Detecting exploitable stages in the life history of koi carp (*Cyprinus carpio*) in New Zealand

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Abstract

Koi carp are a highly coloured strain of common carp (*Cyprinus carpio* L.) and are an invasive alien species to New Zealand. The introduction of koi carp to the lower Waikato River during the 1980s has coincided with a dramatic decline in water quality within the regions riverine lakes. Removing koi carp from riverine lakes may improve water quality and preserve native biodiversity. This study used telemetry to examine the movements and seasonal habitat use of adult koi carp to find key locations to efficiently remove koi carp from the lower Waikato River basin.

Common carp are notoriously difficult to monitor in water temperatures above 20˚C using telemetry due to transmitter expulsion. To prepare for telemetry based field experiments, three tank trials were conducted to determine the most appropriate surgical technique for the implantation and retention of telemetry transmitters in koi carp. To reduce transmitter loss, two methods were initially tested in tank trials including two treatment groups and two control groups of ten adult koi carp. In one treatment, radio transmitters were anchored to the pelvic girdle, and in a second treatment, a polymer coating was applied to acoustic transmitters to reduce tissue irritation. After 365 days, expulsion rates for uncoated acoustic transmitters were 60% (n = 6), coated acoustic transmitters 50% (n = 5), unanchored radio transmitters 60% (n = 6) and anchored radio transmitters 90% (n = 9). Bacterial infection of the wound appears to be the primary mechanism for transmitter expulsion.

To reduce the influence of bacterial infection on transmitter expulsion, a slow-release antibiotic was tested to improve transmitter retention. Dummy acoustic transmitters were implanted in two groups of 20 adult koi carp, an untreated control group, and a group treated with a slow-release, single-dose antibiotic. After 176 days, the rejection rate of control fish (40%, n = 8) was twice that of fish treated with a slow-release antibiotic (20%, n = 4). Although we did not find a statistical difference between test groups, this was likely a function of sample size and we view the results as encouraging, justifying further investigation and use of slow-release antibiotics in koi carp.

Koi carp were monitored on the lower Waikato River using both radio and acoustic telemetry for 18 months. Koi carp migrated throughout the basin and frequently used lateral habitat. At least 74% of fish, that were monitored for at least 250 days, migrated through the waterways between riverine lakes or wetlands and the Waikato River. Waterways connecting riverine lakes and wetlands to the lower Waikato River are ideal locations to intercept migrating koi carp. Fish released at Lake Whangape occupied a total linear range (TLR) of over 120 km in just 218 days, which represents 71% of the potential in river TLR within the lower Waikato River Basin. Adult koi carp were found to be active year-round, but peak movements occurred during spawning season (October) during both years of the study. With a long-term commitment and thoughtful planning, removing a biologically significant proportion of koi carp biomass from the riverine lakes and wetlands of the lower Waikato River is feasible.

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Preface

This thesis consists of six chapters and two appendices that describe the results of experiments relating to this study. Chapters 2 to 5 have been or are in preparation for submission for publication in peer reviewed scientific journals. Hence formatting, grammar, and spelling of these chapters are as per journal style. Except where referenced, the work in this thesis, including field work, laboratory work, data analysis, interpretation, software development and writing was produced from my own ideas and work undertaken while under the supervision of Associate Professor Brendan Hicks, Dr. Nicholas Ling (University of Waikato) and Dr. Bruno David (Environment Waikato).

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Chapter 1: General introduction

1.1 Introduction

Concerns about the environmental consequence of common carp (*Cyprinus carpio* L.) introduction date back to the 1850s in the United States, but nevertheless carp have been spread to every continent of the world with suitable habitat (McCrimmon 1968). Common carp are hardy fish that are well suited for aquaculture and as a result are the third most commonly introduced fish species in the world (Welcomme 1992**.** The introduction of common carp has been linked to the loss of biodiversity or environmental degradation in North America (Lougheed et al. 1998; Zambrano et al. 1999), South America (Sidorkewicj et al. 1998), Australia (Koehn 2004), Africa (Hickley et al. 2004) and Europe (Crivelli 1981; Meijer et al. 1990).

Over the last century, the introduction of exotic fish and mammals to New Zealand has drastically changed native ecosystems (Pimentel 2002). The desire to enhance recreational opportunities or improve food resources have lead to the introduction of most of New Zealand's exotic species (Thompson 1922). Following the "accidental" importation of koi carp in the 1960s (Pullan 1984), their naturalisation into the wild may have been avoided without the intentional spread of koi carp for recreational angling. Koi carp are a highly coloured strain of common carp.

As a result of the actions of a few individuals who spread koi carp, there are now koi carp populations from Northland to Wellington on the North Island of New Zealand (New Zealand Freshwater Fish Database). The potential for further introductions of koi carp in New Zealand is unknown, but Australian research suggests that common carp have the ability to inhabit most lowland rivers and lakes (Driver *et al.* 1997) and have a tendency to flourish in human altered habitat (Kennard *et al.* 2005). If New Zealand koi carp are allowed to spread unchecked, though intentional liberations, it is probable that they will have an effect similar to feral common carp in Australia, dominating and degrading all accessible habitats (Kennard *et al.* 2005).

Since the detection of feral koi carp in the Auckland and Waikato regions in the early 1980s (Pullan 1984), koi carp have spread throughout the lower Waikato River and now dominate the fish biomass (Hicks *et al.* 2005). The introduction and proliferation of koi carp in the Waikato River has coincided with a dramatic decline in water quality in many of the connecting lakes and wetlands (Hayes *et al.* 1992; Chapman 1996). Nutrient loads from agriculture and resuspension of sediment by pest fish have additive negative effects on shallow lakes (Jeppesen *et al.* 1999; Meijer *et al.* 1999), but have not been definitively linked to the degradation of riverine lakes on the lower Waikato River. Currently, the three largest riverine lakes on the lower Waikato River (Lake Waikare, Lake Whangape and Lake Waahi) are hypereutrophic. These lakes are of significant cultural and recreational value to both Maori and European settlers.

Koi carp were declared a “noxious fish” in 1983 (Freshwater Fisheries Regulations) and an “unwanted organism” in 1993 (Biosecurity Act), but little action was taken to investigate management strategies for the Waikato River until 2001 when government agencies began investigating the feasibility of koi carp removal to improve water quality and protect biodiversity (Chadderton 2001). Attempts to develop a successful carp removal strategy in Australia have shown that targetting common carp aggregations is the most cost effective means of removal (Stuart and Jones 2002, Jones and Stuart 2009). The basis of any pest removal programme must be supported by a thorough understanding of the life history of the pest species (Anderson 2005). Although the movements of the common carp have been studied in Australia (Stuart and Jones 2002), North America (McCrimmon 1968) and Europe (Crivelli 1981; Koehn 2004), little was known about the movements of koi carp in New Zealand prior to this study.

This thesis directly addresses knowledge gaps essential to developing an effective removal strategy for New Zealand koi carp. Specifically, I will describe movements, migration timing and habitat types used by koi carp. Movement data reported in this thesis are based on radio and acoustic telemetry. The use of these technologies with New Zealand koi carp was explored during three tank trials that were designed to improve retention of telemetry transmitters for the field study described in this thesis and any future work conducted using internally implanted telemetry transmitters.

1.2 Biology and life history of common carp

The origin of New Zealand koi carp has not been definitively identified, but the consistent ornamental colouration suggests that the lineage is likely linked to the ornamental strain of common carp from Asia (Smith and McVeagh 2005). Due to the lack of a definitive genetic origin I will refer to the highly coloured strain currently found in New Zealand as koi carp and to other strains of *Cyprinus carpio* as common carp.

Koi carp in New Zealand have a moderate growth rate and are relatively short lived compared to common carp populations overseas. Female koi carp have been found to live up to 12 years and grow to lengths of 700 mm (Tempero 2004; Tempero *et al.* 2006). Common carp in Australia and North America can live as long as 28 years and reach sizes approaching 800 mm in the wild (McCrimmon 1968; Brown *et al.* 2005). When compared to common carp in European and Australia, koi carp grow slowly from 0 to 3 years of age and then surpass common carp in Europe after 5 years of age (Tempero *et al.* 2006).

Koi carp mature quickly and are highly fecund giving them the potential for rapid population growth. Koi carp mature sexually relatively quickly at age 1.1 years for males and 2.7 years for females (Tempero *et al.* 2006), similar to common carp in Australia (Brown *et al.* 2005). The overall sex ratio of mature koi carp in New Zealand is approximately equal (Tempero *et al.* 2006) but sex ratio is quite variable. Brown (2005) reported 39% of common carp in Australia were female, whereas Crivelli (1981) found that females represented 67% of common carp sampled in France. Tempero *et al.* (2006) also noted that the overwhelming majority of the oldest koi carp were female, as did Crivelli (1981). Female koi carp in New Zealand lived up to 12 years and males to 10 years (Tempero et. al 2006). The fecundity of New Zealand koi carp is similar to populations of common carp elsewhere (Tempero 2004; Tempero *et al.* 2006). Female common carp, and koi carp in New Zealand, produce an average of 300,000 eggs per year, but large individuals can deposit over 1,000,000 eggs, of which around 90% are fertilised (Swee and McCrimmon 1966; McCrimmon 1968; Brown *et al.* 2005; Tempero *et al.* 2006). Eggs normally adhere to submerged vegetation (Swee and McCrimmon 1966; McCrimmon 1968) and this may be a vulnerable stage in the common carp lifecycle. Hypereutrophic lakes are normally devoid of submerged vegetation limiting common carp spawning habitat to emergent vegetation and flooded margins. Restricting this habitat is a potentially useful control measure (Diggle 2004). Depending on water temperature, common carp eggs harden in 15-25 min and hatch in 3-12 days (McCrimmon 1968).

It is widely accepted that common carp spawning is influenced by water temperature. Stuart and Jones (2002) reported that yearly spawning events occur when water temperatures reach 15-17ºC in Australia, Crivelli (1981) observed spawning in France at 15-16 ºC, and Swee (1966) observed spawning at temperatures down to 17ºC in the United States. Peak spawning is thought to occur at temperatures of 19 to 23ºC (Swee and McCrimmon 1966). Although the majority of common carp spawn when water temperatures and water levels rise in the spring, ripe and spent common carp have been found year-round (Crivelli 1981; Stuart and Jones 2002). Multiple spawning events in a single season have also been documented for both sexes in New Zealand (Tempero *et al.* 2006) and overseas (Swee and McCrimmon 1966).

Spawning activity of common carp is thought to be most prevalent at dawn and dusk, but can occur throughout the day (Swee and McCrimmon 1966; Crivelli 1981). In general, common carp spawning occurs at altitudes below 500 m in shallow water with dense submerged macrophytes or emergent vegetation (Swee and McCrimmon 1966; Crivelli 1981; Koehn 2004). Crivelli (1981) noted that common carp in France tend to spawn in a consistent location year after year. Common carp return annually to the same locations to spawn in North America, despite heavy predation from bow hunters (A. Daniel, pers. obs.). Common carp aggregate in shallow water during spawning and are relatively easy to harvest at this time.

The diets of koi carp have not been studied in New Zealand but are thought to be similar to common carp. Larval common carp (5.0 to 5.5 mm) consume algae, Copepoda, and Cladocera (Specziar *et al.* 1997; King 2005). The diet of juvenile and subadult common carp (<400 mm) is varied but is dominated by macroinvertebrates (Specziar *et al.* 1997; Stuart and Jones 2002; Khan 2003). The diets of adult common carp are very diverse and have been thoroughly studied in other parts of the world. Common carp are true omnivores, consuming chironomids, microcrustaceans, gastropods, ostracods, amphipods, and detritus (McCrimmon 1968; Specziar *et al.* 1997; Garcia-Berthou 2001; Khan 2003; King 2005). Common carp are also efficient foragers and have the ability to locate and consume nearly 100% of available food in pond studies (Zur 1979; Zur and Sarig 1980).

There are conflicting reports on the habitat use of larval common carp, McCrimmon (1968) reported that carp larvae, observed in Canada, tend to stay in the macrophytes in which they hatch, but Stuart and Jones (2002) reported that larval common carp drift up to 150 km down river. Swee (1966) noted that newly hatched common carp in US lakes stayed in shallow depressions for the first two weeks of life and then dispersed to an unknown location. All three observations are likely dependent on environmental conditions after hatching. The habitats used by larval koi carp in New Zealand have not been documented and may represent a vulnerable stage in their life history. Lowering water levels to dry eggs has been used to reduce larval survival (Shields 1958; Yamamoto *et al.* 2006).

The habitat use of juvenile koi carp in New Zealand is not well understood, although there have been observations of large upstream migrations of juvenile koi carp in the Lake Waikare fish pass (Boubée *et al.* 2004), and reports from commercial eel fishers indicate that migrant koi fry are often captured in fyke nets as water recedes from flooded swamp-land (M. Brook, pers. com.). Juvenile common carp collected during Australian electrofishing surveys have been associated with woody cover in shallow backwaters (Stuart and Jones 2002; Brown *et al.* 2005).

The habitat use and movements of adult koi carp in New Zealand are detailed in Chapters 5 and 6. Common carp can survive in a broad range of habitat types. In general, common carp prefer human-altered inland waters below 500 m, but can occupy nearly any waterway from saline coastal waters to high altitude streams as long as there is access to spawning, foraging, and nursery habitat (Stuart and Jones 2002; Driver *et al.* 2005). Optimal habitat for common carp is generally thought of as lowland turbid water, but Driver (1997) found that the highest densities of common carp in New South Wales rivers (Australia) were above dams at mid to high altitude in riffles with cobble substrate.

Common carp have the ability to travel long distances, but a mark-recapture study in the Waikato River found little movement of New Zealand koi carp (Osborne et al. 2009). Because this study used dart tags to monitor the movement of fish, the results may be a product of high site fidelity rather than a lack of mobility (Gowan *et al.* 1994, Osborne et al. 2009). Telemetry studies of common carp in Australia have detected migrations of up to 200 km at speeds of 1 km h^{-1}, but common carp spend the majority of their time in a home range of less than 1 km (Reynolds 2000; Stuart and Jones 2002; Koehn 2004). Crook (2004) found that common carp in the Broken River, Australia had high site fidelity but were mobile and capable of shifting their home range to multiple locations over time. Migrations of common carp may be related to spawning, and to a lesser extent to feeding (Stuart and Jones 2002; Penne and Pierce 2008). Stuart and Jones (2002) noted that carp migrations are often triggered by rising water levels and can be described as lateral or longitudinal. Lateral migrations are short movements away from the main river channel such as to a temporary flood plain and longitudinal movements are migrations within the river channel (Brown *et al.* 2005). Common carp are known to disperse into flood plains when they are accessible, and have been documented aggregating at points of access to these sites (Reynolds 2000; Gilligan *et al.* 2005; Jones and Stuart 2009). Large spawning aggregations of common carp have been well documented and are by far the most visible and vulnerable stage in the life of common carp (McCrimmon

1968; Crivelli 1981; Brown *et al.* 2005). In North America, where water temperatures fall below 10°C, winter aggregations have been reported near warm water inputs (Cooke and McKinley 1999), aeration devices (Penne and Pierce 2008), and in deep water (Johnsen and Hasler 1977).

1.3 Environmental impacts of common carp

Common carp can have serious impacts on native flora and fauna. The most noticeable and possibly the most damaging effect is the resuspension of sediments during feeding (bioturbation). Common carp suck in sediment and discharge indigestible material while foraging, this behaviour is referred to as "mumbling" (Cahn 1929; Roberts *et al.* 1995; Zambrano *et al.* 1999). Common carp can penetrate up to12 cm into a substrate while mumbling, resuspending trapped nutrients, softening the original sediment and increasing turbidity (Zambrano and Hinojosa 1999; Chumchal *et al.* 2005; Driver *et al.* 2005b). The resulting sediment layer is less consolidated and more likely to be disturbed due to further foraging or windblown waves (Zambrano and Hinojosa 1999).

High densities of common carp can destroy macrophyte communities due to increased turbidity and can potentially cause top-down trophic cascades by feeding on microcrustacea (Khan 2003). If common carp forage in nutrient rich substrate those nutrients (e.g., total phosphorus and total nitrogen) are added to the water column and can promote the growth of cyanobacteria blocking the light necessary for plant growth (Roberts *et al.* 1995; Lougheed *et al.* 1998; Chumchal *et al.* 2005). Common carp can also promote the growth of cyanobacteria by resuspending nutrients such as phosphorus through their excretion (Richardson *et al.* 1990). The foraging of common carp can also physically uproot submerged macrophytes, but this is far less detrimental to most plants than the reduction in light penetration (Meijer *et al.* 1990). Shallow lakes with high densities of common carp often shift to a phytoplankton dominated state with less diverse fish communities favouring common carp as a result of the catastrophic loss of macrophytes and increased algal blooms (Bronmark and Stefan 1992; Lougheed *et al.* 1998).

Chapter 1: Introduction

Common carp affect every level of the food web through habitat degradation and direct predation on benthic invertebrates (Richardson *et al.* 1990; Wilcox and Hornbach 1991). Because common carp can physically change the environment that they inhabit through bioturbation, it is possible that they have a negative effect on a wide variety of native aquatic organisms. Although the direct effects of koi carp on native flora and fauna have not been studied in New Zealand, interactions have been described overseas and can be used to predict the potential effects of koi carp in New Zealand. For instance, Hinojosa-Garro and Zambrano (2004) found that common carp reduced populations of Mexican crayfish (*Cambarellus montezumae*) through habitat alteration caused by bioturbation. It is possible that a similar interaction is occurring between New Zealand's native freshwater crayfish (*Paranephrops planifrons*) and koi carp.

Koi carp are likely to have a detrimental effect on waterfowl through destruction of macrophytes and direct competition. Studies of fish (including carp) and waterfowl interactions have consistently shown that fish have a negative effect on waterfowl through direct competition for food resources and bioturbation (Eriksson 1979; Bailey and Titman 1984; Pehrsson 1984; Hanson and Butler 1994; Santoul and Mastrorillo 2003). Native fish are also likely to be indirectly affected by koi carp through habitat alteration, such as bioturbation, but could potentially be affected through direct completion for invertebrates (Taylor 1984). Increased turbidity could reduce the efficiency of sight feeders and the loss of macrophytes would reduce cover for many native fish (Parkos *et al.* 2003).

Reducing koi carp biomass could increase the density of other invasive fish thus increasing the negative effect of those fish on native species. Brown bullhead catfish (*Ameiurus nebulosus*) are known to spawn in shallow habitat with sandy substrate (Eycleshymer 1901) similar to the habitat that common carp use. Common carp consume fish eggs (Khan 2003) and are potentially reducing the brown bullhead catfish populations in locations where they coexist. Increased food resources from the hypereutrophic conditions that are often associated with high densities of common carp would likely benefit juvenile perch (*Perca fluviatilis*), but as adults increased turbidity would limit sight-feeding (Persson 1983). Tench (*Tinca tinca*) and rudd (*Scardinius erythrophthalmus*) may compete for the same invertebrate food resources (McDowall 2000), but are unlikely to be directly affected by common carp (Khan 2003). Although trout are unlikely to use the riverine lakes of the lower Waikato River year-round, due to high water temperatures during the summer, it is likely that the efficiency of sight-feeding for both brown (*Salmo trutta*) and rainbow trout (*Oncorhynchus mykiss*) would increase if lakes could be successfully shifted to a macrophyte dominated state. Trout populations in New Zealand have been negatively correlated with total phosphorus and total nitrogen (Jeppesen *et al.* 2000), and reducing these suspended nutrients through koi carp removal could increase trout densities within riverine lakes.

Fortunately, the detrimental effects of benthivorous fish are not permanent, several studies have shown that the removal of common carp (biomanipulation) can improve water quality and promote the regeneration of submerged vegetation (Giles 1994; Hanson and Butler 1994; Meijer *et al.* 1999; Jensen 2002). Meijer *et al.* (1994) found that a 75% reduction in total biomass of common carp was necessary to improve the water quality of shallow lakes in the Netherlands, although a target biomass was not reported. Similarly, Zambrano *et al.* (1999) modelled the removal of common carp in shallow Mexican ponds, and found a 70% reduction in biomass was necessary to restore water clarity. Biomass reduction must include juvenile and adult fish as juvenile fish can increase nutrient loading through excretion and adults increase nutrient loading through bioturbation (Driver et al. 2005). The critical biomass of koi carp that must be reached to shift shallow New Zealand lakes from a phytoplankton to a stable macrophyte dominated state is unknown. Although fish removal can successfully restore water quality (Meijer *et al.* 1994; Zambrano *et al.* 1999), it is unrealistic to expect that fish removal alone will provide complete restoration of water quality in waterways severely degraded by elevated nutrient inputs. Unfortunately, the positive effects of fish removal are temporary unless benthivorous fish can be eradicated or kept at an artificially low level through continual removal efforts (Meijer *et al.* 1994).

