheries values.

Specific habitats which could support high populations of koi would include several of the lower Waikato lakes. Williams (1984) considered that the lower Waikato was the most important wetland complex in New Zealand for waterfowl. It supports between 20-30% of the nation's black swan, mallard, and grey duck populations, and is one of the principal nesting areas for grey teal, and breeding, feeding, and moulting areas for shoveler. Of this complex, Lakes Whangape, Rotongaro, and Rotongaroiti are probably the most important (A. Roxburgh, DOC, pers. comm.). If koi were able to reach a high density in Whangape, then a loss of aquatic vegetation and an associated decline in waterfowl usage (as has happened in Lakes Waahi, Waikare, and Kimihia) would be predicted, although fisheries values would probably be relatively unaffected. As noted earlier (Section 4.6), the ability of koi to reach a high biomass in a large lake (such as Lake Whangape) is dependent on successful spawning and subsequent larval survival. Koi recently have invaded Whangape (and probably Lakes Rotongaro and Rotongaroiti) and so their impact will be assessable if or when the populations develop. With knowledge gained from ongoing studies in these lakes, a control strategy could then be considered.

Many other wetlands and shallow lakes which harbour waterfowl populations in New Zealand would be potentially "at risk" from koi. Several of these types of waterbodies also support either trout fisheries (e.g., Lakes Rerewhakaaitu, Rotorua, Aniwhenua), or good populations of dwarf inanga (e.g., some Northland dune lakes). Realistically though, impact assessment needs to be carried out on a case-by-case basis. Parameters such as substrate coarseness, depth, flushing time, plant species composition, and possibly the ratio of deep to shallow areas in the waterbodies need to be assessed before an accurate prediction can be made.

Habitats which will probably support only low koi densities include most warm, sluggish rivers (e.g., many rivers around the North Island), and most deep, clear, coarse-bottomed, cool lakes and reservoirs. There are no documented accounts of detrimental effects of carp in these types of habitats (Sigler 1958; McCrimmon 1968; Hume *et al.* 1983a), although isolated damage could conceivably occur in shallow areas of lake bays or inlets.

6. CONTROL MEASURES AND THEIR EFFECTIVENESS

If the potential for koi to become a problem in New Zealand is fully realised, then some measures will be required to manage or control them. However, control of carp is not easily accomplished. Moyle and Kuehn (1964) observed that the control of carp has taxed the ingenuity and finances of conservation agencies for more than 50 years. Control of carp in parts of North America has met with some success (Ricker and Gottschalk 1941; Anderson 1950; Rose and Moen 1952; Cahoon 1953; Shields 1958; Jessen and Kuehn 1960a), although these measures might need to be repeated at frequent intervals (Miller *et al.* 1959; McLaury *et al.* 1975).

Hume *et al.* (1983a) listed three alternatives for controlling carp :

(i) biological control (e.g., viral or genetic);

(ii) control by killing (e.g., poisons, explosives, water drawdown);

(iii) control by physical removal (e.g., seining, netting, targeted control).

These control methods are summarised in Appendix II. Hume *et al.* (1983a) concluded that the risks inherent in the use of either viral or genetic control methods were either scientifically or economically unsound. Control of carp using poisons or explosives has been used in a variety of waterbodies, and, although partially successful, it has not resulted in a complete kill of the fish and has potential side effects on other animals (see also Pullan 1982). Poisons such as rotenone are applied most effectively after a prolonged drought (or water drawdown) has reduced the water level and concentrated the carp into a confined area. Rotenone is generally unsatisfactory because of its damage to non-target species (including invertebrates - and hence waterfowl), its high application cost, its long retention time in the waterbody, and its ineffectiveness.

Hume *et al.* (1983a) noted that the Victorian Fisheries Division recommends the use of swimming pool chlorine (sodium hypochlorite) at 4 ppm, and lime (GBA-1) at 27 kg (1 bag) per 68,000 gallons, for killing carp in small private waters. These products raise the pH of the water to a level that is lethal to fish, then dissipate leaving no toxic residues. The effect of this treatment on invertebrates and vegetation was not given.

In waterbodies where the water level can be controlled artificially (e.g., reservoirs and some pond dams), water drawdown just after spawning can lead to very high egg mortality (see also Section 3.1.3.). Drawdown of water was successful in a reservoir in South Dakota, U.S.A., where only two correctly-timed drawdowns were needed to control carp reproduction in any one year (Shields 1958). This requires monitoring of fish reproductive condition, some knowledge of spawning behaviour, and several seasons of operation, but could be successful in some of New Zealand's smaller hydro lakes or reservoirs. The main disadvantage with this method is that the adult fish survive, so that many years of operation would be required before the carp biomass was significantly reduced.

Physical removal is probably the most commonly used method in carp control programmes (Hume *et al.* 1983a), and is also the least destructive to the environment. Physical removal can be achieved by encouraging anglers or commercial fishers to catch them, or by having ongoing fish removal programmes by fisheries/conservation officers. Common carp are an acceptable angling fish both in Europe and in many parts of North America, although sometimes they may be reluctant to take a bait. McCrimmon (1968) describes several baits used to catch carp, ranging from doughballs to wheat, worms, and maggots. One recommended method involves a bait comprising 80% cornmeal, 20% flour, and a little sugar. The bait is rolled into walnut-sized balls, placed on hooks, and allowed to lie on the lake bottom until taken by a carp. When hooked, large carp are dogged and enduring fighters and are capable of sustained drives (Sigler 1958). Many areas in North America actively encourage anglers to fish for carp by promoting carp derbies, and allowing people to hunt carp using underwater spears or bows and arrows (Sigler 1958; McCrimmon 1968). At present, there are probably only an estimated 200 adult coarse anglers in the Auckland area (A. Moore, DOC, Auckland, pers. comm.), but with active public promotion, this number could be greatly increased.

Hume *et al.* (1983a) considered that staffing and financial constraints prohibited the Victorian Fisheries and Wildlife Division from controlling carp, and that the only cost-effective alternative was to exploit them commercially. However, efficient fishing methods and profitable markets are needed to make commercial exploitation an effective method of control. Hume *et al.* (1983a) advocated the use of small numbers of mobile anglers who could be called into areas as carp densities rose to problem levels. Intensive fishing over a period of days or weeks would reduce carp populations to lower levels and might alleviate the problem for 2-3 years.