1.4 Removal attempts

There are a host of potential removal methods for reducing or eradicating common carp including netting (Cahoon 1953; Stuart and Jones 2002), trapping (Stuart and Jones 2002; Stuart *et al.* 2006), virus introduction (Matsui *et al.* 2008), exclusion (Lougheed *et al.* 1998), gene modification (Grewe *et al.* 2005), radio telemetry (Diggle *et al.* 2004), water level manipulation (Stuart and Jones 2002, Yamamoto *et al.* 2006), and poisoning (Frederieke *et al.* 2005). There is no single method for removing common carp that is effective in all situations. Most removal programmes are ineffective, and to date only small lakes have a high probability of successful removal (Koehn *et al.* 2000). However, the near removal of common carp from Lake Sorell, Tasmania (4,770 ha) gives hope to the possibility of similar successes (Inland Fisheries Service 2008). In New Zealand, attempts to remove koi carp from farm ponds have even proven to be difficult. Pullan (1984b) noted that after removal attempts with a rifle, spear, explosives and poison there were still two fish alive in a small Taranaki pond. However, koi carp were successfully removed from a small municipal pond in Nelson, New Zealand after the pond was poisned and drained (Chadderton et al. 2001). Boat electrofishing can improve catchability of New Zealand koi carp and has been used to catch koi carp in the Waikato River basin (Hicks *et al.* 2006).

Although there has been little or no success eradicating common carp on a large scale, there has been progress that lends hope to future advancements in removal strategies. The most notable is the ongoing effort to remove common carp from two large lakes on the island of Tasmania in Australia. Common carp were discovered in Lake Sorell (4,770 ha) and Lake Crescent (2,365 ha) in 1995 (Diggle *et al.* 2004). Since the discovery of the unwanted carp population, the state government has used a host of removal techniques including applying poison and fish removal guided by radio telemetry at a cost of $300,000 to $400,000 AUD per year (Diggle *et al.* 2004, Inland Fisheries Service 2008). It is estimated that removal efforts will last for a decade and monitoring will continue indefinitely (Diggle *et al.* 2004). In comparison, the estimated potential koi habitat in the lower Waikato River drainage includes 2,750 km of streams and rivers, 5,410 ha of riverine lakes, and 12,731 ha of wetlands.

The most valuable lesson learned from Australian attempts to control invasive carp populations has been prioritising removal efforts based on sound scientific information (Kelly 2003). Stuart and Jones (2002) suggested studying the movements and biology of common carp to target key points in the species' life history, such as migrations or aggregations. This thesis is a direct result of these basic principles and was designed to determine the exploitable stages in the life history of adult koi carp.

1.5 Telemetry and tagging

Radio and acoustic telemetry have been used to monitor fish behavior for decades (e.g., Hart and Summerfelt 1975; Gajdusek *et al.* 1987; Winter 1996). The basic procedure for both methods is based on attaching or implanting a transmitter to or in the study animal and using a receiver to locate or retrieve information from it. Signals from transmitters are monitored using either a fixed-site receiving station (Walsh *et al.*2000) or by mobile tracking (Lucas and Baras 2000). As the name suggests, fixed-site receiving stations are stationary monitoring systems consisting of a logging receiver and an aerial (radio) or hydrophone (acoustic). Fixed-site receiving stations rely on tagged fish passing or staying within range (10-1000 m) so that the aerial or hydrophone can receive information. Fixed-site receiving stations are generally used to monitor study fish in known locations or at obstructions. The resulting data can be used to determine survival rates, behaviour or migration timing. Typically, mobile tracking of radio transmitters involves locating the study fish using a vehicle, aircraft or boat and a directional aerial. The aerial is rotated to determine the direction of the strongest signal to locate the study fish. Once a study fish is located, the relative position and habitat parameters can be recorded.

Both radio and acoustic telemetry have advantages, but radio telemetry is the preferred method in freshwater rivers of depths of under 5 m (Winter 1996; Lucas and Baras 2000). Advances in acoustic telemetry, specifically ease of use, are rapidly changing this perception. The major disadvantage of acoustic telemetry is the inability to effectively mobile track study fish. Although directional hydrophones are available, they must be in contact with the water to function, limiting the operator to scanning at low speeds from a boat (Lucas and Baras 2000). When tracking a fish with an unknown home range over a large area, this is a major disadvantage (Winter 1996). When comparing the two methods in regards to fixed-site receiving stations, they have similar capabilities depending on the physical characteristics of the location. Acoustic transmitters do have a distinct advantage in salinities of >500 $\mu S\ cm^{-1}$ and are ideal for 3-D positioning (Winter 1996; Lucas and Baras 2000).

The expulsion of internally implanted transmitters is common in laboratory and field trials (e.g., Chisholm and Huvert 1985; Bunnell and Isely 1999; Welch *et al.* 2007; Jepsen *et al.* 2008). Transmitters can be expelled through the body wall (Helm and Tyus 1992), insertion site (Chisholm and Huvert 1985) or via the intestinal tract (Baras and Westerloppe 1999).

Common carp are notoriously difficult to monitor using telemetry at temperatures above 20°C due to expulsion of transmitters (Okland *et al.* 2003). Stuart and Jones (2002) found that common carp rejected up to 100% of surgically implanted radio transmitters and Okland *et al.* (2003) experienced 100% mortality or transmitter loss in a common carp field trial. Transmitter retention of common carp at lower temperatures is far more successful with rejection rates between 7% and 40% at temperatures below 15°C (Bauer and Schlott 2004; Penne and Pierce 2007; Penne and Pierce 2008). Chapters 2 and 3 detail the use of innovative surgical techniques, transmitter coatings, and antibiotics to improve transmitter retention in koi carp.

1.6 Thesis overview

This thesis describes five studies detailed in four research chapters written as independent scientific papers (chapters 2-5).

In Chapter 2, two tank trials designed to estimate the transmitter retention of New Zealand koi carp and test two methods for potentially improving transmitter retention are described. To examine the hypothesis that transmitter loss could be reduced, radio transmitters were anchored to the pelvic girdle and a polymer coating applied to acoustic transmitters to reduce tissue irritation in two tank trials.

In Chapter 3, a slow-release antibiotic was tested to improve acoustic transmitter retention based on the hypothesis that bacterial infection was the primary cause of transmitter loss and prolonged antibiotic treatment would improve transmitter retention. Antibiotics are often administered to fish during transmitter implantation procedures to improve transmitter retention, but the antibiotics efficiency have not been tested and are generally inappropriate for use in a single dose. CONVENIA™ (Pfizer, Kirckland, Quebec, Canada), a newly developed single-dose antibiotic, was administered to koi carp during acoustic transmitter implantation.

In Chapter 4, the movements of New Zealand koi carp implanted with telemetry transmitters and monitored for 18 months on the lower Waikato River are described. A total of 106 fish were implanted with radio or acoustic transmitters. Study fish were monitored using fixed-site receiving stations and tracking by boat, vehicle, and light aircraft. Total linear range, daily distance travelled, movement speed, peak movements, and movement between the Waikato River and lateral habitat are described.

In Chapter 5, the telemetry data described in Chapter 4 is used to estimate the invasive potential, potential social cohesion, response to environmental variables and habitat use of koi carp in the lower Waikato River.

In Chapter 6, management implications and recommendations for future work, based on the findings described in Chapters 2-6, are discussed.

In Appendix A, a step-by-step method for automating the processing of both radio and acoustic telemetry data developed for this study is described. Telemetry data for animals confined to a restricted habitat, such as a river, are typically processed manually by connecting fish locations on a base map. Manual processing is time consuming and introduces inconstancies caused by inaccurate tracing of base maps. The automated method described offers improved precision and accuracy.

In Appendix B, the migration locations of koi carp are displayed for each release site.

1.7 References

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Chapter 2: Acoustic and radio transmitter retention in common carp (*Cyprinus carpio* L.) in New Zealand[1]

2.1 Introduction

The loss of surgically implanted transmitters can impede long-term fish telemetry studies. The expulsion of implanted transmitters has been reported in many fish species including rainbow trout (Chisholm and Huvert 1985; Bunnell and Isely 1999; Welch *et al.* 2007), shortnose sturgeon (Kynard and Kieffer 1997), African catfish (Baras and Westerloppe 1999), channel catfish (Summerfelt and Mosier 1984), bluegill (Knights and Lasee 1996) and carp (Bauer and Loupal 2007; see Table 2.1 for scientific names). Transmitters can be expelled through the body wall (Helm and Tyus 1992), insertion site (Chisholm and Huvert 1985) or via the intestinal tract (Baras and Westerloppe 1999). Reasons for transmitter expulsion are largely unknown, although disease (Okland *et al.* 2003), internal irritation (Thoreau and Baras 1997), and water temperature (Knights and Lasee 1996; Bunnell and Isely 1999) are possible factors.

Common carp frequently expel transmitters at temperatures above 20˚C, in some cases up to 100% expulsion or death has been reported (Stuart and Jones 2002; Okland *et al.* 2003). Considering transmitters often consume a large proportion of a typical telemetry project's budget, this is a major concern. Thus far, little work has been done to reduce transmitter expulsion rates in common carp.

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Table 2.1. Common and scientific names of fish.

Common name	Scientific name
African catfish	*Heterobranchus longifilis*
Bluegill	*Lepomis macrochirus*
Channel catfish	*Ictalurus punctatus*
Common carp	*Cyprinus carpio*
Koi carp	*Cyprinus carpio*
Rainbow trout	*Oncorhynchus mykiss*
Shortnose sturgeon	*Acipenser brevirostrum*

In preparation for a New Zealand field study of invasive koi carp, a highly coloured strain of common carp, we conducted laboratory trials to determine the expulsion rate of radio and acoustic transmitters. Our secondary goal was to reduce transmitter expulsion by testing an antimicrobial polymer transmitter coating and a pelvic girdle attachment technique. Transmitter coatings such as beeswax have been used to reduce transmitter expulsions in rainbow trout with some success (Helm and Tyus 1992), but we speculated that modern antimicrobial polymers could improve retention by creating a thin, easily-disinfected barrier around the transmitter. In addition, innovative surgical procedures such as a pelvic girdle attachment could reduce transmitter loss through mechanical means (Penne and Pierce 2006). We hypothesized that applying a polymer coating to transmitters and attaching transmitters to the pelvic girdle would reduce expulsion. Two separate tank trials were conducted to test these hypotheses independently.

2.2 Methods

2.2.1 Experiment 1: Polymer acoustic transmitter coating

Twenty adult koi carp were captured from the Waikato River, New Zealand (175˚09'E 37˚29'S) by boat electrofishing as described in Hicks *et al.* (2006). Fish were transported from their capture location in aerated fish bins to a holding facility where surgeries were immediately performed. Study fish weighed 1.47-2.92 kg with an average weight of 2.01 kg (Table 2.2). There was no significant difference between the weights of the two test groups ($P > 0.05$, Mann-Whitney *U*-test). The control group of 10 koi carp were implanted with uncoated cylindrical (68-mm long x 11-mm diameter) dummy transmitters (Vemco V16, Amirix Systems Inc., Halifax, Nova Scotia, Canada) with an average weight of 24.3 g. Transmitters represented 0.8-1.7% of body mass in air (Table 2.2). The test group of 10 koi carp were implanted with identical dummy transmitters coated with a monolayer of a polydimethylsiloxane-based self-bonding polymer (KISS concentrated gel, KISS Polymers LLC, Tampa, FL, USA).

Fish were transferred individually from the transport containers to a 23˚C anaesthetic bath of AQUI-S® (AQUI-S New Zealand Ltd, Lower Hutt, New Zealand) at a concentration of 0.06 mL L^{-1}. When fish lost equilibrium, they were measured for fork length, photographed, weighed and placed ventral side up on a wet, V-shaped PVC plastic operating table set in a large plastic basin. The operating table was partially submerged in an aerated water bath containing anaesthetic at half the dose used in the initial anaesthetic bath. A 3.7-L min^{-1} recirculation pump mounted in the basin continually irrigated the gills with aerated water.

To reduce the risk of infection to fish, surgical gloves, scalpel blades and syringes were changed between surgeries. All surgical implements were autoclaved prior to surgeries and chemically disinfected with F10-SC veterinary disinfectant for 5 minutes (Chemical Essentials Pty Ltd, Doncaster East, Australia) at a concentration of 8 mL L^{-1} between procedures. Dummy transmitters were also chemically sterilised using F10-SC. All surgical tools and transmitters were rinsed with autoclaved saline solution prior to use. As an added precaution, a

Table 2.2. Weights (wt), lengths (FL) and sex of koi carp *Cyprinus carpio* implanted with dummy acoustic and radio transmitters. Growth expressed as increase in length. Final length and weight recorded at rejection or end of trial.

F: female; M: male

Transmitter expelled	Transmitter retention (days)	Sex	Transmitter wt / body wt (%)	Initial wt (kg)	Final wt (kg)	Initial length (mm)	Final length (mm)	Growth in length (%)
Acoustic uncoated								
Yes	21	F	1.7	1.47	1.46	428	430	0.47
Yes	35	F	1.5	1.66	1.12	389	390	0.26
Yes	42	M	1.5	1.67	1.44	408	410	0.49
Yes	15	M	1.5	1.68	1.49	443	443	0.00
Yes	37	F	1.4	1.74	2.08	484	492	1.65
Yes	23	F	0.9	2.84	2.52	528	535	1.33
No	365	M	1.6	1.49	2.35	421	495	17.58
No	365	F	1.6	1.52	1.60	421	437	3.80
No	365	F	1.3	1.81	2.60	462	487	5.41
No	365	F	0.9	2.60	3.42	530	545	2.83
Acoustic coated								
Yes	21	F	1.4	1.72	1.63	424	435	2.59
Yes	47	F	1.3	1.88	2.51	445	468	5.17
Yes	15	F	1.2	2.01	1.92	490	495	1.02
Yes	42	F	1.0	2.34	2.46	495	503	1.62
Yes	142	F	1.0	2.34	2.73	514	514	0.00
No	365	F	1.6	1.55	2.39	442	498	12.67
No	365	M	0.9	1.81	2.80	462	530	14.72
No	365	M	1.2	1.99	3.78	456	504	10.53
No	365	F	1.1	2.28	2.62	485	507	4.54
No	365	F	0.8	2.92	3.85	515	528	2.52
Radio unattached								
Yes	51	M	1.1	0.93	1.09	338	350	3.55
Yes	33	M	1.1	0.97	0.94	365	374	2.47
Yes	21	M	1.0	1.04	1.01	374	374	0.00
Yes	65	M	0.9	1.12	1.11	390	393	0.77
Yes	38	F	0.7	1.46	2.03	433	499	15.24
Yes	362	F	0.4	2.35	2.90	504	520	3.17
No	365	F	0.9	1.13	1.98	365	424	16.16
No	365	F	0.6	1.82	2.21	436	470	7.80
No	365	F	0.5	2.11	3.29	464	488	5.17
No	365	F	0.5	2.23	3.50	470	490	4.26
Radio attached								
Yes	124	F	1.0	1.08	1.39	365	370	1.37
Yes	63	M	0.9	1.17	1.16	389	390	0.26
Yes	111	M	0.8	1.29	1.50	403	412	2.23
Yes	41	M	0.7	1.57	1.69	445	436	-2.02
Yes	74	F	0.7	1.71	2.40	453	470	3.75
Yes	21	F	0.6	1.71	1.73	442	446	0.90
Yes	33	F	0.5	1.95	1.97	474	485	2.32
Yes	167	M	0.5	1.98	2.67	485	510	5.15
Yes	155	M	0.5	2.27	2.84	502	515	2.59
No	365	M	0.6	1.65	1.42	445	435	-2.25

surgical drape was placed between the incision and the surgeon to maintain the sterility of sutures during wound closure when suture material was long enough to contact the operating table.

Three to five scales were removed 1 cm posterior of the left pelvic fin and 1 cm dorsal of the mid-ventral line. A 1 cm incision was made in the same location with a scalpel while forceps were used to apply upward pressure on the left pelvic fin in an attempt to create space between the body wall and viscera. The initial incision was enlarged to 4-5 cm using blunt-ended surgical scissors to reduce the risk of damaging viscera. Dummy transmitters were inserted toward the anterior and rested over the pelvic girdle. Incisions were closed with three size-1 glyconate monofilament absorbable sutures (Monomend®, Veterinary Products Laboratories, Phoenix, AZ, USA). Each fish was given an intramuscular injection of DOLOREX® (Intervet Ltd, Upper Hutt, New Zealand) as a postoperative analgesic at a dose of 0.4 mg kg^{-1}.

Following implantation, fish were fitted with numbered anchor tags just below the dorsal fin as an additional means of identification. Fish were allowed to recover for 5-15 min in a 400-L aerated swimming pool until they regained equilibrium and were then transferred into an outdoor holding tank. The holding tank was an aerated 10,000-L circular fibreglass tank equipped with a recirculating filtered water supply. The holding tank had a natural photoperiod and the temperature ranged between 7 and 24˚C with an average of 16˚C (Fig. 2.1). Water temperature during the first 30 days (wound healing period) averaged 19˚C and ranged between 18 and 22˚C. Fish were fed a diet of commercial sinking trout pellets at 2.0% of their body weight per day.

Fish were sacrificed after they expelled transmitters in an attempt to determine the cause and location of the expulsion. Fish that retained their dummy transmitters for the duration of the trial (365 days) were sacrificed, examined, measured for fork length and weighed as an indication of fish health.

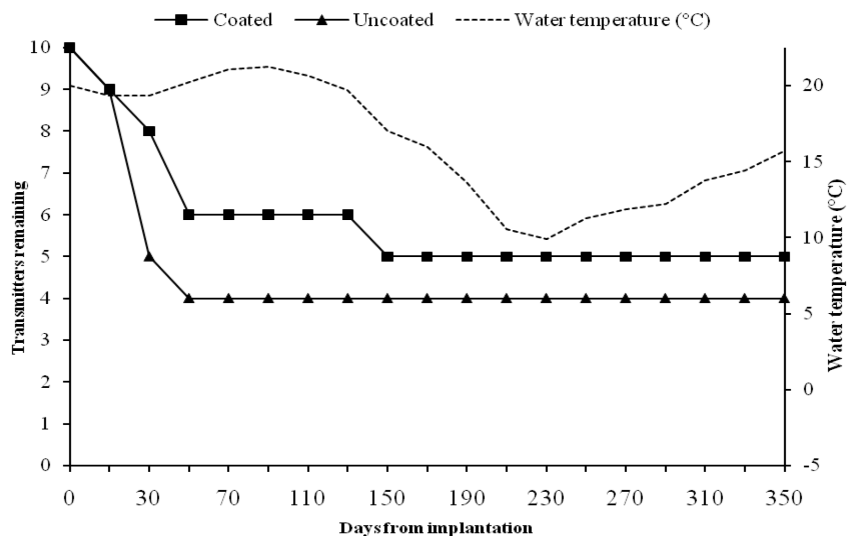

Fig. 2.1. Dummy acoustic transmitters implanted in *Cyprinus carpio* remaining after each period. Dotted line represents the average water temperature during each period.

2.2.2 Experiment 2: Pelvic girdle radio transmitter attachment

Capture location, capture methods and transport were identical to experiment 1. Study fish weighed 0.93-2.34 kg with an average weight of 1.56 kg (Table 2.2). There was no significant difference between the weights of the two test groups ($P > 0.05$, Mann-Whitney *U*-test). The control group of 10 adult koi carp were implanted with cylindrical (47-mm long x 15-mm diameter) 10.2-g dummy radio transmitters with stainless steel attachment loops and Teflon-coated stainless steel external antennas (H.A.B.I.T. Research Ltd, Victoria, BC, Canada). Transmitters represented 0.37-1.10% of body mass and were surgically implanted 1 cm posterior to the pelvic girdle. The test group of 10 adult koi carp were implanted with identical transmitters attached to the left pelvic girdle via an internal suture (Fig. 2.2). Trailing antennas were tunnelled through the body wall using a large catheter needle and wounds were closed with 2/0 Nylene non-absorbable monofilament nylon suture material (Dynek Pty Ltd, Hendan, SA, Australia). All other postoperative procedures were identical to experiment 1. This experiment commenced 92 days after experiment 1 and ran for 365 days. Holding tank temperatures ranged from 7 to 23˚C with an average of 16˚C (Fig. 2.3). Water temperature during the first 30 days (wound healing period) averaged 21˚C and ranged between 18 and 22˚C.