Fishing methods used overseas to catch carp commercially include seine, pound, trammel, gill, and trap nets, as well as electrofishing (McCrimmon 1968; Hume *et al.* 1983a). Of these methods, seine nets are probably the most successful when suitable beaches or substrates are available, although electrofishing from boats has been used commercially with some success in Australia (Hume *et al.* 1983a).

In Australia, carp have been used for fresh fish markets, pet foods, and crayfish baits (Hume *et al.* 1983a), but potential also exists for their use in alternative markets (e.g., carp pituitaries, roe, sashimi, fish meal etc.) (McCrimmon 1968; Hume *et al.* 1983a). In New Zealand, markets currently exist for several freshwater fish, including whitebait, eels, grey mullet, and (occasionally) catfish. There is no apparent reason why koi carp could not be harvested commercially if significant populations of these fish develop. Although they could be sold occasionally on the fresh fish market, their main use would be as pet food, crayfish bait, and angling bait. Because of their predictably low dollar value, it would only be economically viable when their numbers were high.

In summary, carp removal programmes are costly, inefficient, and usually ongoing. Koi can be eradicated from very small waterbodies using high concentrations of poison, combined with water drawdown, but only after considerable effort and cost. This is not a desirable method when the waterbody is used for irrigation or drinking water, or contains valuable populations of other fish or invertebrates. Furthermore, although the vegetation is unaffected by these poisons, the associated invertebrate fauna is affected, so omnivorous waterbirds could no longer use these waterbodies. Water levels can be lowered to control reproduction. However, this would need careful monitoring and many years of operation before koi would be eradicated. Aside from promoting its values as a sports fish, the only cost-effective measure to achieve koi control is through commercial exploitation.

7. GROUPS INTERESTED IN KOI IN NEW ZEALAND

In order to gauge people's attitudes towards koi, several groups were contacted by telephone. This approach is generally unsatisfactory for several reasons:

(i) it is difficult to get hold of individuals for comment, and secretaries or other representatives often know little about koi, or other people's attitudes towards them;

(ii) many people are unaware of the existence of koi or are fairly indifferent to it;

(iii) many people are unaware of the differences between koi and grass carp;

(iv) different groups, and even different people within a group, have different ideas as to the impacts that koi will have, and therefore have different attitudes towards them.

Several people suggested that a random sample of people could be surveyed from each group interested in koi by using questionnaires. Each questionnaire would need to be accompanied by a summary of the potential and probable impacts that koi would have in New Zealand. The questionnaire and summary would need to be checked by several parties to ensure that it was not biased in any way. The questionnaire should also be used to gauge user groups' opinions of the proposed departmental policy on koi (see Section 8).

That said, it is evident both from talking to groups in New Zealand, and from reading the overseas literature, that there would be several groups pro-koi (e.g., fish hobbyists, water garden enthusiasts, some coarse fishers, and some farmers), and several groups anti-koi (e.g., duck shooters, trout anglers). Other groups (e.g., drainage boards, regional authorities, water ski clubs, commercial fishers, conservation groups) may have attitudes concerning koi if given the necessary information. However, at present they are generally unaware of the situation.

A brief summary of some groups' interests in koi follows, but the list is by no means comprehensive, and may not be representative of all views.

7.1 Coarse Anglers

At present there are an estimated 200 adult coarse anglers in the Auckland area, of which between 50-100 are members of one of three clubs (Mr Coulson, President, United Angling Club, pers. comm.). Probably few of these anglers are currently involved in fishing for koi because of the noxious status of the fish. However, the majority would probably fish for koi if they were taken off the noxious list (A. Moore, DOC, Auckland, pers. comm.). It is not known whether coarse anglers intend to continue illegal liberations of koi into new waters. This is because they are becoming concerned that koi may have a detrimental effect on other coarse species (e.g. perch, tench, and possibly rudd).

7.2 Fish Hobbyists and Water Garden Enthusiasts

Because of their bright colours and large size, koi are highly favoured amongst fish breeders and ornamental water garden enthusiasts. Koi may be found in a large number of areas ranging from pools in hotel foyers, to lily ponds, to outdoor garden centres, and may also be kept in some farm ponds for this reason. Although many ponds or pools have screened outlets to retain adult fish, larvae or fry may be small enough to escape into the receiving waterbody, or adults may escape from the ponds during floods. Koi will probably continue to be liberated into small private ponds around the North Island, and perhaps elsewhere in New Zealand, for ornamental purposes.

7.3 Farmers

Koi in the Auckland area have been used widely by farmers, as a means of controlling unwanted aquatic vegetation (S. Smith, fish breeder, pers. comm.). Plants clog up intake valves, pumps, and outlet screens, and are generally seen as being undesirable by many farmers (unless they are also duck shooters!). Stuart Smith, who has liberated koi into many private ponds around the Auckland area, stated that many farmers asked him for fish to clear plants from ponds; many similar requests also come to MAF Fisheries (S. Pullan and N. McCarter, pers. comm.). Because of the farmer's desire for both a weed destroyer and a highly visible fish (which they can show their neighbours), koi are considered a perfect solution.

It is likely that farmers will continue to want to stock koi into their ponds in the future, unless another species (such as grass carp) is readily available. It would be highly desirable to promote the use of triploid grass carp for this use. However, the high cost of grass carp ($10 - $15 per fish), may make this option unfeasible.

7.4 Trout Anglers, Fish and Game Councils, and Conservancy Councils

These groups have not been contacted officially, although there is no doubt considerable opposition from them to the liberation and spread of koi. It would appear from Sections 4.5 and 5.3 that, in most cases, koi will probably not pose a threat to trout. Despite this, there will always be concern for the potential damage which koi could do to trout fisheries, and these groups will want the eradication of koi from potentially "at risk" trout waters.

7.5 Duck Shooters

Duck shooters also have not been contacted officially, but their concerns are probably more valid than those groups involved with trout (see Sections 4.4, 5.4, and 5.5). This group would probably want eradication of koi from "at risk" areas, and/or close monitoring in those areas where eradication is not feasible.