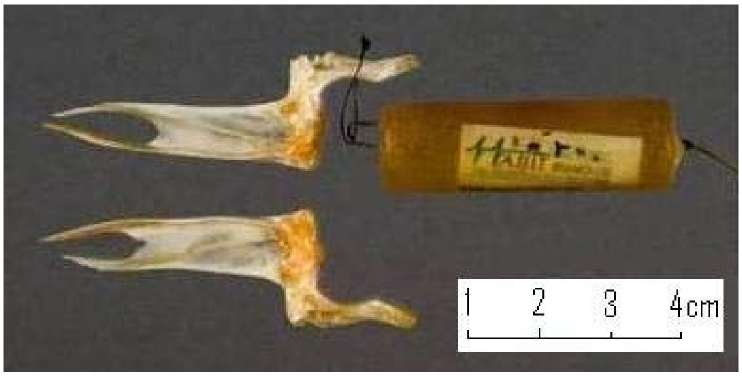

Fig. 2.2. Attachment of a radio transmitter fastened to the left pelvic girdle of a *Cyprinus carpio*. Photograph by Barry O'Brien and Bruce Patty.

2.2.3 Data analysis

Although the radio and acoustic transmitters represented in the trial have similar battery lives, expulsion rates were not directly compared due to differences in dummy transmitter mass and sexual maturation of study fish at the time of implantation. Dummy radio transmitters were implanted after spawning and dummy acoustic transmitters were implanted before spawning. Added pressure from mature gonads and altered physiological state could have influenced the rate at which dummy transmitters were expelled from fish implanted with dummy acoustic transmitters. Rejection rates of treatment groups were compared using a two-tailed Fisher's exact probability test and fish weights were compared using a Mann-Whitney *U*-test. Tests were considered significant if $P < 0.05$. Fish growth during the experiment was expressed as percent relative length change, which was calculated for each fish as (final length-initial length)/initial length x 100. Fish weight was not used due to extreme variability caused by gonad development during the course of the experiment and spawning during the last week of the experimental period.

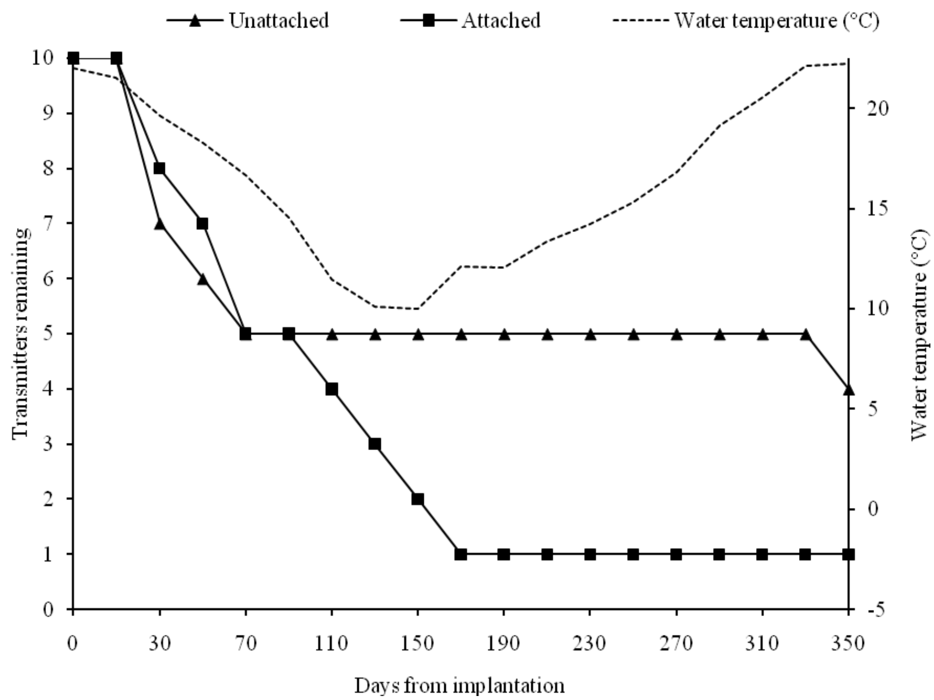

Fig. 2.3. Dummy radio transmitters implanted in *Cyprinus carpio* remaining after each period. Dotted line represents the average water temperature during each period.

2.3 Results

Suture type influenced wound healing; the non-absorbable sutures used in experiment 2 delayed healing and caused infection at the base of intact sutures after 365 days. Absorbable sutures used in experiment 1 were absorbed within 365 days, facilitating good wound healing. No fish died as a result of surgical procedures or dummy transmitter expulsion. Fish that expelled dummy transmitters and were sacrificed during the first month had generally lost weight and fish that retained their dummy transmitters longer than a month generally gained weight (Table 2.2). All expulsions occurred at or near the incision site as a result of ulcers and no dummy transmitters were lost as a result of suture failure.

Fish implanted with dummy acoustic transmitters expelled 6 of 10 (60%) uncoated dummy transmitters and 5 of 10 (50%) coated dummy transmitters. There was no significant difference between coated and uncoated dummy acoustic transmitters (*P* = 1.00, two-tailed Fisher's exact probability test). Of the 10 fish implanted with coated dummy acoustic transmitters, 4 of 7 (57%) females and 2 of 3 (67%) males expelled transmitters. Of the 10 fish implanted with uncoated dummy acoustic transmitters, 4 of 8 (50%) females and 1 of 2 (50%) males expelled transmitters. Dummy transmitters were expelled from 15 to 142 days with a mean of 40 days and a median of 35 days (Fig. 2.1). There was no significant difference between the weight of fish that expelled dummy acoustic transmitters and those that did not (*P* = 0.489, Mann-Whitney *U*-test).

Fish implanted with dummy radio transmitters expelled 6 of 10 (60%) unattached dummy transmitters and 9 of 10 (90%) attached dummy transmitters. There was no significant difference between attached and unattached dummy radio transmitters (*P* = 0.303, two-tailed Fisher's exact probability test). Of the 10 fish implanted with unattached radio transmitters, 2 of 6 (33%) females and 4 of 4 (100%) males expelled dummy transmitters. Of the 10 fish implanted with unattached radio transmitters, 4 of 4 (100%) females and 5 of 6 (83%) males expelled dummy transmitters. Dummy transmitters were expelled from 21 to 362 days with a mean of 90 days and a median of 63 days (Fig. 2.3). There was no significant difference between the weight of fish that expelled dummy acoustic transmitters and those that did not (*P* = 0.226, Mann-Whitney *U*-test).

2.4 Discussion

We observed a clear advantage to using absorbable sutures, similar to Jepsen *et al.* (2008). Early healing was similar, but some non-absorbable sutures remained intact after 365 days and were infected or irritated. All absorbable sutures had dissolved after 365 days, promoting good wound healing. It should be noted that these findings were potentially influenced by differences in the timing of transmitter implantation, gonad development and transmitter types.

KISS concentrated gel did not significantly improve dummy transmitter retention but did create a smooth easily cleaned surface and thus was a suitable transmitter coating. Wax transmitter coatings have also been reported to improve transmitter retention (Helm and Tyus 1992; Sakaris *et al.* 2005); unlike wax, a monolayer of KISS concentrated gel did not increase the diameter or weight of transmitters, was not heat-sensitive and was simply wiped on. Pelvic girdle attachment increased surgery times by approximately 30 s and did not improve dummy transmitter retention. It is likely that this procedure reduced transmitter retention and is not recommended. This presumed reaction to an internal irritant highlights the need for proper transmitter placement, appropriate shape and a benign surface coating. The high expulsion rate of internally attached dummy transmitters was presumably caused by internal irritation that led to infection. These findings could partially explain the 100% loss of transmitters internally implanted using a pelvic girdle attachment procedure described by Okland *et al.* (2003).

Despite the use of a relatively sterile surgical procedure, the expulsion rate of both control groups was high. All expulsions resulted from ulcerations at or near the incision site that appeared to be infected. Regardless of the technique used during wound closing, the incision is vulnerable to infection until completely healed. Even adhesives are unlikely to completely seal a wound for the duration of the healing process. Based on the data presented here, and data from other studies, it appears that lower temperatures are better for transmitter implantation. Unfortunately, the temperature at which microbial activity is reduced and wound healing is still rapid is unknown and likely site-specific. By plotting expulsion rates of this study with other common carp studies that have reported expulsion rates and water temperatures (Okland *et al.* 2003; Bauer and Schlott 2004; Penne and Pierce 2007; Penne and Pierce 2008) there was a clear linear relationship ($r^2 = 0.79$, $y = 5.56x - 23.95$, $n = 8$, Fig. 2.4). The relationship between lower water temperatures and lower rejection rates has also been described for bluegill (Knights and Lasee 1996) and rainbow trout (Bunnell and Isely 1999). Until the mechanisms responsible for transmitter expulsion in common carp have been overcome, we can only give the following suggestions: 1) carefully consider the timing (water temperature and gonad development) of transmitter implantation against the loss of battery life and potential expulsion, 2) maintain sterile surgical conditions, 3) minimise the stress and handling of study fish, 4) use the smallest possible transmitter and largest fish that will meet study objectives, 5) use a transmitter that is appropriate for the shape of the study fish and 6) use absorbable suture material.

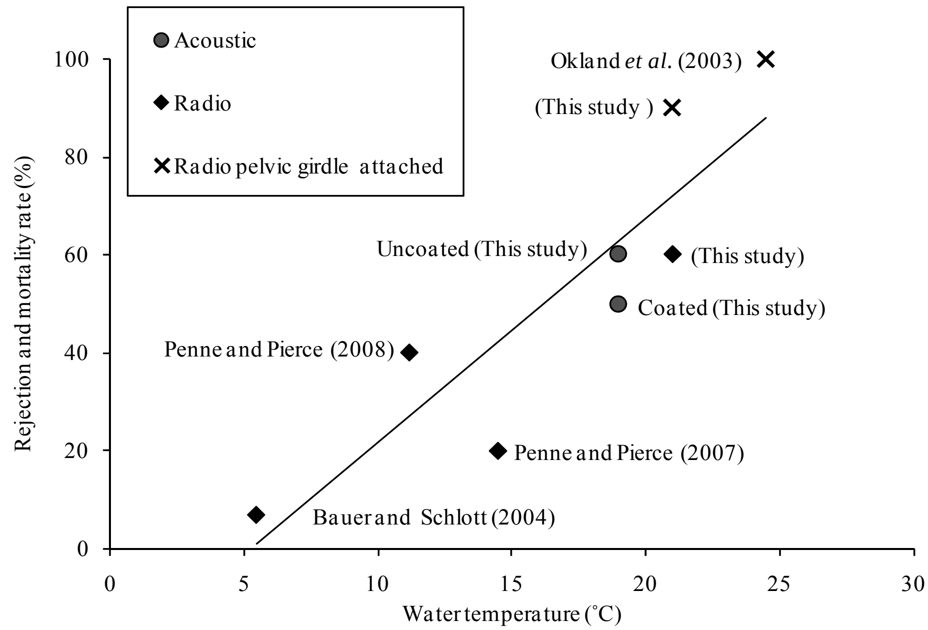

Fig. 2.4. Transmitter expulsion or mortality of *Cyprinus carpio* implanted with radio or acoustic transmitters compared to mean water temperature during first 30 days post implant. Expulsion rates were calculated from the proportion of fish that expelled transmitters within the first 30 days of the experiment.

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Chapter 3: The use of slow-release antibiotics to reduce transmitter rejection in common carp (*Cyprinus carpio* L.)[1]

3.1 Introduction

Transmitter rejection as a result of intraperitoneal transmitter implantation has been studied for over three decades with no major breakthroughs. Although several researchers have related transmitter size (Summerfelt and Mosier 1984; Perry *et al.* 2001; Sutton and Benson 2003) and water temperature (Knights and Lasee 1996; Bunnell and Isely 1999; Chapter 2) to rejection, a method to significantly reduce transmitter loss at elevated water temperatures has proved elusive. The use of sterile surgical procedures (Baras *et al.* 1996), transmitter coatings (Helm and Tyus 1992; Kynard and Kieffer 1997; Chapter 2) and appropriate suture material (Baras and Westerloppe 1999; Jepsen *et al.* 2008; Chapter 2) have lead to minor reductions in transmitter rejection but have not prevented bacterial infection during the healing process. We hypothesised that transmitter rejection is primarily caused by bacterial infection and may be reduced by using slow-release antibiotics to treat infections resulting from intraperitoneal implantation.

Traditional antibiotics, such as oxytetracycline and gentamicin sulphate, are commonly used in a single dose to treat bacterial infection encountered during intraperitoneal transmitter implantation (e.g., Demers *et al.* 1996; Erickson *et al.* 2002; Mitamura *et al.* 2006). This practice has not been proven to be effective (Lucas 1989; Isely *et al.* 2002; Jepsen *et al.* 2002) and is not within the scope of recommended use for either drug (Lees and Aliabadi 2002). In addition, there is growing concern that the improper use of antibiotics can lead to drug-resistant bacteria that could threaten wild and captive fauna (Bjorklund and Bylund 1991; Pathak and Gopal 2005; Ozgumus *et al.* 2007). Wounds caused by intraperitoneal

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transmitter implantation generally heal between 175 and 450 degree days depending on the water temperature (Wagner 1999; Walsh *et al.* 2000; Cooke *et al.* 2003; Bauer and Loupal 2007). A single dose of a traditional antibiotic such as oxytetracycline has a half-life of about 40-45 degree days in rainbow trout (*Oncorhynchus mykiss*) (Bjorklund and Bylund 1991; Abedini *et al.* 1998; Lees and Aliabadi 2002) and is unlikely to adequately protect fish during the healing process associated with intraperitoneal transmitter implantation. Oxytetracycline should be administered over 4-10 days to effectively treat bacterial infection (Lees and Aliabadi 2002), which is not practical for many field studies. There are injectable antibiotics that are recommended for treating bacterial infections in fish (e.g. enrofloxacian, timethoprim sulfamethoxazole, amikacin), but all require multiple treatments (Lewbart 1998). A suitable antibiotic for intraperitoneal transmitter implantation in fish would be active throughout the wound healing process and would provide broad-spectrum antimicrobial protection.

We tested the use of injectable cefovecin sodium (CONVENIA™, Pfizer, Kirckland, Quebec, Canada) on wild adult koi carp, a coloured variety of common carp (*Cyprinus carpio* L.). CONVENIA™ is broad-spectrum cephalosporin with activity against gram-positive and gram-negative aerobic and anaerobic bacteria that was designed to be used as a single dose with a much longer elimination half-life than traditional antibiotics. Although cefovecin sodium has not been tested on fish, when administered to dogs its elimination half-life was much longer than (136 h; Stegemann *et al.* 2006) that of conventional antimicrobials such as oxytetracycline (6 h; Kirkwood and Widdowson 1990; Riviere *et al.* 1997) or gentamicin sulphate (1 h; Riviere *et al.* 1997).

3.2 Materials and methods

3.2.1 Capture, transmitter implantation, and antibiotic treatment

Forty adult koi carp were captured from the Waikato River, New Zealand by boat electrofishing, as described in Hicks *et al.* (2006). Fish were transported from their capture location in aerated fish bins to a holding facility where surgeries were immediately performed. Study fish weighed 1.52-2.93 kg with an average weight of 2.10 kg (Table 3.1). The control group of 20 koi carp (4 male, 16 female) were implanted with cylindrical (69-mm long x 16-mm diameter) Vemco V16 dummy transmitters (Amirix Systems Inc., Halifax, Nova Scotia, Canada) with an average weight of 24.8 g. Beeswax was applied to dummy acoustic transmitters to ensure a benign coating (Helm and Tyus 1992) and added 3.8 mL or 39% to the volume of an uncoated Vemco V16 transmitter. Transmitters represented 0.9-1.6% of body mass in air (Table 3.1). The test group of 20 koi carp (7 male, 13 female) were implanted with identical dummy transmitters and given an intramuscular injection of cefovecin sodium at a dose of 0.01 mg kg^{-1}.

Fish were anaesthetized in a bath of AQUI-S® (AQUI-S New Zealand Ltd, Lower Hutt, New Zealand) at a concentration of 0.06 mL L^{-1}. When fish lost equilibrium they were measured for fork length, photographed, weighed and placed ventral side up on a wet, V-shaped PVC plastic operating table set in a large plastic basin. The operating table was partially submerged in an aerated water bath containing anaesthetic at half the dose used in the initial anaesthetic bath. A 3.7-L min^{-1} recirculation pump mounted in the basin continually irrigated the gills with aerated water.

To reduce the risk of infection to study fish, surgical gloves, scalpel blades and syringes were changed between surgeries. All surgical implements and dummy acoustic transmitters were chemically disinfected with F10-SC veterinary disinfectant (Chemical Essentials Pty Ltd, Doncaster East, Australia) and rinsed with saline solution as described in Chapter 2.

Three to five scales were removed 5 cm posterior to the left pelvic fin and 1 cm dorsal to the mid-ventral line. A 4-cm incision was made in the same location with a scalpel while forceps were used to apply upward pressure on the dermis to create space between the body wall and viscera. Dummy transmitters were inserted toward the anterior and pushed forward with a gloved finger to rest over the pelvic girdle. Incisions were closed with three size-1 glyconate monofilament absorbable sutures (Monomend®, Veterinary Products Laboratories, Phoenix, AZ, USA). Each fish was given an intramuscular injection of

Table 3.1 Weights (wt), lengths (FL) and sex of koi carp (*Cyprinus carpio*) implanted with dummy acoustic and radio transmitters. Trial length was 176 days.