8. LEGAL STATUS AND MANAGEMENT

The legal status of common carp in the USA and Australia is documented below, together with proposed management options for koi in New Zealand.

8.1 USA

Although most of the research on the environmental impacts of common carp have emanated from the United States, there are only six states there which have eradication programmes (Hocutt 1984). In these programmes, exotic fish are removed only under specific conditions and when feasible (Hocutt 1984). Whether common carp are included in these programmes is unknown, but Welcomme (1984) considered that there were a number of exotic species which were considerably worse than the carp.

8.2 Australia

Common carp were declared a noxious fish in Australia in 1962. After an exhaustive 5-year study on carp, Hume *et al.* (1983a) concluded:

> "*As no means of eradication are available, we must realise that carp are permanent residents in Victorian waters and should be treated as a resource and an occasional pest. As previously stated, carp can be said to be a pest when they occur in biomass densities greater than 450 kg/ha in ecologically, recreationally or economically valuable waterbodies. These valuable aquatic habitats should be defined by appropriate sections of the Division*".

They made the following recommendations to the Victorian Fisheries and Wildlife Division:

(a) retain legislation which declares carp a noxious fish;

(b) treat carp as a resource that may be an occasional pest;

(c) adopt, as a minimum level for treating carp as a pest, a biomass density of approximately 450 kg/ha, unless there are strong arguments for acting at lower biomass densities;

(d) be responsible for evaluating complaints received about problems caused by carp that would warrant action to control them. The decision would be based on whether carp were in sufficient biomass density, [and] the water body was ecologically and recreationally valuable, as determined by the Division;

(e) encourage the commercial harvest of carp in waters containing carp, particularly where densities exceed 450 kg/ha, with no effort applied to maintaining a minimum density or biomass density;

(f) monitor the effectiveness of physical removal methods as a means of controlling numbers of carp;

(g) encourage the use of carp as a resource and subsidise markets.

The present situation in Australia is not known because contacts with several of the Australian carp programme staff have not been forthcoming (A. Roxburgh, DOC, pers. comm.).

Although carp have become notorious in areas of Canada, South Africa, and India (Welcomme 1984), its status in those countries has not been examined in this study.

8.3 New Zealand

Koi carp was declared a noxious fish in New Zealand in 1980. After Fisheries Management Division staff (Steve Pullan) discovered a breeding population of koi in the lower Waikato in 1984, a Koi Working Group was formed. This informal group includes representatives from MAF Fisheries, DOC, Waikato Regional Council, and the Auckland Fish and GameCouncil. The purpose of the group is to co-ordinate and share information on koi, with a view to the development of policy recommendations on how to deal with koi-related problems.

The working group have outlined a koi policy document entitled "Policy and strategy recommendations for koi" (see Appendix III). Whilst it is beyond the scope of this study to discuss the policy in any detail, several points are pertinent to this report.

Firstly, while plans for eradication of koi from valuable waterbodies would be desirable, this option is difficult to achieve (see Section 6) and might turn out to be a waste of resources.

In its place, I propose that a control plan should be adopted, along the lines outlined below:

1. valuable waterbodies which presently contain koi should be monitored to determine whether or not populations are increasing and/or to determine if there is a strong indication that koi are responsible for the deterioration of beds of aquatic vegetation;

2. if there is sufficient evidence to suggest that carp are having a major impact on the environment, then commercial fishers should be encouraged, perhaps with incentives, to fish the waterbody. If the waterbodies are small other control methods could be used experimentally;

3. the effectiveness of the removal techniques and the recovery of the affected area should be evaluated and procedures revised as necessary;

4. regional DOC officers should identify valuable waterbodies which are likely to be capable of supporting large koi populations, but which do not presently contain koi. Depending on the size and nature of these waterbodies, and on the effectiveness of control methods in other areas, control methods should be prepared in case they are required. This could also involve an evaluation of the willingness of commercial fishers to catch koi in these areas.

In outlining this control plan, I have generally followed the strategy recommended by Hume *et al.* (1983a) for carp in Australia. However, my strategy differs from the Australian one in that no specific biomass levels are given. I feel that biomass levels have little value in the control of carp because of the difficulty in obtaining accurate biomass figures for carp in these sorts of waterbodies. In overseas studies, all biomass estimates have derived from either killing all of the fish, or from intensive tagging studies. I believe an approach based on monitoring relative koi numbers, and on monitoring aquatic vegetation, is more practical.

A second criticism I have of the koi policy document concerns the Amnesty Policy. Although I believe that it is a good idea in principal, it is unlikely to work in practice. Farmers would need to be offered an alternative fish in exchange for the koi - perhaps grass carp? Owners of ornamental ponds are unlikely to want to lose their fish unless replacements are available.

9. CONCLUSIONS

1. The origin of koi carp is uncertain. They may be a strain of common carp, or a hybrid between common carp and goldfish.

2. In Australia, fish similar to koi (the "Yanco" strain) have inhabited a small part of the Murray/Darling system for many years. During this time, the fish have not extended their range, but a more virulent strain has. I have been unable to find any documented studies on the environmental impacts of koi, or the "Yanco" strain, either in Australia or elsewhere.

3. Koi in New Zealand appear to have very fast growth rates, and similar feeding and spawning habits to common carp overseas.

4. A review of the overseas literature has shown that common carp have a detrimental effect on the aquatic vegetation, fish, and waterfowl in some waterbodies, if their populations reach high enough densities. The density depends on the waterbody concerned, but typically varies between 300 kg/ha and 500 kg/ha.

5. Those waterbodies which support high densities of common carp are usually shallow (<10 m depth), warm (>18°C), eutrophic, silty, and small, although larger areas may sometimes be affected.

6. The potential for koi to damage aquatic vegetation in New Zealand has already been demonstrated in at least two small (<2 ha), shallow (<3 m), silty waterbodies.

7. Waterbodies which could support high populations of koi in New Zealand generally have low fisheries values (with the exception of some dune lakes, and shallow lake trout fisheries), but generally high waterfowl values and extremely high wetland values (except those which have already lost their vegetation).