F: female; M: male; K= (weight (g)/length^3 (cm)) x 10^5

Expelled	Transmitter retention (days)	Sex	Transmitter wt / body wt (%)	Initial wt (kg)	Final wt (kg)	Initial length (mm)	Final length (mm)	Initial *K*	Final *K*	Change in *K* (%)	Fish ID
Control (untreated)											
Yes	13	F	1.63	1.53	1.77	402	411	2.35	2.55	8.6	19
Yes	23	M	1.49	1.67	2.01	425	430	2.17	2.52	16.3	36
Yes	13	F	1.40	1.77	1.94	432	430	2.19	2.44	11.4	4
Yes	27	F	1.40	1.78	2.01	442	442	2.06	2.32	12.8	28
Yes	23	M	1.17	2.12	2.23	465	471	2.11	2.14	1.5	31
Yes	13	F	1.06	2.34	2.32	476	479	2.17	2.11	-2.9	18
Yes	19	F	1.04	2.38	2.81	490	491	2.02	2.37	17.3	37
Yes	61	F	1.02	2.44	3.41	475	490	2.28	2.90	27.4	14
No	176	F	1.48	1.67	2.09	425	438	2.18	2.48	14.0	37
No	176	F	1.47	1.69	2.15	452	456	1.82	2.27	24.4	3
No	176	M	1.43	1.74	2.24	442	455	2.01	2.38	18.2	40
No	176	F	1.33	1.87	2.27	430	450	2.35	2.50	6.2	1
No	176	F	1.33	1.87	2.31	475	500	1.75	1.85	5.7	30
No	176	M	1.19	2.09	2.56	470	475	2.01	2.39	18.6	15
No	176	F	1.16	2.14	2.59	487	489	1.85	2.22	19.7	39
No	176	F	1.12	2.22	2.64	464	470	2.22	2.54	14.4	25
No	176	F	1.12	2.22	2.84	457	456	2.32	2.99	28.7	32
No	176	F	1.06	2.34	3.06	445	449	2.66	3.38	27.2	26
No	176	M	0.97	2.55	3.08	493	498	2.13	2.49	17.0	33
No	176	F	0.85	2.93	3.31	525	520	2.02	2.35	16.3	21
Test (CONVENIA™)											
Yes	30	M	1.33	1.86	2.00	481	483	1.67	1.77	6.1	29
Yes	19	F	1.32	1.88	2.13	428	434	2.39	2.60	8.6	24
Yes	23	M	1.31	1.89	2.23	454	460	2.02	2.29	13.3	10
Yes	29	M	1.11	2.24	2.99	501	516	1.78	2.18	22.4	34
No	176	F	1.58	1.57	2.02	425	440	2.05	2.37	15.7	20
No	176	F	1.52	1.64	2.03	420	431	2.21	2.54	15.0	23
No	176	M	1.33	1.86	2.11	460	469	1.91	2.05	6.9	38
No	176	F	1.29	1.92	2.12	443	446	2.21	2.39	8.2	13
No	176	F	1.27	1.96	2.15	426	430	2.53	2.71	6.8	17
No	176	F	1.26	1.98	2.16	425	430	2.57	2.72	5.6	12
No	176	F	1.24	2.00	2.20	423	428	2.64	2.81	6.4	2
No	176	F	1.17	2.13	2.21	445	442	2.42	2.56	6.0	27
No	176	F	1.12	2.22	2.26	488	500	1.91	1.81	-5.1	5
No	176	M	1.10	2.25	2.51	459	465	2.33	2.50	7.3	9
No	176	F	1.05	2.37	2.53	455	450	2.51	2.77	10.3	8
No	176	F	1.05	2.37	2.54	470	475	2.28	2.37	3.8	7
No	176	F	0.96	2.57	2.62	457	455	2.69	2.78	3.1	35
No	176	M	0.95	2.60	2.86	492	490	2.18	2.43	11.4	16
No	176	M	0.93	2.68	2.93	478	488	2.45	2.52	2.9	22
No	176	F	0.92	2.69	3.18	516	520	1.96	2.26	15.4	11

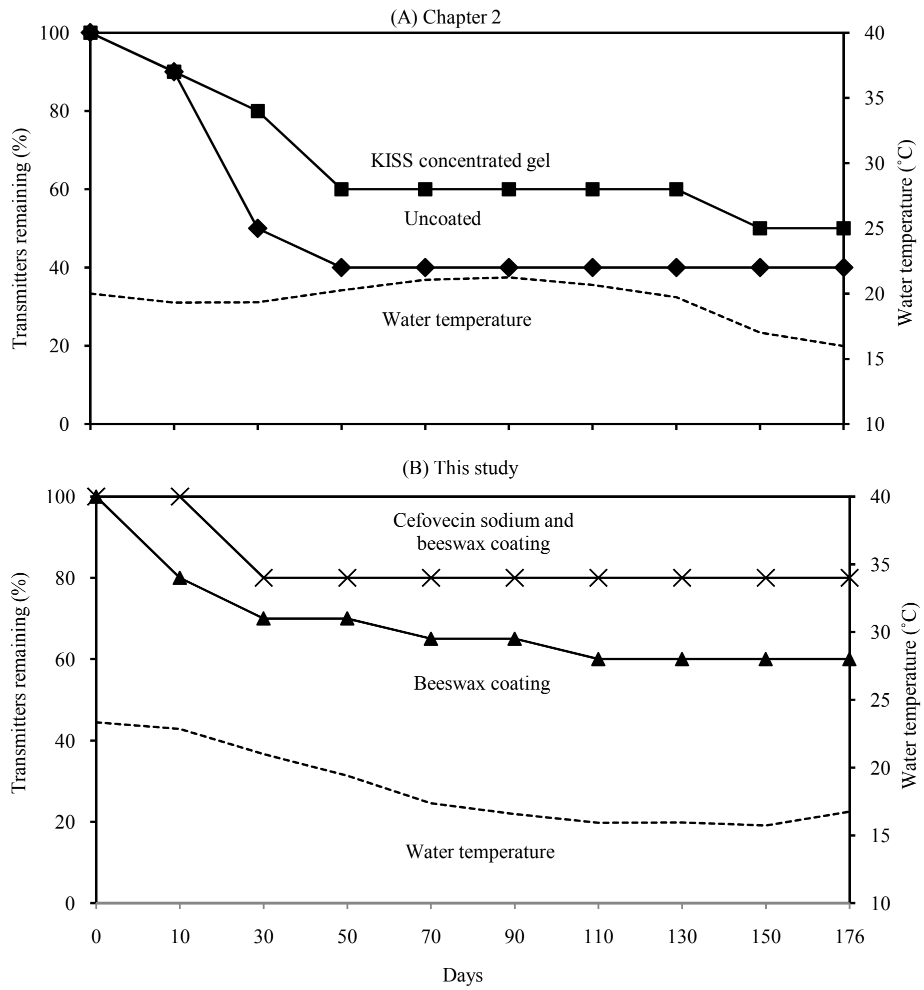

Fig. 3.1. (A) Retention of coated and uncoated dummy acoustic transmitters implanted in *Cyprinus carpio* (B) Retention of dummy transmitters coated in beeswax implanted in *Cyprinus carpio* treated with cefovecin sodium and untreated. Dotted line represents the average water temperature during each period.

DOLOREX® (Intervet Ltd, Upper Hutt, New Zealand) as a postoperative analgesic at a dose of 0.4 mg kg^{-1} to mitigate the pain caused by the procedure. Following implantation, fish were fitted with numbered dart tags (Hallprint, Victor Harbor, Australia) just below the dorsal fin as an additional means of identification. Fish were allowed to recover for 5 to 15 minutes in a 400 L aerated swimming pool until they regained equilibrium and were then transferred into an outdoor holding tank as described in Chapter 2. The holding tank had a natural photoperiod (9.5–12 h) and the temperature ranged between 14 and 24˚C with an average of 18˚C (Fig. 3.1). Water temperature during the first 30 days (the wound healing period) averaged 22˚C and ranged between 18 and 24˚C. Fish were fed a diet of commercial sinking trout pellets at 1.0-2.0% of their body weight per day. All study fish were inspected for wound healing after 90 days. The duration of the trial was based on the results of a previous trial (Chapter 2) conducted under similar conditions, where rejections ceased at 2867 degree-days (142 days). This trial was conducted for 3117 degree-days (176 days), at which time all fish were sacrificed and examined. Fork length and weight were measured as an indication of fish health at the end of the trial. Remaining sutures were counted as an indication of wound healing.

3.2.2 Data analysis

Rejection rates of treatment groups were compared using a two-tailed Fisher's exact probability test. Condition factor was calculated as K = weight/fork length $cm^3 \times 10^5$, similar to Busacker *et al.* (1990). Condition factors were compared between treatment and control groups using a one-way ANOVA. Weight and remaining sutures were compared using a Mann-Whitney *U*-test. Data days were defined as the sum of days transmitters were retained for each group and these were compared using a Mann-Whitney *U*-test. All data used in comparisons were checked for normality using a Kolmogorov-Smirnov and Lilliefors test for normality. All statistical calculations were performed using Statistica 8 (StatSoft, Inc, Tulsa, Oklahoma, USA). Tests were considered significant if $P < 0.05$.

3.3 Results

The rejection rate of untreated fish (40%, *n* = 8) was twice that of treated fish (20%, *n* = 4), although there was no significant difference between the rejection rate of the two groups (*P* = 0.30, two-tailed Fisher's exact probability test; Fig. 3.1B). Rejections occurred 13-103 days after implantation as a result of ulcers at or near the surgical wound and there was no mortality from either group (Table 3.1, Fig. 3.1B). Fish treated with cefovecin sodium retained dummy acoustic transmitters for a total of 22% longer (2917 data days) than untreated fish (2384 data days; *P* = 0.24, Mann-Whitney *U*-test).

Fish size influenced rejection, fish that lost dummy transmitters were smaller (1990 g) on average than fish that retained dummy transmitters (2146 g; *P* = 0.03, Mann-Whitney *U*-test; Table 3.1). Of the three original sutures, fish treated with cefovecin sodium retained an average of 0.5 sutures compared to 0.7 sutures for control fish after 176 days (*P* = 0.43, Mann-Whitney *U*-test). Fish that did not expel transmitters, regardless of test group, retained an average of 0.4 sutures and fish that lost transmitters retained 0.9 sutures on average (*P* = 0.25, Mann-Whitney *U*-test).

The percent increase in condition factor of treated fish (8.5%, *n* = 20) was significantly lower than untreated fish (15.1%, *n* = 20; *P* = 0.006, one-way ANOVA). However, the condition factors for control and test groups were similar before and after the trial (*P* > 0.05, one-way ANOVA), as well as fish that retained and lost transmitters (*P* > 0.05, one-way ANOVA).

Overall, 42% (*n* = 5) of males and 25% (*n* = 7) of females rejected transmitters, but there was no significant difference between the rejection rate of male and female fish (*P* > 0.05, two-tailed Fisher's exact probability test). Treated males (43%, *n* = 3), untreated males (40%, *n* = 2), and untreated females (40%, *n* = 7) rejected a higher proportion of transmitters than treated females (8%, *n* = 1). However, there was no significant difference between any of the groups (*P* > 0.05, two-tailed Fisher's exact probability test).

3.4 Discussion

The rejection rate of fish treated with cefovecin sodium, and held at a mean temperature of 22°C for the first 30 days, was half that of untreated fish and lower than rejection rates of similar published studies at similar temperatures (Okland *et al.* 2003; Bauer and Schlott 2004; Penne *et al.* 2007; Penne and Pierce 2008, Chapter 2; Fig. 3.2). Fish treated with cefovecin sodium had a lower rejection rate compared to other *C. carpio* trials conducted at comparable temperatures and was similar to the rejection rate reported by Penne *et al.* (2007) in a trial conducted at 14°C water temperature (Fig. 3.2). Treated fish also retained transmitters longer than untreated fish by a cumulative margin of 22%, indicating the potential for substantial savings by reducing the number transmitters lost. Although the findings of this experiment were not conclusive, we believe they are encouraging and justify further investigation.

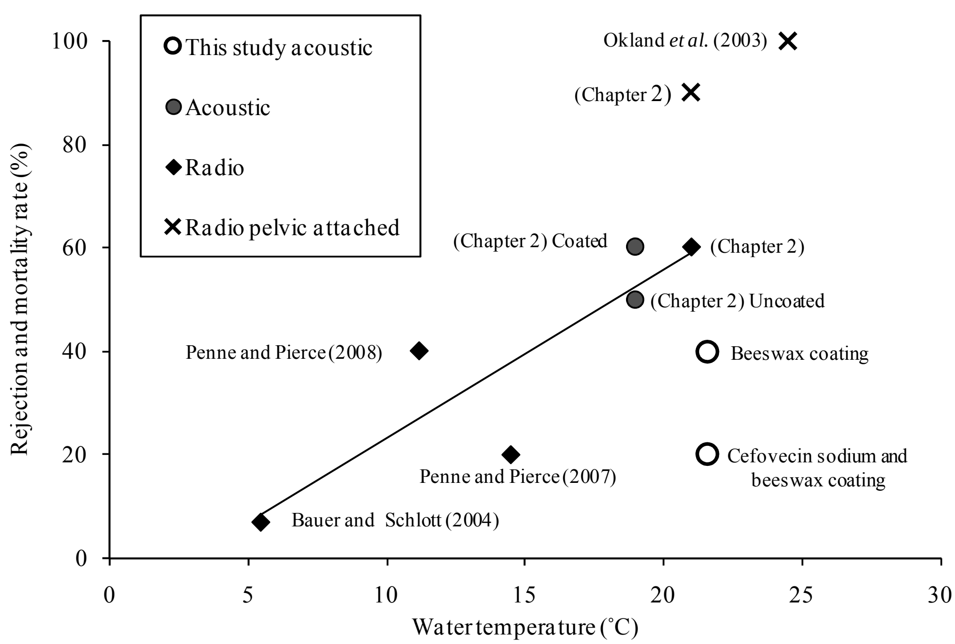

Fig. 3.2. Transmitter expulsion or mortality of *Cyprinus carpio* implanted with transmitters within 30 days of implantation compared to mean water temperature during the same period. Transmitters include acoustic transmitters, radio transmitters with trailing antennas and radio transmitters with trailing antennas attached to the pelvic girdle. Expulsion rates were calculated from the proportion of fish that expelled transmitters within the first 30 days of the experiment. Regression line ($r^2 = 0.77$, $y = 3.26x - 9.49$, $n = 6$) does not include this study (**O**) or radio transmitters attached to the pelvic girdle (**X**).

The primary mechanism for transmitter rejection in fish treated with cefovecin sodium appeared to be bacterial infection of the wound. Relative transmitter size influenced loss, as smaller fish were more likely to expel transmitters. Several authors (Chisholm and Huvert 1985; Tyus 1988; Welch *et al.* 2007) have shown a relationship between transmitter rejection and the percent body mass of transmitters, we believe that this relationship may be linked to relative incision size rather than just the weight or volume of the transmitter compared to fish size. A larger incision to body size ratio is likely to increase healing time and reduce retention. In this trial, we used the same dummy transmitters as a previous trial (Chapter 2) and found that despite being coated with beeswax (increasing volume by 39%), there was a similar retention rate for most of the trial (Fig. 3.2). The incision length for the two trials was similar because we made the smallest possible incision and forced transmitters through an undersized hole during this trial, resulting in a similar incision size to the original trial (Chapter 2). Most transmitters are cylindrical with relatively flat ends that require a large incision to diameter ratio. Altering the transmitter shape to a oval cylinder with a tapered end would reduce the incision length and minimise fish suffering potentially increasing transmitter retention. We acknowledge that this comparison could potentially be confounded by slightly improved retention as a result of the beeswax coating (Helm and Tyus 1992) and requires further investigation.

Suture material was retained longer than necessary for wound closure. Although the suture material used was absorbable, 15 of 40 test fish retained at least one suture after 176 days. All wounds were closed when fish were inspected at 90 days, but tissue surrounding any remaining sutures was inflamed. Ideally, sutures would be absorbed soon after wound healing is complete. Absorbable sutures that are expelled promote good wound healing (Jepsen *et al.* 2008; Chapter 2) but sutures that remain after wound healing cause unnecessary irritation. We recommend testing absorbable sutures to ensure they physically close the surgical wound long enough to allow healing and are absorbed soon after. Remaining sutures, however, were a poor indication of wound healing. We found very little difference between test and control groups. Although fish that lost transmitters retained more sutures, on average, than those that did not, these results were inconclusive.

Untested use of antibiotics, to improve transmitter retention has been a feature of past telemetry studies. More than a dozen authors have reported using traditional antibiotics during field intraperitoneal transmitter implantation without testing antibiotic efficacy (e.g., Demers *et al.* 1996; Erickson *et al.* 2002; Mitamura *et al.* 2006). The use of traditional short-term antibiotics (e.g., oxytetracycline or gentamicin) has not been proven effective for reducing transmitter rejection (Isely *et al.* 2002; Mulcahy 2003). This practice is therefore ethically questionable because haphazard use of antimicrobial drugs without scientific foundation is not acceptable, undermines the credibility of fisheries science, and could have potentially harmful effects on native flora and fauna.

To our knowledge, the only previous laboratory study on the use of antibiotics to prevent transmitter rejection was conducted on hybrid striped bass *Morone saxatilis X M. chrysops* using gentamicin sulphate. This study found an increase in time to first mortality but less than 5% difference in survival between treated and untreated fish (Isely *et al.* 2002). Considering the relatively short half-life of gentamicin sulphate, it is likely that the positive effects of the antibiotic dissipated prior to closure of surgical wounds through healing. We found no effect on growth associated with transmitter implantation, similar to other studies on transmitter retention and survival (Tyus 1988; Lucas 1989; Isely *et al.* 2002).

Based on our study, we recommend that the use of any antibiotic be tested for effectiveness prior to use. We also recognise that the use of antibiotics should be carefully considered in fish released to the wild, because such substances are legally regulated for most food fish, and should only be used when necessary. However, our findings suggest that slow-release antibiotics have the potential to improve transmitter retention and reduce animal suffering. The results of this study are not conclusive but are encouraging and justifying further investigation of slow-release antibiotics to prevent the epulsion of transmitters.

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Chapter 4: Movements of radio and acoustic tagged adult common carp (*Cyprinus carpio* L.) in the Waikato River, New Zealand[1]

4.1 Introduction

Common carp (*Cyprinus carpio* L.) are amongst the most notorious invasive fish species in the world and have been implicated in the degradation of aquatic habitats from temperate to tropical climates (Lougheed et al. 1998; Zambrano et al. 1999; Koehn 2004). The feeding activity of common carp disrupts and softens sediments, which are then easily resuspended by wind waves (Scheffer 2004). Resuspended sediment and carp excretion transfer nutrients into the water column and can cause a shift from a macrophyte to an algal-dominated equilibrium, if carp biomass is high (Lougheed et al. 1998; Zambrano and Hinojosa 1999). Low light penetration caused by increased turbidity can greatly reduce or eliminate macrophytes (Van Dijk and Van Donk 1991; Parkos et al. 2003). To reduce the damage caused by common carp, it is believed that at least 75% of carp biomass must be removed to restore shallow lakes to a macrophyte-dominated state (Meijer et al. 1999; Zambrano et al. 2001). Biomanipulation of shallow lakes by fish removal has been shown to be successful providing fish biomass is maintained at a low level (Meijer et al. 1999; Schrage and Downing 2004). Government agencies in Australia (Stuart and Jones 2002; Diggle et al. 2004; Driver et al. 2005), North America (Shields 1958; Tyus and Saunders 2000; Zambrano 2001), and Europe (Meijer et al. 1999) have attempted common carp control programs to improve water quality and restore biodiversity with varying degrees of success, but to date no agency has completely eliminated a large breeding population.

Koi carp, a highly colored variant of the common carp, are an invasive alien species in New Zealand. Koi carp were first documented in the lower Waikato River in 1983 (Pullan 1984) and now dominate the fish biomass in the lower

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reaches of the river (Hicks et al. 2006). The introduction and proliferation of koi carp in the Waikato River has coincided with a dramatic decline in water quality in many of the connecting lakes and wetlands (Hayes et al. 1992; Chapman 1996). During the same time period, land use in the surrounding catchment has intensified resulting in increased nutrient loads (Chapman 1996) making it difficult to attribute degraded water quality to a single factor.

In New Zealand, koi carp were declared a "noxious fish" (Freshwater Fisheries Regulations 1983) and an "unwanted organism" in 1993 (Biosecurity Act 1993), but little action was taken to investigate management strategies for the Waikato River until 2001 when government agencies began investigating the feasibility of koi carp removal to improve water quality and protect biodiversity (Chadderton 2001).

Recent studies on koi carp in the Waikato River indicate that this species exhibits little movement (Osborne 2006; Osborne et al. 2009) and high fecundity (Tempero 2004; Tempero et al. 2006). This work suggested that successful control efforts would require the removal of a large proportion of the population to surpass recruitment and the low mobility of koi carp would make it difficult to target large numbers of fish. The objective of this study was to investigate the movements and migration timing of koi carp in the lower Waikato River basin over 18 months to aid in evaluating the feasibility of a successful removal program and validate existing movement data. Our secondary goal was to identify high-use areas where point-source control of koi carp could occur to achieve a management goal of improving water quality and biodiversity in connecting riverine lakes and wetlands.