8. Several valuable waterbodies in the lower Waikato (particularly Lake Whangape) have populations of koi in them. At present, the likelihood of koi reaching high enough biomasses to cause an impact on these waterbodies cannot be predicted accurately. This is because the role of eels in regulating numbers of koi is unknown, as is the ability of koi to destroy the aquatic vegetation in these lakes. Nevertheless, a monitoring programme should be implemented and potential control methods should be examined in case these impacts occur.

9. Control methods for common carp are costly, inefficient, and usually ongoing. Apart from small waterbodies, and perhaps reservoirs, the only realistic means of control is through commercial exploitation.

10. Several groups have been identified which have an interest in koi. It is likely that the liberation of koi into private ponds and waterbodies around the North Island will continue, despite the noxious status of the fish.

10. MANAGEMENT RECOMMENDATIONS

1. Identify "valuable" waterbodies within each district.

2. Determine whether these valuable waterbodies are potentially "at risk" from koi (i.e., have the attributes listed in this study).

3. Determine whether or not koi are already present in these valuable "at risk" waterbodies (e.g., through netting programmes, local knowledge).

4. Monitor these waterbodies, particularly during the summer months for:

   (a) increasing numbers of koi;
   (b) damage to vegetation.

5. Contact local commercial freshwater fishers (i.e. eel or mullet fishers) and/or fish processors, to see if they are willing to catch and/or process koi - with or without subsidies.

6. Send a balanced questionnaire to interested parties, summarising the probable potential impacts of koi, and outlining proposed policy changes.

7. Fund research on basic aspects of the taxonomy, biology, ecology, and actual impacts of koi in New Zealand (see Section 11).

11. RECOMMENDATIONS FOR FURTHER RESEARCH

1. Basic biological information needs to be collected and written up on koi, particularly details concerning fecundity, food and feeding, spawning areas and spawning times, predators, early growth, and early life history. The potential for a mark-recapture programme also should be evaluated. This could give valuable information on population size, movements of fish, and growth rates.

2. Electrophoretic work should be carried out to determine whether New Zealand koi are the same fish as the "Yanco" strain of carp present in Australia.

3. With our present knowledge, it is possible to make fairly crude predictions about which waterbodies will support high populations of koi. Because of the many areas in the USA where common carp have caused a problem, it should be possible to improve prediction of "at risk" waterbodies using multivariate modelling techniques. However, some effort would be involved in getting the necessary, relevant information on waterbodies from the authors (e.g., water depths, areas, % littoral areas, substrate coarseness, temperatures etc.). Some modelling of carp standing crops in reservoir and riverine habitats has been carried out in the USA (Gilbert 1984).

4. Work needs to be carried out to determine which plants are most sensitive to koi, and the population densities that are required to destroy all the vegetation. (In particular, the effect of koi on the more resistant exotic plants should be evaluated.) Both exclosure and enclosure experiments are recommended, together with an evaluation of the impacts of koi on ponds in the field (perhaps those ponds in the Auckland area).

5. Because of the relative importance of Lakes Whangape, Rotongaro, and Rotongaroiti, their koi populations should be monitored closely. In particular, an effort should be made to determine whether the populations are growing, whether or not reproduction is successful, and what impact is occurring, if any.

6. Ponds where koi are known to have had an impact (e.g., Harrison's pond) should be rotenoned or drained to obtain biomass densities, and then left to see whether the vegetation and waterfowl return (i.e., the success of koi control needs to be evaluated for New Zealand). The numbers of other fish and their condition, and the abundance of invertebrates, also should be noted to determine whether or not koi have had an impact on them.

7. The possibility of koi control using commercial fishers and other methods needs to be evaluated. The possibility of netting koi whilst spawning, and spraying eggs, also should be investigated.

8. If koi fisheries are to be managed along with other coarse fisheries, then the impacts of koi on other coarse fish need to be assessed. This could be achieved by monitoring populations of perch, tench, and rudd in ponds containing koi.

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APPENDIX I. Known distribution of koi carp in New Zealand.

					Liberated			
#Ref	Site	Location	Map Ref. NZMS260	Informant	Who	Date	Number	Comments
Northern North Island								
1	T.A. Drinkwaters	61 Beach Road, Papakura	R12 825469	AAS	AAS	1987	-	Ornamental pond, had MAF permit. Retained on resignation from AAS.
2	Mill Road pond	Mill Road, Pukekohe	R12 860435	AAS	-	01.87	-	Horticultural dam. Koi from Waikato River by anglers. Prosecuted AAS.
3	Lake Whatihua (Thompsons)	Kariotahi Road, Waiuku	R12 585350	A Moore	-	-	-	Natural sand dune lake, no outlet. Several large koi sighted.
4	Papukura water supply dam	Hayes Creek Road, Ardmore	R10 897570	AAS	-	-	-	Several small koi caught seining. Had large lateral scales.
5	Burns and Ferrall	East Tamaki Road, Auckland	-	AAS	-	-	-	Small cooling water pond for factory, polythene lined. Netted 18.2.87.
6	Massey Pig Farm	Sunnyvale Road, Massey, Auck.	R11 508831	Anglers	-	-	-	Not seen.
7	Carter Holts sawmill pond	Forestry Road, Riverhead	R10 507928	Anglers	-	-	-	Not seen.
8	Mon Desire Hotel	The Promenade, Takapuna	R11 688893	A Moore	-	-	-	Ornamental pond inside hotel building.
9	Great Outdoors Centre	Wairua Road, Takapuna	R11 662899	A Moore	-	-	-	Three ornamental ponds in their display grounds.
10	Slipper Lake, Tomarata	Ocean View Road, Tomarata	R08 573575	Smith	Smith°	22.04.73	1	Natural lake, not seen.
11	Frank Gills	Gleason Road, Coatsville	-	Smith	Smith	15.05.73	few	Not seen.
12	Woodhill Park Road dam	Woodhill Park Road, Waimauku	Q10 418915	Smith	Smith	31.01.85	11	Seven acre dam. Netted AAS 25.2.87, several koi caught.
13	John Hardens	Hardens Lane, Paremoremo	R10 585929	Smith	Smith	27.10.85	8	In largest pond. Not observed.
14	Sunny Side Road pond	Sunny Side Road, Coatsville	R10 556957	AAS	-	-	-	In small pond by road.
15	Macadamia nut farm	South Head Road, Kaipara	-	Smith	Smith	10.11.85	23	One pond poisoned, not seen.
16	Lake Parawanui	Red Hills, Dargaville	P08 873706	Smith	Smith	27.01.86	some	Ten hectare natural sand dune lake, no outlet, koi not seen.
17	Fred Rocicho	-	-	Smith	Smith	01.03.86	-	Not seen.
18	Mr Meek	Dale/Waimarie Rd, Whenuapai	-	Smith	Smith	27.12.86	-	Not seen.
19	Dianne Balich	Henderson or Swanson	-	Smith	Smith	27.07.86	7	May have been destroyed.
20	Dick Prides	Tauhoa, RD4, Warkworth	-	Smith	-	-	-	Not seen.
21	Milton Bradleys	Albany Highway, Albany	-	Smith	Smith	27.04.86	15	Has been drained, not seen.
22	Danske Moblers Panorama Farm	Sturges Road, Henderson	-	Smith	Smith	12.05.86	25	Not seen. Koi reported by anglers.
23	Peter Smith	Foster Road, Waimauku	Q11 897440	Smith	Smith	19.12.86	7	Small pond. Netted AAS 1987, no koi caught.
24	Phil Shevlan	Highway 18, RD3, Albany	-	Smith	Smith	20.12.86	5	Not seen.
25	Binghem	Pomana Road, Kumeu	-	Smith	Smith	23.12.86	10	Not seen.
26	Bob Wallace	Matua Road, Waimauku	Q10 455920	Smith	Smith	28.12.86	9	Pond small, observed, no fish seen.
27	Rosa's pond	Constable Road, Muruwai	Q11 830391	Smith	Smith	17.12.86	4	Small pond. Netted AAS, no fish caught. Owner said died.
28	Kallaway	East Tamaki Road, East Tamaki	R11 815703	Smith	Smith	17.01.87	-	Fish observed in pond by A. Moore.
29	Webbers dam	Maire Rd, South Kaipara Head	-	Smith	Smith	03.02.87	9	Not seen.
30	Tony Clapham	Opposite Topuni Forest, RD	-	Smith	Smith	08.02.86	few	Not seen.
31	Tony Clapham's father	Topuni Forest area	-	Smith	Smith	08.02.86	few	Not seen.
32	Fred Beaumont	-	-	Smith	-	-	-	Not seen.
33	Lake Kareta	South Kaipara Head	Q10 250114	Anglers	-	-	-	First koi caught by anglers in January 1987.
34	Lake Okaihou (Houghton)	Muruwai	Q11 389870	Angler	-	-	-	Comment from coarse angler survey.
35	Chelsea Sugar Works	Chelsea Sug. Ref. Birkenhead	R11 643854	Angler	-	-	-	Anglers have caught koi in these ponds.
36	Lake Pupuke	Takapuna	R11 680986	Angler	-	-	-	Comment from coarse angler survey.
37	Smales Quarry	Northcote Road, Takapuna	R11 675896	Angler	-	-	-	Comment from coarse angler survey.
38	Lake Hakanoa	Huntly	S13 018032	Angler	-	-	-	Comment from coarse angler survey.
39	James Mackie Road pond	SH 16 just north Woodhill	-	Smith	-	-	-	Recorded in Smith's diary. Observed by AAS.
40	Oratia Opunuku Creeks	Henderson	R11 562798	Ranger	-	-	-	Comment from ranger to A. Moore, not substantiated.
41	Hoteo River	Hoteo	Q09 410285	Ranger	-	-	-	Comment from ranger to A. Moore, not substantiated.
42	Martin Doutre	Main Road, Coatsville	R10 593975	Smith	-	-	-	Obtained koi from Harrisons pond.
43	Brian Connolly	Luckens Road, Whenuapai	-	Smith	-	-	-	Not seen.

APPENDIX I. (contd.)