4.2 Materials and methods

4.2.1 Study area

The Waikato River (175˚09'E 37˚29'S) koi carp population is currently restricted to the lower 152 km of the river, below Karapiro Hydroelectric Dam (Figure 4.1). The Waikato River drains 13% of the North Island, is 450 km in length, has a mean flow of 344 m^3/s, and has eight hydropower dams (Chapman 1996). The lower Waikato River (below Karapiro Dam) has an extensive network

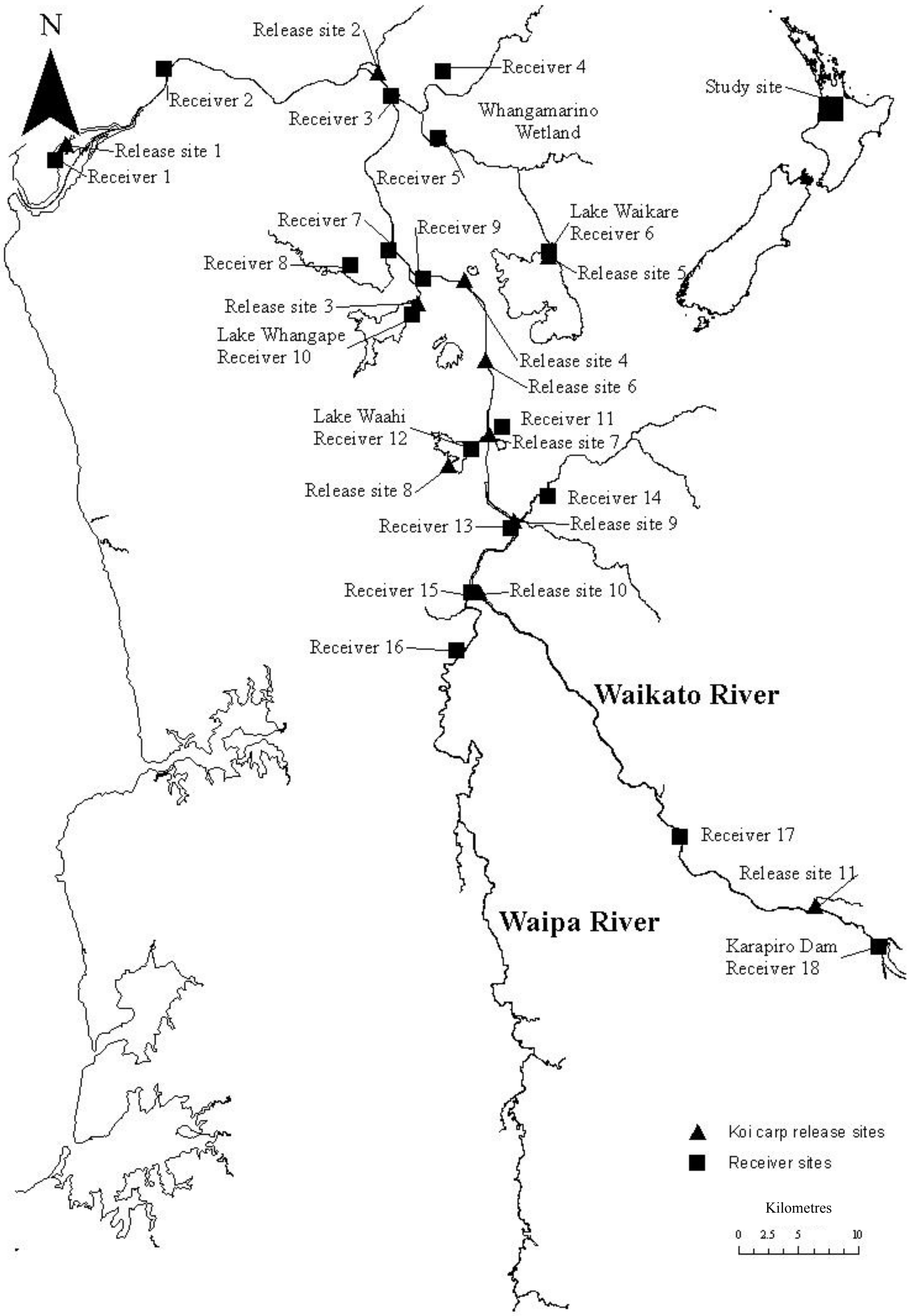

Figure 4.1—Fixed site receiving stations and release locations of koi carp implanted with radio and acoustic transmitters. See Table 4.1 for site names and coordinates.

of shallow lakes and wetlands including the Whangamarino Wetland, a Ramsar designated wetland of international importance (7,100 ha). There are 14 riverine lakes connected to the lower Waikato River, the three largest of which (Lake Whangape, Lake Waikare, Lake Waahi) have transitioned from eutrophic to hypertrophic since the introduction of carp and range between 522 and 3,442 ha. The cause of the rapid increase in lake productivity is unknown and could be partly related to land use changes in the catchment. The land use in the lower Waikato River basin is predominantly dairy farming with pockets of urban development (Chapman 1996). The lower Waikato River has a low gradient (mean 0.14 m/km) and is subject to heavy nutrient and sediment loads (Environment Waikato 2008). The estimated potential koi carp habitat in the lower Waikato River basin includes 2,750 km of streams and rivers, 5,410 ha of riverine lakes, and 12,731 ha of wetlands.

4.2.2 Radio and acoustic Transmitters

To maximize both spatial and temporal monitoring of study fish we utilized 41 radio and 66 acoustic transmitters. Twenty-one radio transmitters were implanted in adult koi carp in 2007. Of these, 10 radio transmitters were implanted in adult koi carp at Lake Whangape (release site 3) and 11 at the Waikato River at release site 7 (Table 4.1 and 4.2, Figure 4.1). All radio transmitters implanted in 2007 were designed to operate for 14 months (48.4-mm X 16.7-mm diameter, 10.2-g, 45-cm external antenna; H.A.B.I.T. Research Ltd., Victoria, BC, Canada). We anticipated up to 60% loss of implanted transmitters based on transmitter retention trials conducted in preparation for this study (Chapter 2). To replace expelled and malfunctioning transmitters we implanted an additional 20 radio transmitters (Sirtrack Limited, Havelock North, New Zealand) in August 2008 at sites 5 and 9 (Table 4.1 and 4.2, Figure 4.1). To increase the size range of fish monitored, 10 radio transmitters were 2.2 g (21-mm X 11-mm diameter, 40-cm external antenna, 2-month battery life) and 10 were 8.0 g (40-mm X 13-mm diameter, 40-cm external antenna, 5-month battery life).

Table 4.1.—Locations of acoustic receivers and release sites of adult koi carp implanted with transmitters. See Figure 4.1 for map locations. Latitude and longitude coordinates are in decimal degrees.

Site name	Site number	Latitude (°S)	Longitude (°E)	NZ map grid northing	NZ map grid easting
Receiver sites					
Waikato Heads	1	37.3487	174.7429	6426921.67	2664722.95
Elbow Reserve	2	37.2784	174.8439	6434528.35	2673840.49
Whangamarino River A	3	37.6650	175.1518	6391020.43	2700078.49
Maramarua River	4	37.6665	175.1523	6390848.51	2700122.56
Whangamarino River B	5	37.6658	175.1521	6390927.54	2700101.04
Lake Waikare	6	37.6688	175.1536	6390595.01	2700227.57
Opuatia Stream A	7	37.4090	175.0594	6419420.54	2692582.67
Opuatia Stream B	8	37.4133	175.0562	6419147.21	2692306.24
Whangape Stream	9	37.4145	175.0703	6418985.62	2693548.62
Lake Whangape	10	37.6651	175.1518	6391008.03	2700083.54
Waikato River (Huntly)	11	37.5478	175.1573	6404001.62	2700885.33
Lake Waahi	12	37.5555	175.1407	6403191.09	2699398.06
Mangawara Stream A	13	37.6091	175.1847	6396945.01	2703113.72
Mangawara Stream B	14	37.6102	175.1883	6396817.29	2703425.92
Waipa River A	15	37.6629	175.1446	6391070.45	2699427.28
Waipa River B	16	37.6696	175.1401	6390334.55	2699009.36
Narrows bridge	17	37.8440	175.3479	6370514.31	2716819.71
Karapiro Dam	18	37.8991	175.4762	6364294.25	2727960.74
Release sites					
Waikato River (Aka Aka)	1	37.3254	174.7528	6429283.69	2665633.20
Waikato River (Mercer)	2	37.2762	175.0448	6434183.76	2691629.13
Lake Whangape	3	37.4484	175.0873	6414982.60	2694943.12
Waikato River (Rangariri)	4	37.4298	175.1304	6416957.88	2698805.91
Lake Waikare	5	37.4109	175.2088	6418881.21	2705794.57
Waikato River (Ohinewai)	6	37.4904	175.1527	6410185.65	2700610.00
Waikato River (Huntly)	7	37.5461	175.1575	6404001.62	2700885.33
Lake Waahi	8	37.5644	175.0736	6402141.73	2693422.27
Mangawara Stream	9	37.6096	175.1829	6396894.75	2702953.63
Waikato River (Ngaruawahia)	10	37.6641	175.1523	6390912.08	2700103.44
Waikato River (Cambridge)	11	37.8936	175.4781	6364697.70	2728119.49

Smaller transmitters enabled us to implant smaller koi carp (>110 g) without exceeding a tag/body weight ratio of 2% (Winter 1996). Hereafter, koi carp implanted with radio transmitters will be referred to as 'radio fish'.

We implanted 66 fish with Vemco acoustic transmitters (AMIRIX Systems Inc. Halifax, Canada) during the winter of 2007 and 2008. In May 2007, 51 cylindrical Vemco V16 acoustic transmitters (68-mm long x 11-mm diameter,

Table 4.2.—Total linear range and daily travel distance for koi carp implanted with radio transmitters from 2007 to 2008. Fork lengths (FL), weights (wt), % body mass in air of transmitters, sex (F: female; M: male), and release locations (see Figure 4.1). The distance by water between the two furthest contacts (total linear range, TLR) and the sum of all movements divided by days at large (daily travel distance). -, indicates no data.

Fish ID	Tagging Date	FL (mm)	Weight (kg)	Transmitter wt / body wt (%)	Sex	Contacts	Days monitored	Release location	Daily travel distance (km)	TLR (km)
296	1-Aug-07	429	1.97	0.52	F	21	300	3	0.07	4.6
596	1-Aug-07	460	2.44	0.42	F	20	363	3	0.54	53.5
96	1-Aug-07	494	2.82	0.36	M	19	343	3	0.41	68.0
145	1-Aug-07	529	3.95	0.26	M	12	324	3	0.14	25.5
246	1-Aug-07	550	3.05	0.33	M	0	0	3	-	-
745	1-Aug-07	555	3.69	0.28	F	10	243	3	0.75	108.3
644	1-Aug-07	560	3.47	0.29	F	33	366	3	0.08	3.7
542	1-Aug-07	566	3.64	0.28	M	16	366	3	0.35	86.7
196	1-Aug-07	640	5.62	0.18	F	7	103	3	0.62	4.2
495	1-Aug-07	682	7.56	0.13	F	15	286	3	0.38	56.1
397	28-Aug-08	240	0.29	0.76	M	6	48	5	0.01	0.3
476	28-Aug-08	250	0.27	0.82	M	2	6	5	0.25	1.5
417	28-Aug-08	269	0.37	0.6	M	4	27	5	0.02	0.3
337	28-Aug-08	270	0.3	0.74	M	2	16	5	0.48	7.7
516	28-Aug-08	270	0.39	0.56	M	6	48	5	0.1	4.6
456	28-Aug-08	282	0.5	0.44	F	3	70	5	0.01	0.6
376	28-Aug-08	289	0.52	0.42	M	9	62	5	0.01	0.5
536	28-Aug-08	323	0.22	1.01	M	9	62	5	0.01	0.9
258	28-Aug-08	389	1.29	0.62	F	13	103	5	0.03	1.6
197	28-Aug-08	415	1.47	0.15	F	3	143	5	0.05	4.2
117	28-Aug-08	440	1.57	0.51	M	11	103	5	0.37	7.5
217	28-Aug-08	440	1.54	0.52	M	9	62	5	0.05	0.5
387	28-Aug-08	460	2.15	0.37	M	11	70	5	0.11	7.4
157	28-Aug-08	470	1.93	0.41	F	5	70	5	0.33	6.3
137	28-Aug-08	478	2.31	0.1	F	10	70	5	0.22	4.4
237	28-Aug-08	513	2.18	0.37	F	4	103	5	0.07	1.8
318	28-Aug-08	519	2.59	0.31	F	8	70	5	0.11	5.2
471	31-Jul-07	420	1.64	0.62	M	3	301	7	0.23	68.3
522	31-Jul-07	425	1.58	0.65	M	31	364	7	0.12	18.6
619	31-Jul-07	438	1.68	0.61	M	25	310	7	0.22	6.1
446	31-Jul-07	441	2	0.51	M	13	336	7	0.29	71.8
946	31-Jul-07	456	2.47	0.41	M	5	57	7	2.3	70.2
220	31-Jul-07	489	2.6	0.39	M	8	133	7	0.29	33.1
771	31-Jul-07	490	2.64	0.39	F	38	367	7	0.01	2.1
845	31-Jul-07	495	2.68	0.38	F	0	0	7	-	-
347	31-Jul-07	512	2.89	0.35	F	2	57	7	0.78	37.8
797	31-Jul-07	524	4.3	0.24	F	6	57	7	1.07	0.4
896	31-Jul-07	545	4.18	0.24	F	11	218	7	0.64	64.3
359	28-Aug-08	268	0.5	0.44	F	2	6	9	0.48	2.9
557	28-Aug-08	310	0.73	0.3	F	1	0	9	-	-

Table 4.3.— Total linear range and daily travel distance for koi carp implanted with acoustic transmitters from 2007 to 2008. Fork lengths (FL), weights (wt), % body mass in air of transmitters, sex (F: female; M: male), and release locations (see Figure 4.1). The distance by water between the two furthest contacts (total linear range, TLR) and the sum of all movements divided by days at large (daily travel distance). -, indicates no data.

Fish ID	Tagging Date	FL (mm)	Weight (kg)	Transmitter wt / body wt (%)	Sex	Contacts	Days monitored	Release location	Daily travel distance	TLR (km)
3989	24-May-07	440	2.72	0.89	M	3670	90	1	0.06	0.7
3995	24-May-07	448	2.21	1.10	M	0	0	1	-	-
3992	24-May-07	570	5.34	0.46	M	847	306	1	0.10	14.6
4016	24-May-07	593	5.80	0.42	F	1319	225	1	0.26	12.5
3994	24-May-07	600	5.36	0.45	M	3337	325	1	0.27	14.6
3997	24-May-07	615	6.26	0.39	F	0	0	1	-	-
3996	24-May-07	637	6.67	0.36	F	5003	481	1	1.23	83.1
3993	24-May-07	710	8.15	0.30	F	2889	511	1	0.81	58.5
4001	21-May-07	440	2.00	1.22	M	6578	499	2	0.23	38.1
4010	21-May-07	480	2.55	0.95	F	546	429	2	0.03	5.3
3998	21-May-07	482	2.50	0.97	M	9408	529	2	0.14	8.0
4007	21-May-07	484	2.35	1.03	M	1341	367	2	0.01	2.3
4015	21-May-07	491	2.65	0.92	M	29971	539	2	0.31	43.9
4014	21-May-07	500	2.62	0.93	M	29120	481	2	0.03	8.2
4004	21-May-07	515	4.54	0.54	F	167	7	2	0.78	31.8
4013	21-May-07	614	5.02	0.48	F	30630	504	2	0.16	39.6
503	1-Aug-07	450	1.93	1.26	M	261	273	3	0.56	90.7
4005	1-Aug-07	490	2.32	1.05	M	0	0	3	-	-
4000	1-Aug-07	595	5.31	0.46	F	5022	488	3	0.51	83.0
4026	22-May-07	400	1.58	1.54	F	893	185	4	0.73	43.6
4022	22-May-07	410	1.52	1.60	M	0	0	4	-	-
3988	22-May-07	448	1.96	1.24	M	0	0	4	-	-
4029	22-May-07	454	2.05	1.19	M	6	231	4	0.13	29.8
4028	22-May-07	454	2.53	0.96	F	7997	440	4	0.47	58.8
3980	22-May-07	490	2.70	0.90	F	0	0	4	-	-
3987	22-May-07	512	2.96	0.82	M	738	477	4	0.13	19.8
4027	22-May-07	544	3.54	0.69	F	0	0	4	-	-
12242	8-Jul-08	267	0.33	0.55	U	8846	11	5	0.04	0.4
12243	8-Jul-08	284	0.39	0.46	M	8136	11	5	0.04	0.4
12241	8-Jul-08	375	1.12	0.16	U	8024	11	5	0.04	0.4
12244	8-Jul-08	414	1.31	0.14	F	5766	10	5	0.04	0.4
12245	8-Jul-08	449	1.83	0.10	U	8706	11	5	0.04	0.4
12246	8-Jul-08	480	1.72	0.10	M	2114	11	5	0.04	0.4
12240	8-Jul-08	558	3.00	0.06	U	7104	11	5	0.04	0.4
12239	8-Jul-08	595	3.72	0.05	F	5401	11	5	0.04	0.4
4009	22-May-07	396	1.40	1.74	M	3606	466	6	0.38	23.4
3986	22-May-07	404	1.85	1.31	M	261	24	6	2.31	28.3
4002	22-May-07	418	1.61	1.51	F	0	0	6	-	-
3983	22-May-07	429	1.45	1.68	M	133	24	6	0.24	0.6
3981	22-May-07	438	2.07	1.17	M	9	187	6	0.24	45.1
4020	22-May-07	450	2.21	1.10	F	8430	393	6	0.18	59.5
4018	22-May-07	502	3.10	0.78	M	1550	442	6	0.07	9.0
4012	22-May-07	535	3.83	0.63	M	0	0	6	-	-
12232	8-Jul-08	415	1.55	0.12	U	1449	132	8	0.03	3.4
12233	8-Jul-08	418	1.88	0.10	M	24	39	8	0.09	3.4
12234	8-Jul-08	468	2.12	0.08	U	0	0	8	-	-
12238	8-Jul-08	560	3.74	0.05	F	0	0	8	-	-
3984	21-May-07	462	2.45	0.99	F	642	436	10	0.07	9.6
4025	21-May-07	462	1.57	1.55	M	18857	456	10	0.24	40.7
4006	21-May-07	470	2.11	1.15	M	0	0	10	-	-
4024	21-May-07	476	2.89	0.84	F	50716	540	10	0.39	72.0
4021	21-May-07	484	2.10	1.16	F	12395	244	10	0.14	9.6
4019	21-May-07	489	2.26	1.08	M	3799	357	10	1.07	39.9
4017	21-May-07	492	2.39	1.02	F	9820	520	10	0.45	19.4
4003	21-May-07	570	3.44	0.71	F	1315	468	10	0.26	31.8
3982	25-May-07	410	1.89	1.29	M	23185	437	11	0.35	63.0
501	25-May-07	413	1.91	1.27	M	2784	210	11	0.64	79.8
4011	25-May-07	414	1.66	1.47	M	475	183	11	0.62	66.6
3990	25-May-07	430	2.01	1.21	M	0	0	11	-	-
3985	25-May-07	430	1.87	1.30	M	1811	210	11	0.61	83.0
3991	25-May-07	445	2.09	1.16	M	0	0	11	-	-
3999	25-May-07	473	2.83	0.86	F	2452	466	11	1.21	98.7
202	25-May-07	540	3.49	0.70	F	0	0	11	-	-

Table 4.4.— Total linear range and daily travel distance for koi carp implanted with radio and acoustic transmitters from 2007 to 2008. Fork lengths (FL), weights (wt), % body mass in air of transmitters, sex (F: female; M: male), and release locations (see Figure 4.1). The distance by water between the two furthest contacts (total linear range, TLR) and the sum of all movements divided by days at large (daily travel distance). -, indicates no data.

Transmitter type	Fish ID	Tagging Date	FL (mm)	Weight (kg)	Transmitter wt / body wt (%)	Sex	Contacts	Days monitored	Release location	Daily travel distance (km)	TLR (km)
Radio & Acoustic	178 12237	28-Aug-08	555	4.47	0.23	F	25	97	9	0.01	0.50
Radio & Acoustic	619b 12236	28-Aug-08	530	3.37	0.36	F	73	31	9	0.02	0.50
Radio & Acoustic	096b 12235	28-Aug-08	505	2.95	0.42	M	0	0	9	-	-

24.3-g, 16-month battery life) were implanted in adult koi at seven sites on the Waikato River (Table 4.1 and 4.3, Figure 4.1). As with radio transmitters, additional acoustic transmitters were implanted to increase the size range of fish monitored and to replace rejected transmitters. Fifteen Vemco V7 acoustic transmitters (21.6-mm long X 10-mm diameter, 1.8-g, 5-month battery life) were implanted at three sites in July of 2008 (Table 4.1 and 4.3, Figure 4.1). Fish with acoustic transmitters were released at ten sites to reduce the risks of over representing any one subpopulation within the study area (Table 4.1 and 4.3, Figure 4.1). Hereafter, adult koi carp implanted with acoustic transmitters will be referred to as ‘acoustic fish’.

Three fish were double tagged with radio (two 10.2 g H.A.B.I.T. Research Ltd. transmitters and an 8.0-g Sirtrack Limited transmitter) and acoustic (1.8-g Vemco transmitters) transmitters in August of 2008 to test the reliability of the acoustic monitoring system by comparing acoustic and radio detections (Table 4.1 and 4.4, Figure 4.1). H.A.B.I.T. Research Ltd. transmitters used were expelled and recovered after the 2007 fish releases.

4.2.3 Transmitter implantation

Koi carp were captured from the Waikato River by boat electrofishing as described in Hicks et al. (2006). Fish were transported from their capture location in aerated fish bins to a nearby tagging station where surgeries were immediately performed. Study fish had a mean fork length (FL) of 469 mm (range 240-710 mm; Tables 4.2 and 4.3). There was no significant difference between the mean FL of radio and acoustic fish (*P* = 0.11, *N* = 103, one-way ANOVA), but the length of fish tagged in 2007 (mean 498 mm, *N* = 72) was greater than fish implanted in 2008 (mean 405 mm, *N* = 34; *P* < 0.001, one-way ANOVA). Smaller transmitters allowed implantation in smaller adult koi carp during 2008. Transmitters represented 0.05-1.74% of body mass in air (Tables 4.2, 4.3, and 4.4).