‡Ref	Site	Location	Map Ref. NZMS260	Informant	Who	Liberated Date	Number	Comments
Northern North Island (contd.)								
44	Thackrays	Huapai	-	Smith	-	-	-	Not seen.
45	Harrisons Pond	Forestry Road, Waitoki	Q10 488037	AAS	Smith	10.73	15	Large man-made dam. Source of Smith's koi.
46	Pupuke Golf Course pond	East Coast Road, Auckland	R10 668928	MAF	-	-	-	Small pond in golf course.
47	Auckland Zoological Gardens	Western Springs	R11 638807	MAF	-	-	-	Display ponds and tank in zoo. 11 koi held, permit holder.
48	Alex Harvey Industries	640 Great South Rd, Auckland	-	MAF	-	-	-	Large concrete pond in factory grounds. 270 koi held. EPH.
49	NZ Heritage Park	3 Harrison Rd, Mt Wellington	-	AAS	-	-	-	In display aquaria in complex.
50	Griffiths Holdings	2 Wairau Road, Takapuna	R11 662899	MAF	-	-	-	Four koi held. EPH.
51	Kumeu River	At Oraha Road, Kumeu	Q10 487912	MAF	-	-	-	Reported by Chris Hatton, Auckland Regional Water Board.
52	Manganui River	Dargaville area	#N23 633676	FER 47	-	-	-	Reported in *McDowall (1984).
53	Okahu Stream	Dargaville area	#N23 537678	FER 47	-	-	-	Reported in *McDowall (1984).
54	Omaru River	Dargaville area	#N28 673600	FER 47	-	-	-	Reported in *McDowall (1984).
55	Whangaparoa drainage creek	Whangaparoa Peninsula	-	MAF	-	-	-	Reported by MAF. Koi collected.
56	Lower Waikato River	Waikato	-	MAF	-	-	-	Throughout lower Waikato. See Figure 2 in text for details.
Other Parts of North Island								
	John Oliver	East of Te Kuiti	N83 865805	AAS	-	-	-	Private waterway. Contact Doug Taucher, AAS, Otorohonga.
	Woosters	Otorohonga	-	AAS	-	-	-	Private waterway. Contact Doug Taucher, AAS, Otorohonga.
	McRae	South-east of Otorohonga	-	AAS	-	-	-	Garden pond. Contact Doug Taucher, AAS, Otorohonga.
	Don Caulton	Otewa Road, Otewa, Otorohonga	-	AAS	-	-	-	Private waterway. Contact Doug Taucher, AAS, Otorohonga.
	"Chindie" pond	South-east of Otorohonga	N83 901864	WVA	-	-	-	Farm pond. Contact Marcus Simons, DOC.
	Ohaupo pond	Ohaupo, Hamilton	S15 138582	MAF	-	-	-	Ornamental pond. Electric fished by MAF 5.7.84.
	Herberts pond	Kent Road, New Plymouth	-	MAF	-	-	-	Farm pond. Poisoned by MAF 4.12.81.
	Herberts house pond	Kent Road, New Plymouth	-	MAF	-	-	-	Farm pond. All poisoned by MAF.
	Wanganui pond	Wanganui	-	MAF	-	-	-	Domestic pond. Poisoned with chlorine by MAF 29.9.83.
	Ivan Horn	79 Thatcher Rd, Castlecliff	-	MAF	-	-	-	Domestic pond. 8 koi held EPH.
	John Carr	18 Fromont St, Wanganui East	-	MAF	-	-	-	Domestic pond. 30 koi held EPH.
	Waihi waterlily gardens	Pukekauri Road, Waihi	-	Ranger	-	-	-	May have been washed away. Contact A. Taylor, Paeroa 7495.
	P. Lowes	Rapoura watergardens, C/- Tapu PO	-	MAF	-	-	-	17 koi held EPH.
	Tauranga "Begonia" pond	Tauranga	-	AS	-	-	-	Confirmed by V. Ormond, Acclimatisation Society, 6.9.84.
	Tauranga ornamental pond	Tauranga	-	AS	-	-	-	Caught 26.9.84. Koi/goldfish hybrids. Contact Acc. Soc. Tauranga.
	Martin's farm pond	Ohauiti, Tauranga RD3	-	MAF	-	-	-	Confirmed by B. Wright, MAF, Tauranga, 14.2.85.
	Logans Run	Snodgrass Rd, Te Puna, Tauranga	-	MAF	-	-	-	Confirmed by B. Wright, MAF, Tauranga, 8.8.85.
	Robbins Park pond	Cliff Road, Tauranga	-	MAF	-	-	-	Confirmed by Ian Walker, MAF, Tauranga.
	Waimapu River	Tauranga	-	MAF	-	-		Fish speared by S. Pullan, MAF, 7.3.83.
	Hawkes Bay Aquarium	Hawkes Bay	-	MAF	-	-	-	Curator holds 11 koi - permit holder.
	R. Marshall	3 Exeter Crescent, Napier	-	MAF	-	-	-	Four koi held. EPH.
	M.J. Hicks	120 Chatham Road, Flaxmere	-	MAF	-	-	-	27 koi held. EPH.
	S. Davies	15 Cabot Place, Flaxmere	-	MAF	-	-	-	Six koi held. EPH.
	R.D. Little	41 Dover Road, Flaxmere	-	MAF	-	-	-	Four koi held. EPH.
	J. Carter	26 Melville Street, Waipawa	-	MAF	-	-	-	Nine koi held. EPH.
	Wellington Zoo	Wellington	-	MAF	-	-	-	20 koi held. Permit holder.
	D. Hughes	8a Burwah Street, Wellington	-	MAF	-	-	-	Three koi held. EPH.

APPENDIX I. (contd.)

‡Ref	Site	Location	Map Ref.	Informant	Liberated			Comments
			NZMS260		Who	Date	Number	
Northern North Island (contd.)								
	C. Hogarth	Main Road, Makara	-	MAF	-	-	-	10 koi held. EPH.
	Mrs Brandon	24 Bay Street, Petone	-	MAF	-	-	-	Two koi held. EPH.
	C. Haines	7 Kaihuia Terrace, Wellington	-	MAF	-	-	-	14 koi held. EPH.
	B. Walters	46a Owhiro Road, Wellington	-	MAF	-	-		13 koi held. EPH.
	J. Wong	24 Kauri Street, Wellington	-	MAF	-	-	-	Five koi held. EPH.
Unconfirmed Sites								
	J.L. Needham	Pauls Road, RD2, Whakatane	-	MAF	-	-	-	Rumour only. Contact P. Armstrong, MAF, Whakatane.
	Thornton Lagoon	Thornton, Bay of Plenty	-	MAF	-	-	-	Large goldfish caught there, probably no koi. (Contact as above.)
	Matata Lagoon	Matata, Bay of Plenty	-	MAF	-	-	-	Suspected presence. Contact P. Armstrong, MAF, Whakatane.
	Te Awanga Lagoon	Te Awanga, south of Napier	-	AS	-	-	-	Suspected presence. Contact L.W. Spooner, AS, Napier.
	Westminster Drain	Tamatea, Napier	-	AS	-	-	-	Suspected presence. Contact L.W. Spooner, AS, Napier.
	Waimapu Stream	Tauranga	-	MAF	-	-	-	Suspected presence. Contact G. Steel, MAF, Tauranga
	Ongarue/Matiere dams	Taumaranui County	-	MAF	-	-	-	Koi possibly released 15 years ago. Contact G. Manning, MAF, Taumaranui.
	A.L. Thomson	446/450 Frankley Rd, New Plym.	-	MAF	-	-	-	Unconfirmed. Contact Nu/Lincoln, MAF, New Plymouth.
	Unnamed pond	South of New Plymouth	-	MAF	-	-	-	Unconfirmed. Contact Nu/Lincoln, MAF, New Plymouth.
	Waitoa River	Walton - Ngarua area	-	MAF	-	-	-	Suspected presence. Contact I. Walker, MAF, Tauranga.
	Mangawhero Stream		-	AAS	-	-	-	Contact D. Taucher, PO Box 241, Otorohanga 7415.
	Martin Anso	Kiokio	-	AAS	-	-	-	Private. Contact D. Taucher, PO Box 241, Otorohanga 7415.
	Jeff Carr	Kiokio	-	AAS	-	-	-	Private. Contact D. Taucher, PO Box 241, Otorohanga 7415.
	Jim Reed	Otorohanga	-	AAS	-	-	-	Private. Contact D. Taucher, PO Box 241, Otorohanga 7415.
	Rotary Park	Otorohanga	-	AAS	-	-	-	Public. Contact D. Taucher, PO Box 241, Otorohanga 7415.
	L. Kimihia	Waikato	-	MAF	-	-	-	Suspected presence. Contact R. Clark, Huntly 87602 (eel fishing).
	Kaipara River	Kaipara, Helensville	-	AAS	-	-	-	Suspected presence. Contact R. Blackshaw, Helensville 8513.
	P. Burke	Ormond Valley Road, Gisborne	-	MAF	-	-	-	Suspected presence. Contact P. Scott, MAF, Gisborne 79139.
	Orewa Golf Club	Orewa Golf Club, Orewa	-	MAF	-	-	-	Suspected presence. Contact D. Armstrong, MAF, Warkworth 8139.

‡ = reference number on Figure A1.1
AAS = Auckland Acclimatisation Society (now Auckland Fish and Game Council).
° = records from the diary of J.S. Smith.
EPH = expired permit holder.
# = NZMS 1 map reference.
* = McDowall, R.M. 1984. The status and exploitation of non-salmonid exotic fish in New Zealand. *N.Z. Ministry of Agriculture and Fisheries, Fisheries Environmental Report No. 47.* 61 p.
AS = local Acclimatisation Society (now Fish and Game Councils).

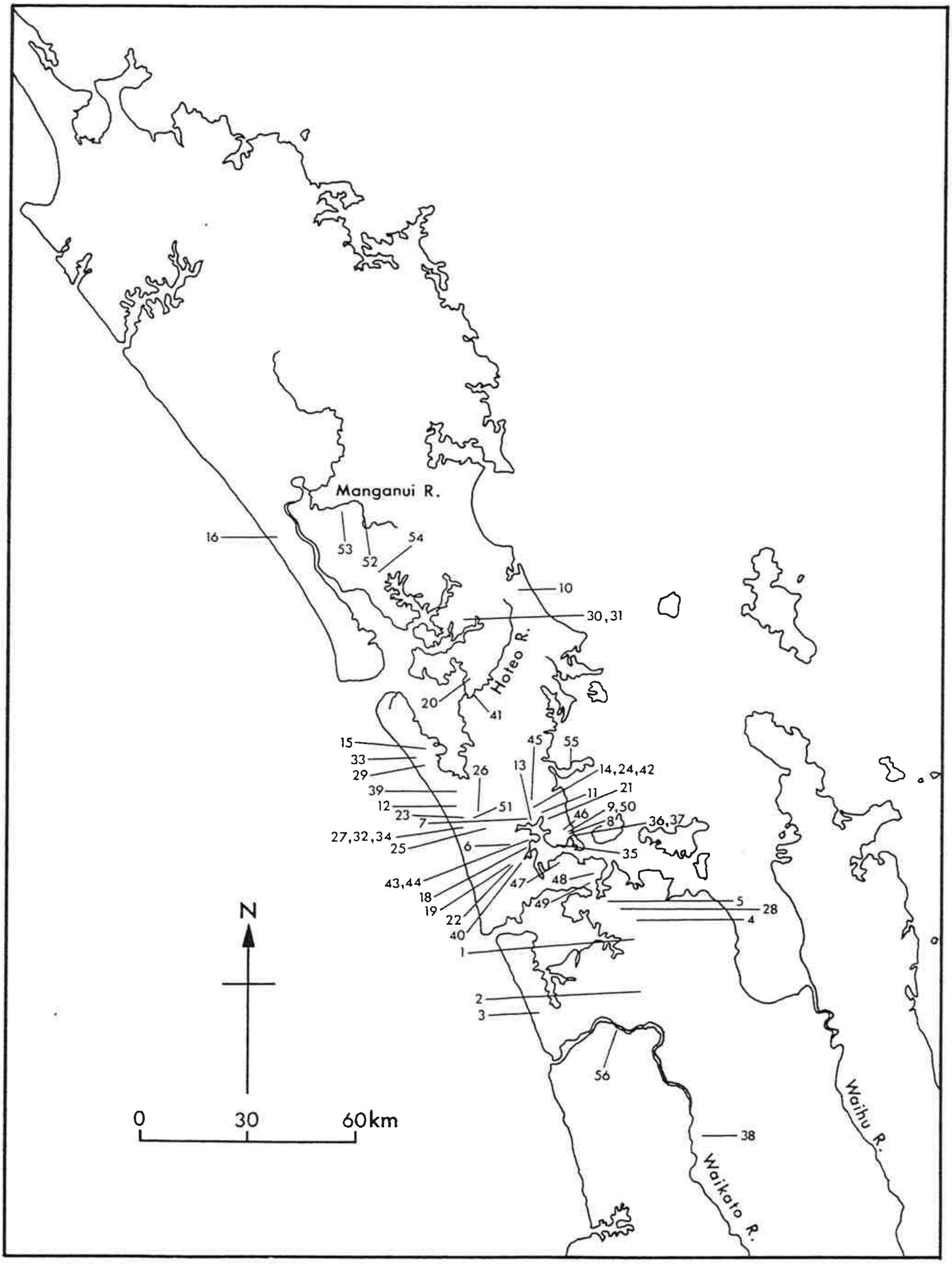

FIGURE A1. Known distribution of koi carp in the northern North Island. (Refer to Appendix I for details of site numbers.)

APPENDIX II. Policy and strategy recommendations for koi (from the Koi Working Group).

BACKGROUND SUMMARY

There is a need to adopt a more specific policy and plan to deal with koi (*Cyprinus carpio*) in New Zealand. Koi are now established in the wild (lower Waikato River area). There are a large number of koi in private ponds throughout the North Island, giving a potential to spread into other waterways. Unless a specific plan is adopted, it is inevitable that koi will become widespread in natural waterways throughout the North Island. The potential impacts of koi seriously threaten fisheries and wildlife habitats and values, especially in the Central Conservancy, as well as in other "at risk" areas.