Fish were transferred individually from the transport containers to an anaesthetic bath of AQUI-S® (AQUI-S New Zealand Ltd, Lower Hutt, New Zealand) at a concentration of 0.06 mL/L. When fish lost equilibrium, they were measured for FL, photographed, weighed, and placed ventral side up on a wet, portable V-shaped PVC plastic operating table set in a large plastic basin. The operating table was partially submerged in an aerated water bath containing anaesthetic at half the dose used in the initial anaesthetic bath. A 3.7-L min^{-1}, 12-volt, recirculation pump mounted in the basin continually irrigated the gills with aerated water and anaesthetic. Transmitters were inserted posterior of the pelvic girdle and pushed forward with a gloved finger to rest above the pelvic girdle. All other surgical procedures were as described in Chapter 2. Following implantation, fish were fitted with individually numbered anchor tags just below the dorsal fin as an additional means of identification. Fish were allowed to recover for 5-15 minutes in a 100-L aerated transport container and released within 1 km of the capture location.

4.2.4 Radio fish monitoring

Radio fish were tracked by boat, car, or light aircraft using an Osprey HR2600 DLT digital scanning receiver (H.A.B.I.T. Research Ltd., Victoria, BC, Canada). We attempted to locate fish weekly from August 2007 to November 2008 by car or boat tracking. Monthly light aircraft flights of the study area, including all major tributaries, lakes, and wetlands, were conducted over the same period. Radio fish were monitored, during the day, for 496 days (July 2007 – December 2008) and of 43 fish implanted with transmitters 40 were located a total of 430 contacts.

Fish were located to within 5 m by boat and 500 m by light aircraft. Recovery of expelled transmitters confirmed the accuracy of boat locations to within 0.25 m^2. Fish locations determined by light aircraft were confirmed by boat when possible. Fish that did not move for two consecutive months were investigated intensively (e.g., wading or SCUBA diving) to confirm their status. All positions were recorded with a Garmin eTrex® GPS (Garmin International, Inc., Olathe, KS, USA).

4.2.5 Acoustic fish monitoring

We used 18 Vemco VR2 receivers to monitor the Waikato River from Port Waikato (river km 5) to Karapiro Dam (river km 152) including most major tributaries and riverine lakes (Table 4.1, Figure 4.1). Tributaries and lakes were monitored by mooring an acoustic receiver at the confluence of the Waikato River and a second receiver within the tributary or lake to determine directional movement. Several receivers were lost or removed from the water due to vandalism and flooding resulting in incomplete monitoring of some locations (Figure 4.2). The outflow and fish-pass at Lake Waikare were monitored, but the Te Onetea Stream between the Waikato River and Lake Waikare was not monitored, making it possible for fish to enter and exit the lake undetected. Acoustic fish were monitored for 547 days (May 2007 - November 2008) and 314,360 detections were recorded.

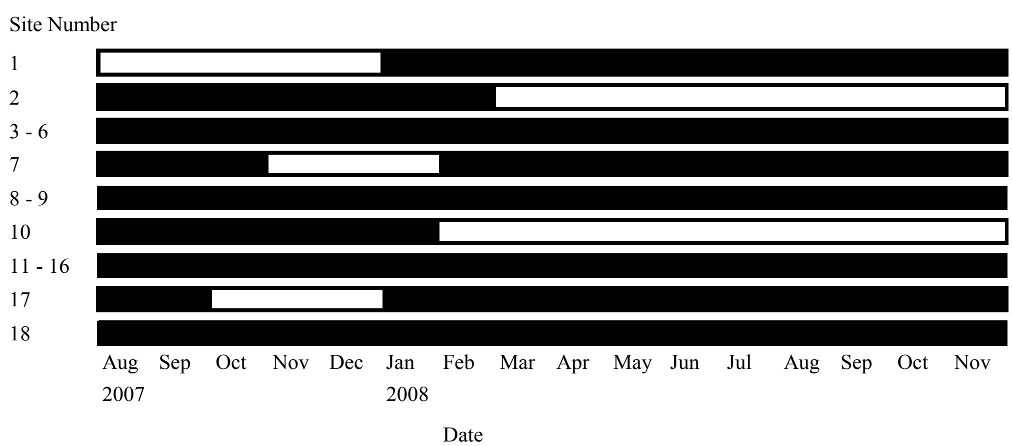

Figure 4.2.—Black bars indicate periods of successful data collection at acoustic receiver sites. White bars indicate periods of missing data. See Figure 4.1 for site locations.

4.2.6 Data analysis

Daily distance moved and total linear range (TLR) were calculated using the Network Analyst extension in ArcMap 9.2 (ESRI, Redlands, CA, USA). The Network Analyst extension was used to automate distance calculations, create movement paths, increase accuracy and ensure precision (Appendix A). Fish that did not move beyond the accuracy of the location method were considered to have not moved. Fish monitored for less than 4 days and data collected within a week of release were excluded from all analysis due to the potential behavioral effects of transmitter implantation.

Mean daily distance travelled and TLR were calculated from acoustic and radio data. Acoustic data offered superior temporal resolution, but the receiver array covered only part of the study area. Conversely, radio data had superior spatial resolution, due to the use of light aircraft, but had limited temporal resolution. As a result, the movement data presented is likely a conservative estimate of the true distance moved. Mean daily distance travelled was defined as the total km moved divided by the days a fish was monitored. Mean monthly movements were defined as the sum of all movements during the period divided by the number of individuals contacted during that month, including fish that were contacted and did not move. Data from transmitters that did not move for two consecutive months were suspected to have been expelled, and were excluded from analysis from the last known movement. TLR was defined as the shortest distance between the two furthest detected locations by water.

Maximum sustained movement speed was calculated from detections of acoustic fish that had moved in the previous 24 h and had moved more than 3 km. The distance between detection locations was divided by the elapsed time between detections to give and approximant movement speed. Correcting movement speed values for river velocity (range 0.5-1.5 m/s; unpublished data, Bevan Jenkins) accounted for very little (<10%) of acoustic fish movement speeds and suggested that fish did not move in the mid-channel in high water velocities. Koi carp were only observed travelling in the littoral margins in water velocities of less than 0.4 m/s. For this reason, corrected speed was not incorporated into maximum sustained movement speeds.

To investigate potential differences between release years, data compared were based on the time period that fish released in 2008 were monitored (i.e., 31 July to 11 November in both 2007 and 2008). To determine if a relationship between movement and fish size existed, fish were assigned a small (<466 mm) or large (≥466 mm) size classification based on the mean FL of all study fish (466 mm). TLR and mean daily distance travelled of radio and acoustic fish were compared between release sites using a Kruskal-Wallis ANOVA and were considered significant if $P \leq 0.05$.

Waikato River temperatures and discharge data were supplied by Environment Waikato (Waikato District Council, Hamilton; Rangiriri gauging station). Temperature and water level data was not available for riverine lakes.

Diel movements were classified as day or night based on an individual fish's first contact at a receiver, using sunrise and sunset times in New Zealand standard time. The distance associated with each contact was based on the distance travelled from the last receiver contacted and only individuals with contacts within 24 h were used. Day and night movements were compared using a Mann-Whitney *U*-test. The hourly count of contacts that were associated with fish movements were used to validate diel movement data.

All data used in comparisons were tested for normality using Kolmogorov-Smirnov and Lilliefors tests. Non-normal data were evaluated using nonparametric tests. All statistical calculations were performed using Statistica 8 (StatSoft, Inc, Tulsa, OK, USA). All values presented are means±SD unless otherwise noted.

4.3 Results

4.3.1 Total linear range

Total linear range (TLR) differed substantially between years. The mean TLR of radio fish during 2007 was 22.7±19.9 km ($N = 19$; Figure 4.3A) compared to 3.5±3.6 km ($N = 26$; Figure 4.3B) during the same period in 2008 (31 July to 11 November; $P < 0.001$, Mann-Whitney *U*-test). Similar to radio fish, acoustic fish had substantially larger TLRs in 2007 (20.2±22.8 km, $N = 25$) compared to the same period in 2008 (7.8±16.2 km, $N = 25$; $P = 0.045$, Mann-Whitney U-test). Twenty-one acoustic fish, tagged in the Waikato River and monitored during both years of the study, had a reduced mean TLR during 2008 (11.8±22.8 km) compared to the same time period during 2007 (39.9±22.8 km; $P = 0.16$, Mann-Whitney U-test).

(A)

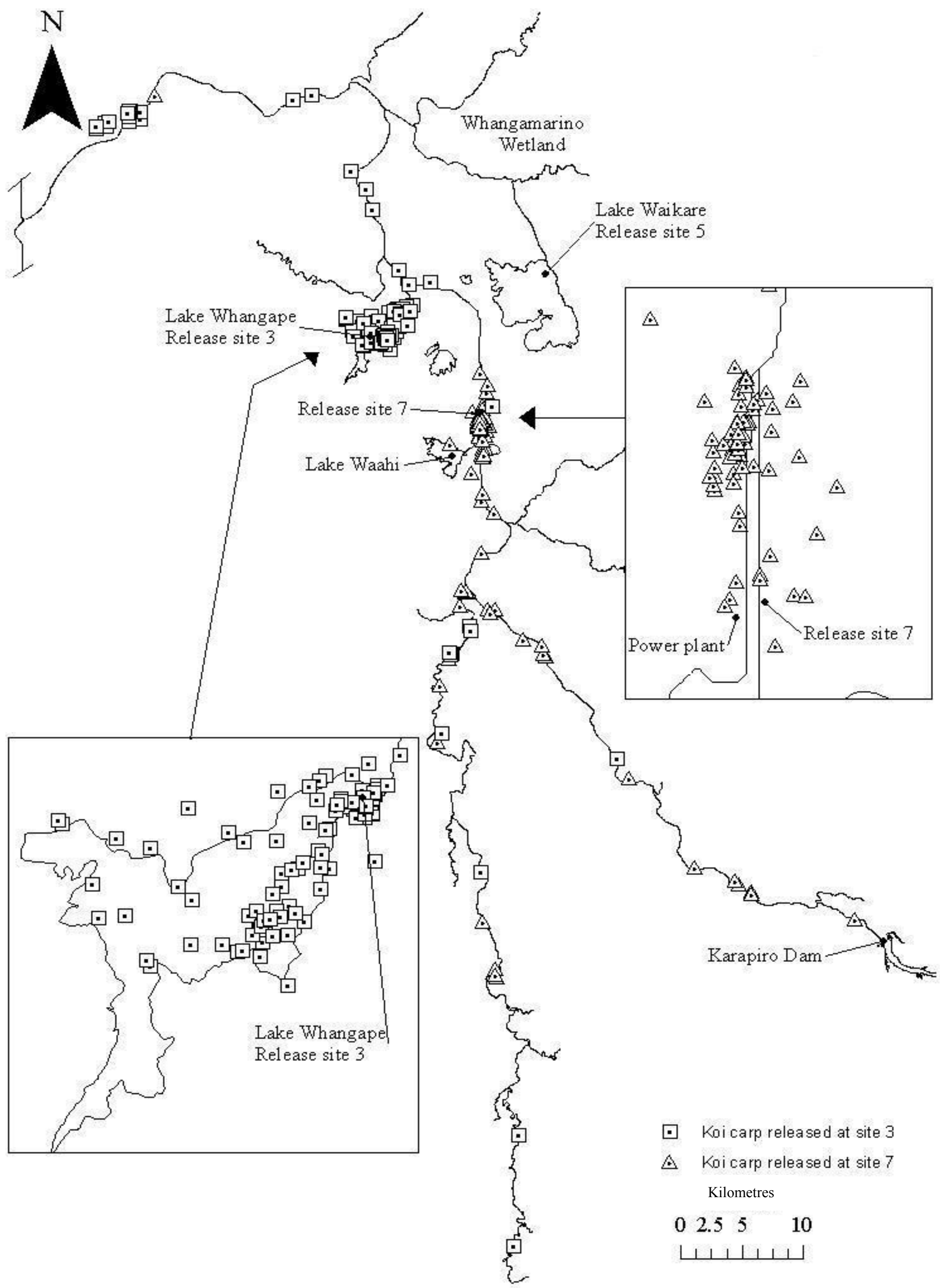

Figure 4.3.—(A) Locations of koi carp implanted with radio transmitters and released in Lake Whangape (N = 10) and Waikato River (N = 11) in 2007.

(B)

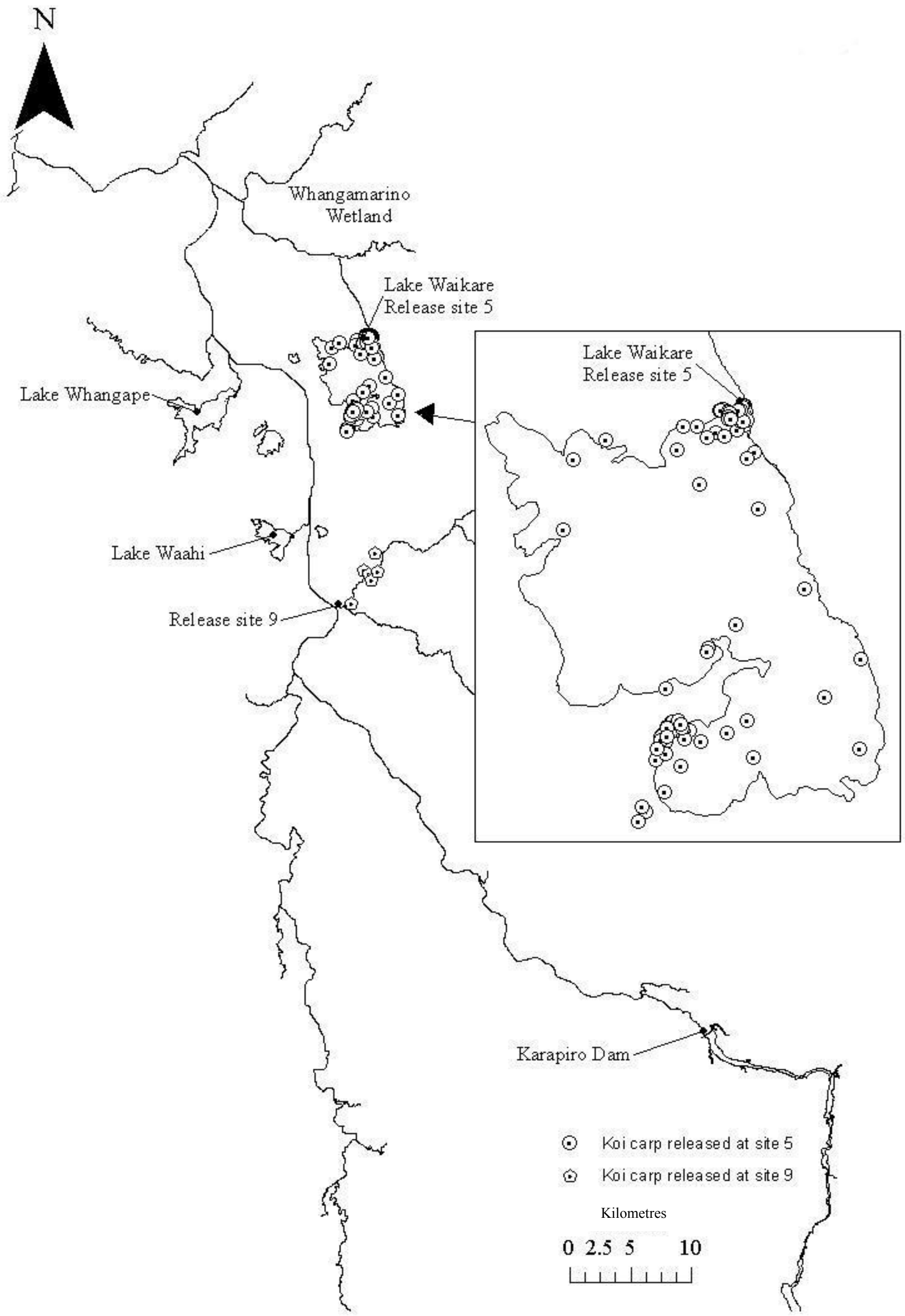

Figure 4.3.—(B) Locations of koi carp implanted with radio transmitters and released in Lake Waikare ($N = 17$) and Mangawara Stream ($N = 5$) in 2008.

The mean FL of radio and acoustic fish used in the 2008 TLR calculation (471±84 mm, N = 39) was smaller than that of fish monitored during the same period in 2007 however the difference was not significant (508±106 mm, N = 29, P = 0.11, one-way ANOVA). The mean water temperature from 31 July to 11 November for both 2007 and 2008 was 13.4˚C, but the flow was much lower in 2007 (413±120 m^3/s) than in 2008 during this period (619 ±222 m^3/s, P < 0.001, Mann-Whitney U-test).

The average TLR for radio fish 21.4±29.7 km (N = 40) was similar to acoustic fish 29.6±29.8 km (N = 50; P = 0.12, Mann-Whitney U-test; Tables 4.2 and 4.3). The mean TLR of male radio and acoustic fish (28.0±29.1 km, N = 44) was similar to the mean female TLR (28.4±32.1 km, N = 38; P = 0.85, Mann-Whitney U-test; Table 4.2 and 4.3). There was no significant difference between the TLR of small (<466 mm) and large (>466 mm) radio and acoustic fish (P = 0.24, Mann-Whitney U-test). TLR varied between individuals, with 11% of radio and acoustic fish occupying a TLR of less than 5 km, 26% occupying a TLR of less than 10 km and 74% occupying a TLR of greater than 10 km (N = 38, individuals monitored for >250 days).

Days monitored affected TLR values of radio and acoustic fish but did not affect mean daily movement values (Figure 4.4). TLR peaked between 250 and 300 days and the mean TLR of fish monitored more than 250 days (39.4±29.6 km, N = 38) was significantly higher than fish monitored less than 250 days (16.0±26.2 km, N = 52; P < 0.01, Mann-Whitney U-test). However, the mean daily movement of fish monitored more than 250 days (0.32±0.31 km, N = 38) was similar to fish monitored for less than 250 days (0.33±0.50 km, N = 49; P = 0.15, Mann-Whitney U-test).

4.3.2 Mean daily distance travelled

Similar to TLR, the mean daily distance travelled of study fish was significantly higher in 2007 compared to 2008. The mean daily distance travelled of radio and acoustic fish monitored from 31 July to 11 November 2008 (0.63±0.86 km, N = 32) was significantly less than fish monitored over the same period in 2007 (0.89±0.78 km, N = 36; P = 0.01, Mann-Whitney U-test). Radio and acoustic fish had similar daily distance travelled values (radio, 0.33±0.42 km, N = 40; acoustic, 0.35±0.42 km, N = 50; P = 0.58, Mann-Whitney U-test). The mean daily distance travelled values of male radio and acoustic fish (0.33±0.49 km, N = 44) were similar to female fish (0.37±0.35 km, N = 38; P = 0.40, Mann-Whitney U-test). The mean daily distance travelled of small radio and acoustic fish (0.31±0.48 km/day, N = 45) was similar to large fish (0.35±0.35 km/day, N = 42; P = 0.27, Mann-Whitney U-test). The overall mean daily distance travelled of radio and acoustic fish was 0.33±0.42 km (N = 87).