It is recommended that MAF adopt a three-point policy and strategy to deal with koi to prevent, as far as possible, their spread into "at risk" areas.

POLICY PROPOSALS

Three main policy areas require consideration, and represent an overall strategy to deal with the problem in a balanced and planned manner. It should be noted that the three points are inter-related as a package.

1. Containment Areas

It is recommended that a policy be adopted to allow the establishment of "containment areas" for koi, within which the presence of koi will be tolerated or accepted. The primary criteria for the establishment of such areas need to be defined, but should include:

- relatively low risk in terms of potential environments which could be affected if koi establish themselves in natural waterways;
- the fact that koi are already prevalent in some areas;
- to what extent these areas are relatively separated or isolated from "at risk" catchments;
- the fact that there may be little likelihood of successful eradication (e.g., lower Waikato).

This policy recognises the difficulty of eradication, the potential costs of eradication, and the advantages of putting available resources in other areas where specific action or eradication is likely to be of greater benefit.

2. Eradication Plan

It is recommended that a policy to actively eradicate koi from locations outside defined containment areas be adopted. Specifically, policy is required to support eradication through the provision of adequate resources. To date, no active eradication programme has been developed due to a lack of priority and resources.

This policy recognises MAF's statutory responsibilities to protect valuable fisheries habitats and prevent environmental risks both by eradicating koi from at risk areas, as well as by preventing their spread through future escapes from ponds into natural waterways where valuable fisheries or wildlife resources are present.

3. Amnesty Policy

It is recommended that a policy to adopt an amnesty programme, backed by a major public relations exercise, be adopted to promote the location and eradication of koi from privately owned ornamental and farm ponds. This policy would contain the following elements:

- development of a high profile, but targeted, public relations campaign on koi;
- provision of an amnesty period for the public to report the possession of koi with immunity;
- a provision that koi reported before the expiry of the amnesty would be destroyed at MAF's expense, but after that at the owner's expense (legal checking is required on powers to do this);
- co-ordination with the concurrent development of containment areas and the eradication programme.

COMMENT

The Directorate needs to establish what priority the koi situation should be given. While there is a range of views on the level of risk that koi pose to New Zealand, overseas experience suggests that complacency would at best be inappropriate, and at worst irresponsible. The proposal outlined is not an over-reaction. An appropriate input to the delineation of at-risk areas would probably result in many areas where koi are now present being included in containment areas, lessening the need for resources for eradication. Nonetheless, some additional resources will be needed if the policy proposals are accepted, and the Directorate needs to be aware of this in formulating its response.

It is not possible to quantify what additional resources may be required. There is simply too little information on the number of privately owned ornamental and farm ponds with koi. It is our assessment that there could be up to hundreds of such ponds, although hopefully most of these are located in possible containment areas. The potential costs of eradication from each pond is in the vicinity of $1,000 plus.

RECOMMENDATIONS

1. That the three-point policy and strategy proposal be adopted in principle by the Directorate, with the provision that a small working group be appointed to write a specific draft policy and prepare an action plan with initial costings.

2. That if the policy/plan is not adopted, the Directorate should consider whether it is worthwhile for Exotic Fish Unit staff to continue undertaking any work on koi, and what the priority for such work should be.

3 That if the policy/plan is not adopted, the Directorate should re-consider the value of having koi declared a noxious fish. The current status of koi as noxious must be taken as a policy that MAF considers their presence in New Zealand to be a serious threat, deserving of an active programme to eradicate where possible.

APPENDIX III. **Evaluation of methods used for control of the common carp.**

Control	Operation	Advantages	Disadvantages	Case studies	References
Viral	Introduction of carp virus *Rhabdovirus carpio* into population.	Selective control. Relatively low cost.	Possible side effects on other parts of environment.	Not used.	Stevenson 1978. Hume *et al.* 1983a.
Genetic	Release of sterile males and production of sterile progeny.	Not harmful to other aquatic life.	Cost effectiveness.	Not used.	Brown 1980. Hume *et al.* 1983a.
Chemicals	5% Rotenone.	Kills 50-80% of fish.	Non-selective. High application cost. Not completely effective.	100% kill in Glen Lake, Vancouver Island, Canada. 50-80% kill in Lake Guthridge, Australia. 95% kill in Malheur Lake, Oregon	McCrimmon 1968. Rogan 1972. McLaury *et al.* 1975.
	Sodium hypochlorate at 4 ppm, and lime at 27 kg per 68000 gallons.	Kills carp. No toxic residues.	High application cost. Effect on invertebrates unknown.	None known.	Hume *et al.* 1983a.
Water drawdown	Lower water levels to kill eggs.	Only slight impacts on environment.	Only useful in areas where water level can be controlled. Only controls reproduction, doesn't kill fish.	Except for original paper, method is untested.	Shields 1958. Hume *et al.* 1983a.
Explosives	Use gelignite or cordex to kill fish.	Can kill up to 50% of fish.	Only partially successful. Non-selective.	Pullan killed 60% of koi in pond. No success in Australia.	Pullan 1982. Hume *et al.* 1983a.
Seining	Use 2½" mesh seine net. Can concentrate fish prior to capture.	Probably best removal method. Selective.	Ongoing and expensive. Small fish escape.	Used extensively in North America to catch carp.	Ricker and Gottschalk 1948. Miller 1952. Cahoon 1953.
Baited traps/trap nets	Set traps and retrieve fish later	Selective, traps can be semi-permanent	Cost of construction. Only fishes small area.	Used in Australia/ North America.	McCrimmon 1968. Hume *et al.* 1983a.
Other nets	Gill nets, fyke nets, trammel nets	-	Generally too size specific. Not efficient.	-	-
Fences and barriers	Exclude carp from shallow areas/arms using fences/ barriers.	May reduce impacts on weedbeds.	High cost of construction and maintenance.	Used in some areas of North America.	Sigler 1958. McCrimmon 1968.
Electric fishing	Use boat electro-shockers to stun fish.	Selective, allows release of non-target species.	Only useful in areas of high density. NZ has no boat electro-shockers capable of catching carp.	Used commercially in Australia.	Hume *et al.* 1983a.