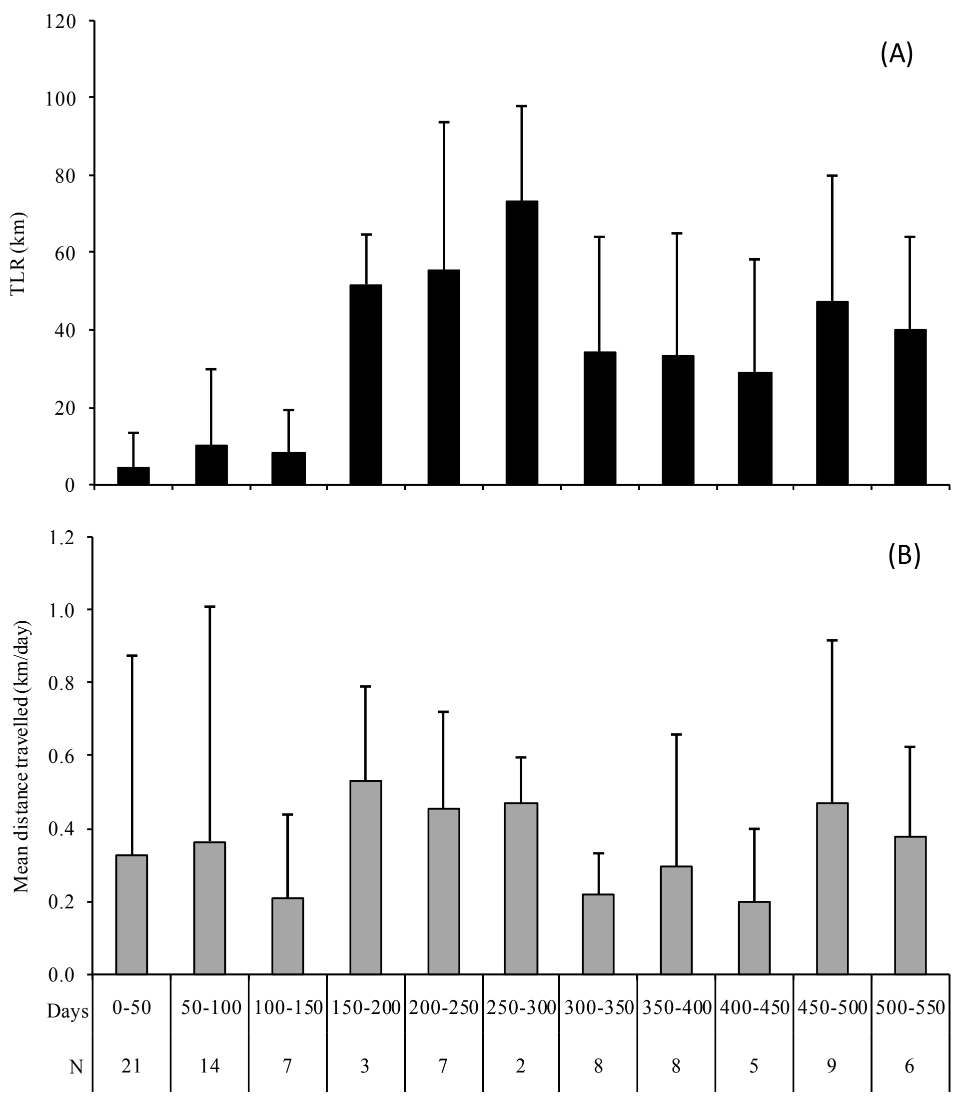

Figure 4.4.—Days monitored and individuals with calculated total linear range (TLR) and mean daily distance travelled of koi carp implanted with radio and acoustic transmitters. See Table 4.2 and 4.3 for release dates. Error bars represent one standard deviation.

4.3.3 Movement speed

Maximum sustained movement speeds of actively moving acoustic fish were calculated for all individuals that moved at least 3 km in a 24-hour period (*N* = 16 individuals). Movement speeds ranged from 0.15 to 3.66 km/h (1.22 ±0.94 km/h, *N* = 268 movements). Movement speed declined rapidly as the length of time between detections increased (Figure 4.5). Movement speeds calculated using detections greater than 10 h apart (0.213 ±0.38 km/h, *N* = 237 movements) were significantly slower than speeds calculated using detection less than 10 hours apart (1.99 ±1.57km/h, *N* = 31 movements; *P* < .001, Mann-Whitney *U*-test).

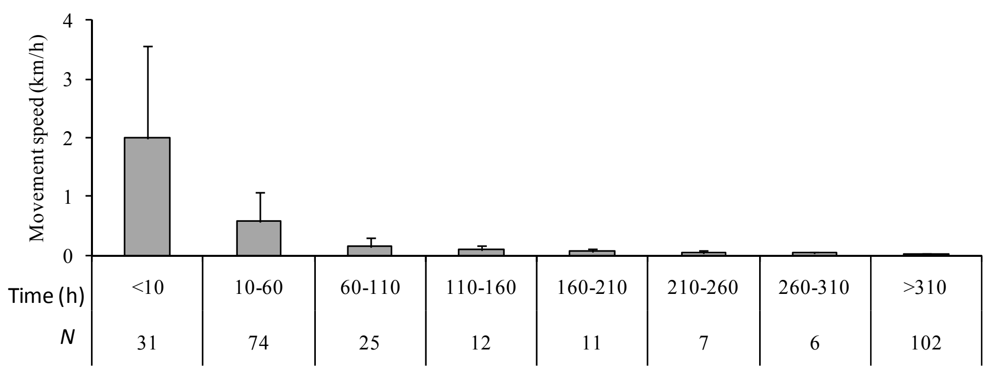

Figure 4.5.—Elapsed time between detections with calculated movement speed of koi carp implanted with acoustic transmitters. Error bars represent one standard deviation.

4.3.4 Movement by release site

Both TLR and mean daily distance travelled were variable between release sites (Figure 4.6, Appendix B). However only radio and acoustic fish released at site 5 (Lake Waikare, *N* = 25) had significantly different TLR from other sites (release site 3, *N* = 11; release site 7, *N* = 10; release site 10, *N* = 7; release site 11, *N* = 5; *P* < 0.05, Kruskal-Wallis ANOVA; Figure 4.6A). Similarly, radio and acoustic fish released at Lake Waikare were the only study fish to have significantly different mean daily distance travelled values compared to other release sites (release site 3, *N* = 11; release site 11, *N* = 5; *P* < 0.05, Kruskal-Wallis ANOVA; Figure 4.6B).

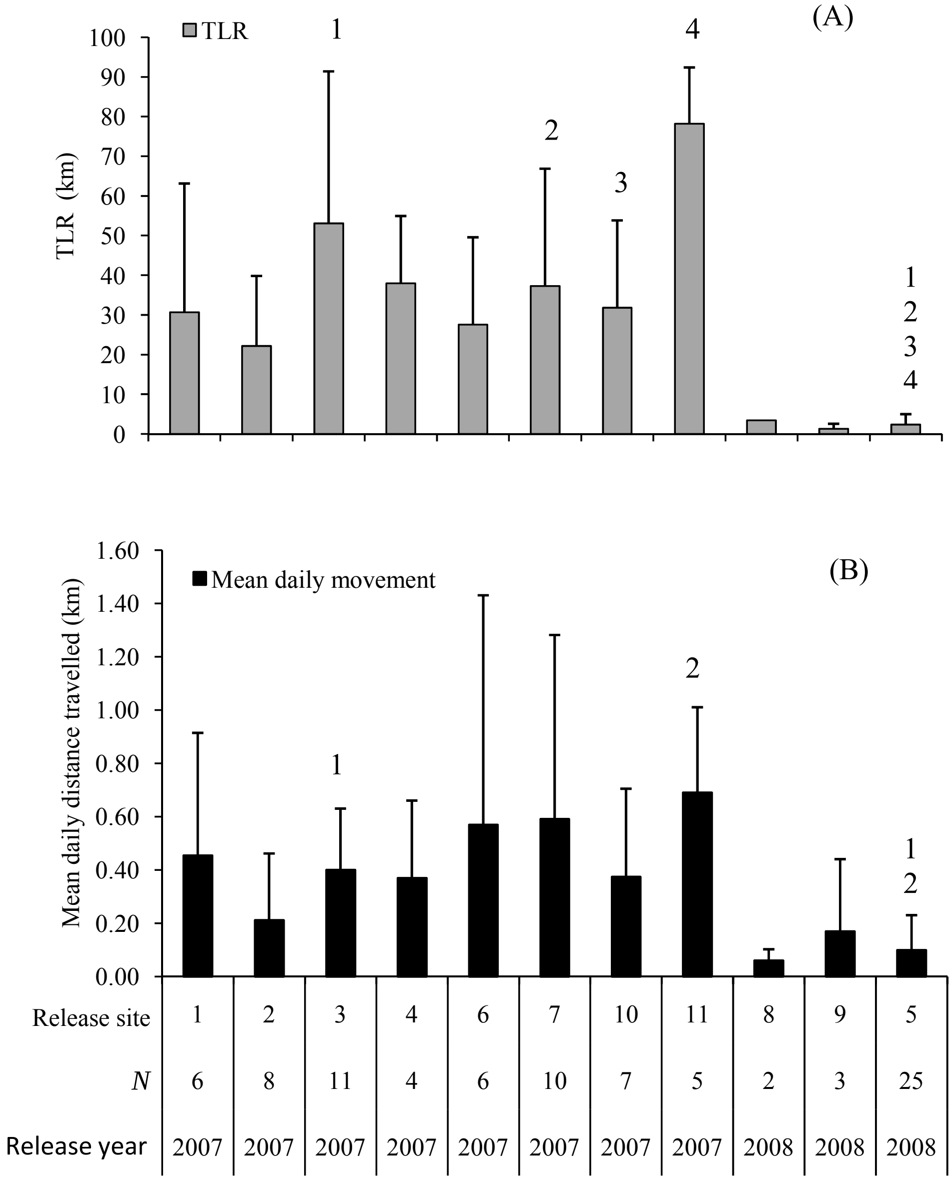

Figure 4.6.—(A) Total linear range (TLR) and (B) mean daily distance travelled of adult koi carp implanted with radio and acoustic transmitters by release site. Labels indicate year of release, individuals monitored (*N*), and release site (see Figure 4.1). Error bars with like numbers are significantly different ($P < 0.05$, Kruskal-Wallis ANOVA). Error bars represent one standard deviation.

4.3.5 Peak movements Acoustic tagged fish were active throughout the year with peak activity occurring in October (spawning season of both years) and in April of 2008 (Figure 4.7). Although acoustic fish had significantly lower TLR and daily distance travelled during 2008 there was a marked increase in activity in October of 2008. All of the fish that moved more than 10 km during October 2008 were released in the Waikato River during 2007, indicating a potential behavioral difference between lake and river fish. Similarly, all study fish that moved during September of 2007 were tagged and released in the Waikato River. Adult koi carp released in Lake Whangape did move during August and November of the 2007 spawning season, representing 5% and 20% of the movement during those months, although they represented approximately 50% of radio fish at liberty. Peak movements for fish released in riverine lakes were recorded in December 2007 when acoustic and radio fish moved out of Lake Whangape during a period of receding water and migrated to the lower (receiver site 2, Figure 4.1) and upper Waikato River (receiver site 18, Figure 4.1).

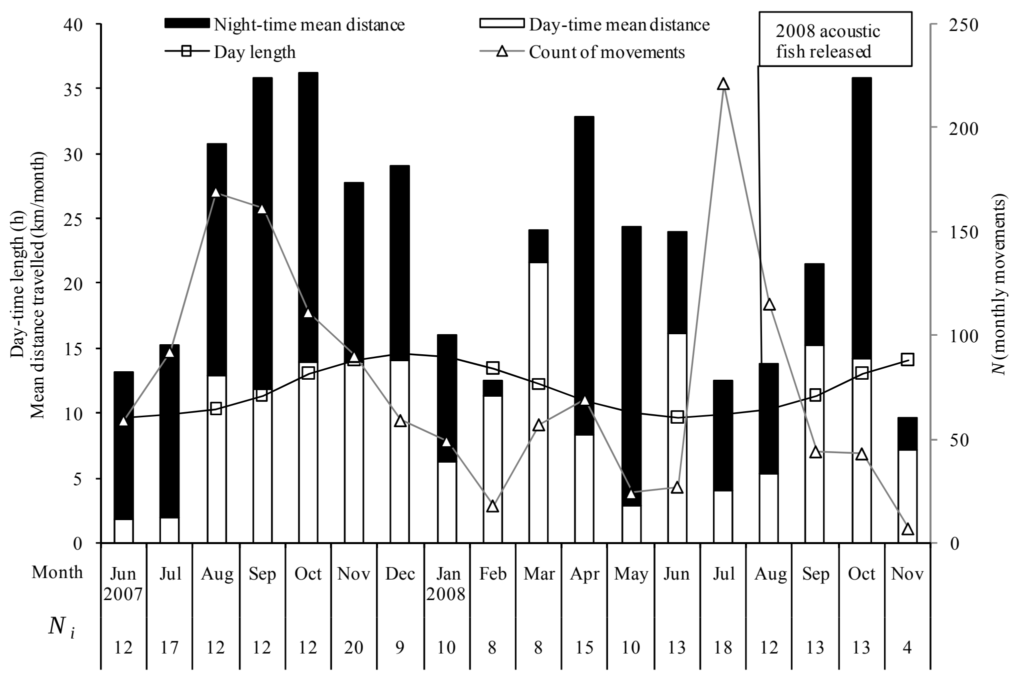

Figure 4.7.—Diel mean distance travelled and movements per month of radio and acoustic tagged koi carp with mean day length. Labels indicate month and individuals monitored (N_i).

4.3.6 Diel and hourly movements

Acoustic fish were active throughout the day (Figure 4.7) and there was no significant difference between mean distance travelled during the day (2.2±7.6 km, $N = 970$) or night (2.4±7.3 km, $N = 1071$; $P = 0.24$, Mann-Whitney U-test). Movement based on a 24-h clock was variable, with reduced movement around midday (Figure 4.8).

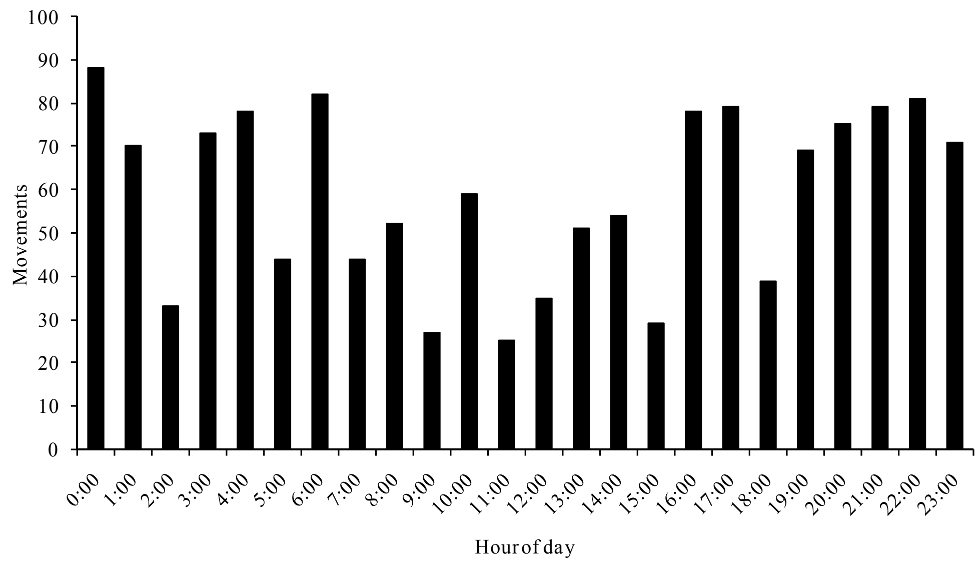

Figure 4.8.—Hour of the day and movements of acoustic tagged koi carp, from June 2007 to November 2008, that were recorded during each hour.

4.3.7 Movement between habitats

Seventy-four percent of acoustic fish monitored for more than 250 days (N = 23) moved between riverine lakes or wetlands and the Waikato River. Movement of adult koi carp between riverine lakes or wetlands and the Waikato River only occurred during 2007 (Appendix B). Overall, 56 fish implanted with transmitters (acoustic or radio) were located after release in 2007 and 55% were detected moving from the Waikato River to a riverine lake or wetland. Of the 35 acoustic fish released in the Waikato River (release sites 1, 2, 4, 6, 9, 10, and 11; Figure 4.1) and detected at any site during 2007, 60% ($N = 21$) migrated to a riverine lake or wetland. These detections included; nine fish contacted in the Whangamarino Wetland, six at Lake Whangape, four at Lake Waahi and three at Lake Waikare. Two fish visited multiple lakes or wetlands during the study. Two of three acoustic fish released in Lake Whangape (release site 3) were detected after release and both were contacted in the Waikato River. Only one of ten radio fish released in the Waikato River (release site 7) in 2007 and located after release was found in a riverine lake. Of the nine radio fish released in Lake Whangape (release site 3) that were located after release seven were detected in the Waikato River.

It is important to note that movements reported are minimums due to incomplete monitoring of Lake Whangape and Lake Waikare. Lake Whangape accounted for 17% of movements between river and lake or wetland habitat and was only monitored for 43% of the study due to receiver loss. Koi carp were also observed moving out of Lake Waikare in a small unmonitored stream. Additionally, the temporal resolution of radio tracking data was not sufficient to detect all movements between the Waikato River and riverine lakes or wetlands.

4.4 Discussion

Study fish moved further and utilized larger ranges in 2007 than in 2008. The reduction in mean daily distance moved and TLR may have been related to higher flows in 2008. Similar to the lateral movement described by other authors (Brown et al. 2001; Jones and Stuart 2007; Jones and Stuart 2009) high water during the 2008 spawning season opened access to flooded margins that were not available during 2007 allowing fish to forage and spawn in a reduced TLR. The increased foraging area available during high flow conditions could improve fitness by increasing feeding opportunities for koi carp. Tempero (2004) found a significant correlation between somatic condition and habitat availability in the Whangamarino River where high water levels drastically increased habitat availability in adjacent wetlands, but no such correlation was observed at Lake Waikare where habitat availability was less variable.

Release sites were unique during both years so there is no definitive method for determining if the difference between years was that of release site or environmental conditions. However, behavioral differences between release sites is unlikely to be the cause because the 21 acoustic fish that were monitored during both years utilized one third the mean TLR in 2008 that they occupied during the same period in 2007. Furthermore, the TLR for fish released during 2008 at river and lake sites are far lower than the TLR values for 2007 release sites (Figure 4.6).

Large differences in koi carp behavior, within and between release sites, resulted in large SDs for most parameters during this study and is typical of common carp behavior in large river systems (Stuart and Jones 2002; Jones and

Stuart 2009). TLR varied between individuals, with 11% of radio and acoustic fish occupying a TLR of less than 5 km and 74% occupying a TLR of greater than 10 km (N = 38, individuals monitored for >250 days). We found that koi carp typically occupy a small home range (1 km) and occasionally make long-range movements. Following the 2007 release, fish returned to within 1 km of their capture locations until water levels receded when most fish migrated to other habitat. During 2008, fish returned to their capture location and remained nearby for the duration of the study. The drastic difference in behavior within and between years highlights the need for long-term studies and is an example of the adaptability of common carp to changing environmental conditions.

The mean TLR of common carp implanted with radio transmitters in the Murray-Darling Basin, Australia (mean±SD, 30±61 km, N = 40, Jones and Stuart 2009) was less than koi carp with implanted radio or acoustic transmitters in the lower Waikato River that were monitored for more than 250 days (39±30 km, N = 38) but similar to acoustic fish (30±30 km, N = 50) monitored between 7 and 540 days. The discrepancy in TLR is potentially due to the difference in monitoring periods, Jones and Stuart (2009) calculated TLR of common carp with an average monitoring period of 240 days and stated that TLR was not related to monitoring period. TLR of koi carp on the Waikato River were influenced by monitoring period and likely underestimated at monitoring periods less than 250 days (Figure 4.4). The mean TLR of radio and acoustic fish, in the lower Waikato River, monitored for less than 250 days (16±26 km, N = 52) was under half that of fish monitored for greater than 250 days (39±30 km, N = 38; P = 0.01, Mann-Whitney U-test). Data presented by Jones and Stuart (2009) suggests a similar relationship between days monitored and TLR. Common carp with a TLR of less than 5.0 km were monitored for significantly less time (174±121 days, N = 15) than those with a TLR of greater than 5.0 km (281±111 days, N = 25; P = 0.01, Mann-Whitney U-test; Jones and Stuart 2009). Our results and those of Jones and Stuart (2009) again highlight the importance of conducting long-term studies with high temporal resolution.

The maximum up or downriver sustained movement speed of acoustic-tagged koi carp in the lower Waikato River (3.7 km/h) was four times greater than movement speeds of radio-tagged common carp in the Murray-Darling Basin (0.9 km/h) reported by Jones and Stuart (2009). We believe both measures are accurate and the difference in reported movement speeds was likely related to the travel times used in the calculations. Jones and Stuart (2009) calculated movement speeds using a single movement from seven individuals with a mean travel time of 639.8 hr. We found that movement speeds calculated from travel times of more than 10 hours (0.2±0.4 km/h, $N = 237$) were significantly lower than those calculated from travel times of less than 10 hours (2.0±1.6 km/h, $N = 31$; $P < 0.001$, Mann-Whitney *U*-test; Figure 5). It is likely that common carp rarely have sustained movements of greater than 10 hours and the discrepancy was a result of monitoring resolution. In addition, calculating movement speeds of acoustic tagged fish using movements of less than 3 km was not precise due to detection range variability of fixed site receiving stations.

Peak movements occurred during the spawning season (October of 2007 and 2008) and are likely associated with spawning migrations similar to common carp migrations in the Murray-Darling Basin, Australia, reported by Jones and Stuart (2009). In the Waikato River basin, increased activity during April to June of 2008 coincided with the first rains (increased flow) following an unusually dry summer. Koi carp in the lower Waikato River were observed returning to habitat occupied prior to water receding during the dry summer of 2007-2008. For example, a study fish that had overwintered in Lake Whangape in 2007 migrated 54 km downstream to the lower Waikato River as lake levels dropped during early summer. The fish returned to Whangape Stream in December of 2007 when the lake was not accessible due to low water. The fish then travelled back to the lower river to within 0.5 km of its previous location until May of 2008 when it returned to and entered Lake Whangape during elevated flows.

Movement patterns of koi carp are varied with some koi carp rarely moving and others moving almost continually. Most koi carp spend the majority of their time moving very little but 89% of fish, monitored for more than 250 days ($N = 38$), travelled greater than 5 km during some point in the study. Osborne et al. (2009) reported that 85% of dart-tagged koi carp on the Waikato River had moved less than 5 km. These findings are in complete contrast but highlight the potential misrepresentation that can result from mark-recapture studies (Gowan et al. 1994). The variable behavior of New Zealand koi carp is consistent with the behavior of common carp in both North America (Penne and Pierce 2008) and Australia (Jones and Stuart 2009).

Koi carp spawning in riverine lakes on the lower Waikato River are likely to have high recruitment rates due to the phytoplankton-dominated state of the lakes and could represent a large proportion of the successful breeding population within the basin. Survival and growth of juvenile common carp is positively related to phytoplankton production (Sharma and Chakrabarti 1999; Umesh et al. 1999) and the riverine lakes of the Waikato River have five times the phytoplankton production of the lower Waikato River itself (Benfield 1990). Lateral floodplains in Australia, similar to the riverine lakes and wetlands of the lower Waikato River basin, are also recognized as highly productive spawning and nursery habitat (Brown et al. 2005; Jones and Stuart 2009).

There was considerable movement of koi carp between riverine lakes or wetlands (lateral movement) and the Waikato River. Nearly three-quarters of koi carp (74%, $N = 23$) monitored for more than 250 days moved through drainage ditches and canals that connect the Waikato River to lateral habitat. Lateral movements could be exploited to reduce biomass of koi carp in riverine lakes and wetlands by targeting fish in these high-use areas. Australian managers have successfully implemented similar removal strategies by exploiting high-use areas to remove large numbers of common carp from lateral habitat, up to 76 tonnes a year of common carp have been harvested from Moira Lake as carp enter and exit the lake (Jones and Stuart 2009).

Koi carp have highly diverse behavioral patterns that seem to be related to habitat availability. During low water conditions, koi carp are highly mobile and frequently move between the Waikato River and lateral habitat making them susceptible to capture in large numbers. The diverse behavioral patterns of koi carp would suggest that multiple removal techniques applied on large temporal and spatial scales would be necessary for complete removal. Our findings highlight the importance of conducting long term monitoring of species with complex life histories. A monitoring period of at least 250 days was necessary to accurately describe the TLR of koi carp in the Waikato River. These findings are likely to apply to other species with complex life histories and should be considered when planning future studies.

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Chapter 5: Invasive potential, social cohesion, and habitat utilization of radio and acoustic tagged adult common carp (*Cyprinus carpio* L.) in the Waikato River, New Zealand[1]

5.1 Introduction

Introduction of non-native fish is a global phenomenon that has occurred for well over a century (McCrimmon 1968; Welcomme 1992; Casal 2006). Common carp (*Cyprinus carpio* L.) have been intentionally spread around the world despite recognition of their potentially detrimental effects on native flora and fauna dating back to the 1850s (McCrimmon 1968). Unfortunately once common carp establish a breeding population they are extremely difficult to eliminate (Diggle et al. 2004; Schrage and Downing 2004; Gilligan et al. 2005) and we are unaware of any successful eradications of large breeding populations to date. Early detection and rapid response may be the only effective means of eliminating introductions of highly invasive aquatic organisms and is recognized as an effective tool against invasive fish (Iguchi et al. 2004).

Koi carp, a colored variety of common carp have been present in New Zealand for at least 25 years and are well established in the North Island (Pullan 1984; Hanchet 1990; Hicks et al. 2006). Fortunately, the majority of New Zealand waterways are free of koi carp (New Zealand Freshwater Fish Database). However, there is a legacy of intentional introductions of coarse fish in New Zealand (McDowall 2000). Although there are fines for the intentional live transport of koi carp (Biosecurity Act 1993), the potential for further introductions is not only high but likely.

The first line of defence in preventing the spread of aquatic invaders is education and public awareness (Elvira and Almodovar 2001). It is also prudent

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for managers to develop early detection and rapid response procedures to maximize the chances of successful intervention if an introduction is detected (Wotton and Hewitt 2004). Knowing the invasive potential and basic biology of an aquatic invader is important information for the development of effective rapid response plans and techniques (Anderson 2005).

Two of the biggest challenges to planning a successful carp removal program are determining the scope of the invasion and successfully locating small populations of carp. This paper will discuss both issues based on data from radio and acoustic tagged adult koi carp collected during an 18-month study in the lower Waikato River Basin. The first hypothesis we will explore is that the invasive potential of koi carp is low based on previous work conducted in the basin (Osborne et al. 2009).

One of the most successful techniques for locating small populations of common carp is the use of “Judas” fish (Diggle et al. 2004). This technique is based on the assumption that carp are attracted to other carp (social cohesion) and by implanting a radio transmitter in “Judas” fish they can be followed to remnant populations of common carp to improve the efficiency of removal efforts. It is also possible that carp are attracted to high quality habitat and conspecifics are found in the presence of “Judas” fish due to high sight fidelity to mutually occupied habitat rather that a social attraction. The second hypothesis we will explore is that high sight fidelity in high productivity habitat is likely the cause of “Judas” fish being found in locations where other carp are present rather than social cohesion. A previous study conducted in the lower Waikato River basin reported high site fidelity and potential social cohesion of koi carp (Osborne 2006; Osborne et al. 2009). If koi carp are attracted to conspecifics and invasive potential is low it may be possible to thwart future introductions of koi carp if they are detected before successful spawning occurs.

5.2 Methods

5.2.1 Study area

The study area consisted of the lower 152 km of the Waikato River and the Waipa River, a major tributary (Chapter 4). The lower Waikato River basin includes 14 riverine lakes, the three largest of which range between 522 and 3,442 ha (Lake Waikare, Lake Whangape, Lake Waahi) and have degraded from eutrophic to hypertrophic in the past 25 years.

5.2.2 Transmitters and implantation

Radio and acoustic telemetry were used to maximize spatial and temporal resolution. A total of 41 radio and 66 acoustic transmitters were implanted in 106 adult koi carp (mean fork length 240 mm, range 240-710 mm) between July 2007 and August 2008. Three fish were implanted with both radio and acoustic transmitters. Transmitter specification, tagging dates, tagging locations, and implantation procedures are as described in Chapter 4.

5.2.3 Monitoring

Fish implanted with radio transmitters (radio fish) were tracked by boat, car, or light aircraft between August 2007 and December 2008 (Chapter 4). Fish implanted with acoustic transmitters (acoustic fish) were monitored between May 2007 and November 2008 with 18 fixed-site receiving stations moored in the Waikato River from Port Waikato (5 km from the sea) to Karapiro Dam (152 km from the sea; Chapter 4).

5.2.4 Data analysis

Distance travelled and total linear range (TLR) were calculated as described in Chapter 4. We defined site fidelity as contacting an individual in the same location on more than one occasion at least 30 days apart. Social cohesion was defined as the long-term association of two or more fish and was determined using radio telemetry locations. We considered social cohesion to occur if two study fish occupied the same habitat (<20 m) on at least 70% of contacts over a period of greater than 30 days time.

Environmental conditions that were compared to acoustic fish movements include barometric pressure, change in barometric pressure, hours of sunlight, water temperature, river flow, moon phase, rainfall, and wind run. These were used to identify potential triggers of acoustic fish movements. Change in barometric pressure was calculated as the product of the weekly mean minus the previous weekly mean. Various other resolutions of barometric pressure were examined, and none was found significant. Wind run was defined as the total distance wind travels in a day and was used to quantify total daily wind. Weekly movements of acoustic fish were compared to mean weekly environmental conditions using a Spearman correlation. All results of Spearman correlations are shown with r_s values and N and were considered significant at $P < 0.05$.

Waikato River temperatures and discharge data were supplied by Environment Waikato (Waikato District Council, Hamilton; Rangiriri gauging station). Barometric pressure, daily hours of sunlight, mean daily rainfall, and daily wind run readings were obtained from New Zealand's National Climate Database. All readings were taken at Hamilton International Airport (NIWA 2009). Moon phase data were obtained from the U.S. Naval Observatory (U.S. Naval Observatory 2009).

Habitat characteristics were used to describe locations where study fish were contacted. Each time study fish were located by boat the distance to shore, vegetation within 5 m, habitat structure within 5 m, depth, water velocity, and substrate were recorded. Seasons were classified based on behavioral observations, i.e., spawning (September – November), summer (December - March) and fall/winter (April - August).

All data used in comparisons were tested for normality using Kolmogorov-Smirnov and Lilliefors tests. Non-normal data was evaluated using nonparametric tests. All statistical calculations were performed using Statistica 8 (StatSoft, Inc, Tulsa, OK, USA), means are presented ± SD unless otherwise stated.

5.3 Results

5.3.1 Site fidelity and social cohesion

Site fidelity was observed for 82% (N = 29) of radio fish monitored more than 30 days and included individuals returning to previously occupied habitat after periods of over 6 months. Two fish that were released in the Waikato River (release site 7, Figure 5.1) were observed within a 100-m home range on 70% of contacts. Both individuals migrated from and returned to their primary home range during the study. A second pair of fish occupied a small home range in Lake Whangape (release site 3, Figure 5.1) where they were released, migrated 54 km downstream, and returned to, the same location after approximately 197 days.

Social cohesion appeared to exist amongst study fish, but in all cases was attributed to strong site fidelity. Five of ten radio fish captured and released together at Lake Whangape (1 August 2007) were relocated in a large spawning aggregation (175˚04’57”E 37˚27’10”S, Figure 5.1) within 400 m of their capture location 78 days after release indicating potential social cohesion. Two fish that were released at Lake Whangape travelled 54 km down river to a similar location, within 0.5 km, but they did not migrate together (they were located up to 40 km apart) and were not found together at their downstream destination. Both fish were relocated on the same day 12 times (over a period of 286 days), were contacted within 2 km of one another on 9 occasions and occupied three separate locations together over a TLR of 55 km. However, they were contacted in separate locations, 19-42 km apart, during 3 of the 12 days they were both contacted. Two additional fish captured and released together at site 7 (Figure

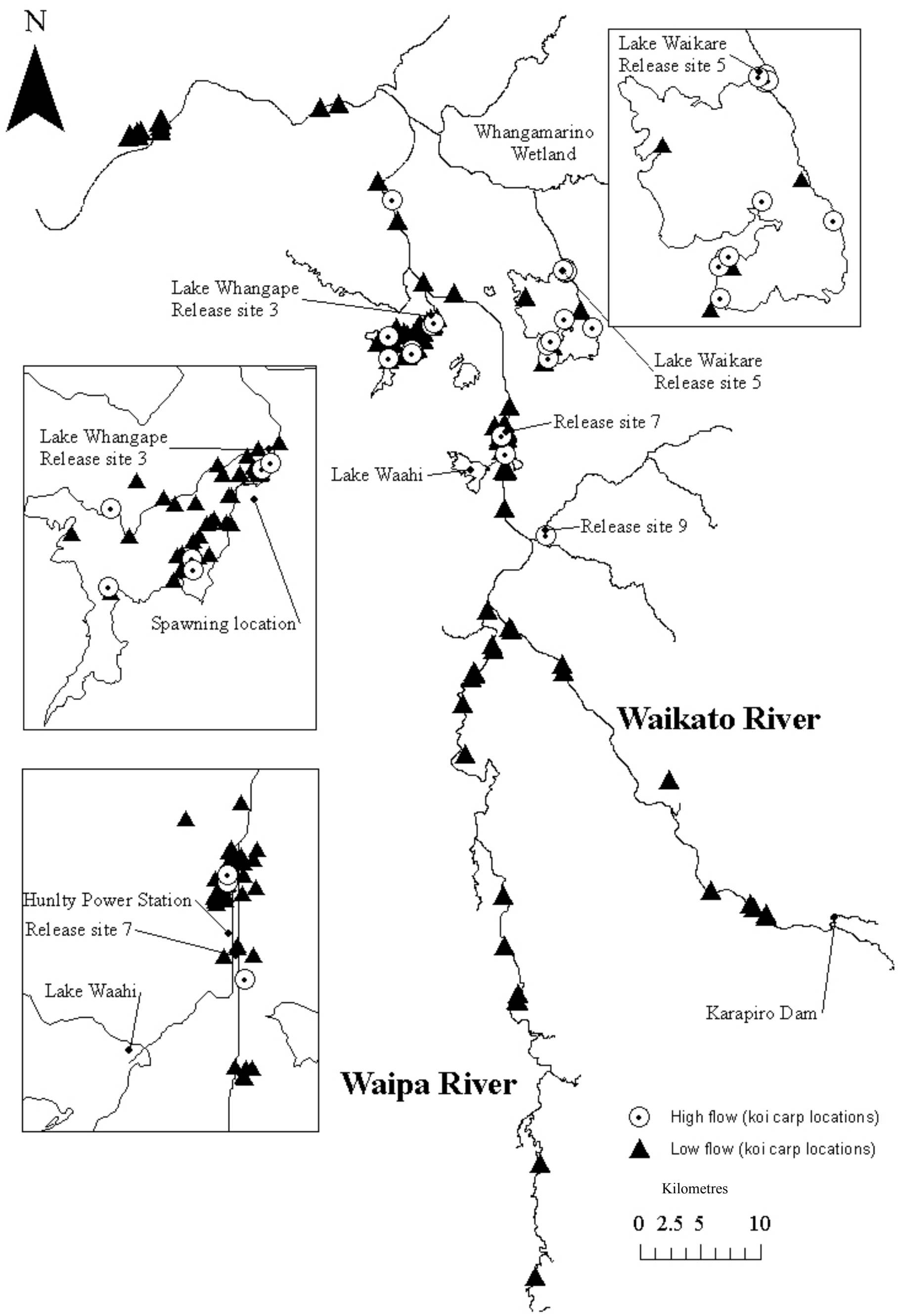

Figure 5.1.—Locations of koi carp implanted with radio transmitters at high flows (>600 m^3/s) and low flows (<300 m^3/s) from 8 August 2007 to 12 December 2008. Flows based on Rangiriri gauging station Waikato River.

5.1) on the Waikato River occupied separate small home ranges within 100 m of each other. These individuals were frequently contacted and observed with conspecifics, but were never located together (<20 m apart) despite being captured together and occupying the same small backwater adjacent to the Waikato River.

5.3.2 Invasion potential

Movements (>1 km) of acoustic fish were infrequent but sometimes substantial. On average, acoustic fish only made movements greater than 1km 1.1±1.5 days per month (range 1-9 movements, $N = 40$, for fish monitored >30 days). However, koi carp were highly mobile when motivated. Radio fish occupied a TLR of over 120 km in just 218 days, representing 71% of the potential in river TLR within the lower Waikato River basin.

Radio fish remained near or returned to their capture location when water levels were high (>600 m^3/s, $N = 41$) occupying a TLR of less than 5 km based on their release site. However, when flows were low (<300 m^3/s, $N = 20$) koi carp dispersed throughout the Waikato and Waipa Rivers (Figure 5.1) occupying TLRs of up to 150 km. Overall, acoustic fish had a net downriver movement of 125 km ($N = 50$, mean 277 days at liberty). Male fish moved a total of 3,019 km overall (48% upriver; 48% downriver, and 4% lateral; $N = 20$, mean 287 days at liberty). Similarly, female acoustic fish travelled 2,099 km in total (42% upriver, 50% downriver, and 7% lateral; $N = 25$, mean 324 days at liberty). The mean daily up and downriver distance travelled by male acoustic fish (upriver, 0.10±0.14 km; downriver, 0.20±0.29 km; $N = 25$) was not significantly different from female fish (upriver 0.19±0.22 km, downriver, 0.18±0.18 km, $N = 20$; upriver, $P = 0.17$, downriver; $P = 0.85$, Mann-Whitney *U* Test).

5.3.3 Movement and environmental conditions

We found no correlation between mean weekly movements (including up and downriver movements) and mean weekly environmental conditions such as barometric pressure, change in barometric pressure, hours of sunlight, water temperature, river flow, moon phase, daily rainfall, and wind run. However, several sudden increases in movement (in weeks 46, 48, 55, 57, and 58; Figure

5.2) corresponded with increased flow following a prolonged period of reduced flow (weeks 25 to 45; Figure 5.2).

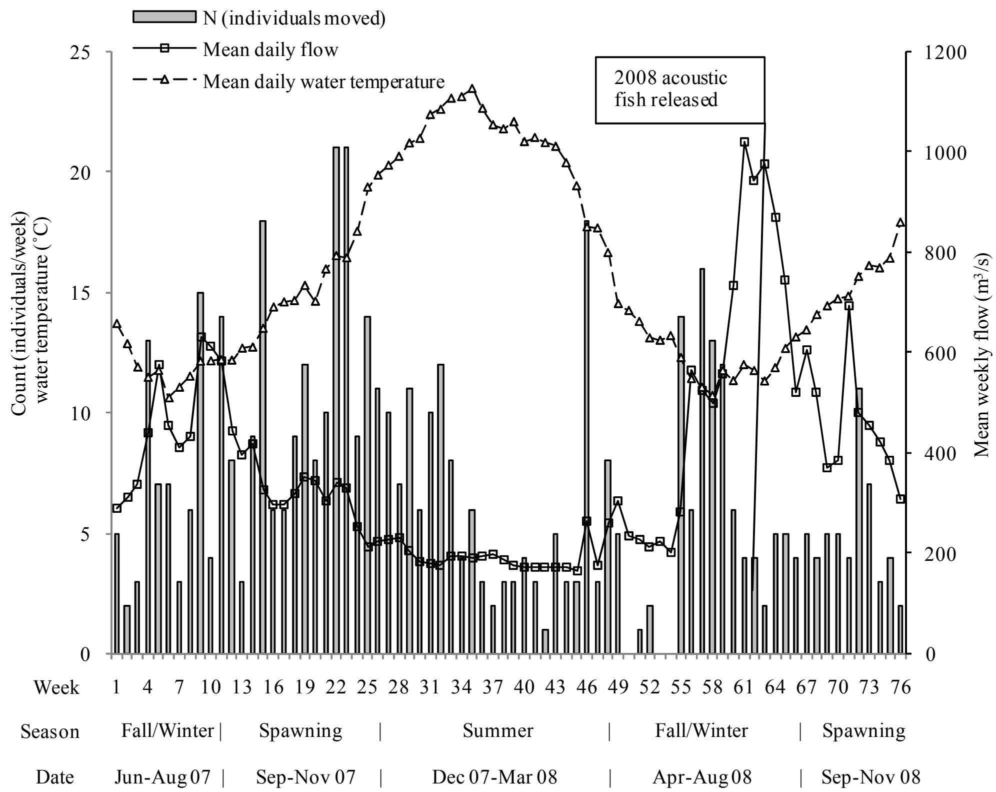

Figure 5.2.—Weekly count of adult koi carp implanted with acoustic transmitters that moved, mean daily water temperature and mean daily Waikato River flow.

Movements associated with large increases in flow did not lead to net downriver movement of fish (Figure 5.3). Movement of acoustic fish was reduced during periods of low temperatures (<11˚C), although water temperature was not correlated with acoustic fish movements overall (Figure 5.4).

Movements of acoustic fish into riverine lakes (lateral habitat) were positively correlated with weekly hours of sunlight and wind run (r_s = 0.28, r_s = 0.31, $P < 0.05$, $N = 76$; Figure 5.5). Movements out of riverine lakes were negatively correlated with water temperature (r_s = -0.32, $P < 0.05$, $N = 76$) and positively correlated with flow (r_s = 0.31, $P < 0.05$, $N = 76$; Figure 5.6). Some lateral habitat was disconnected from the Waikato River during low flows (< 250 m^3/s) restricting movement of study fish, hence correlations presented should be interpreted with caution.

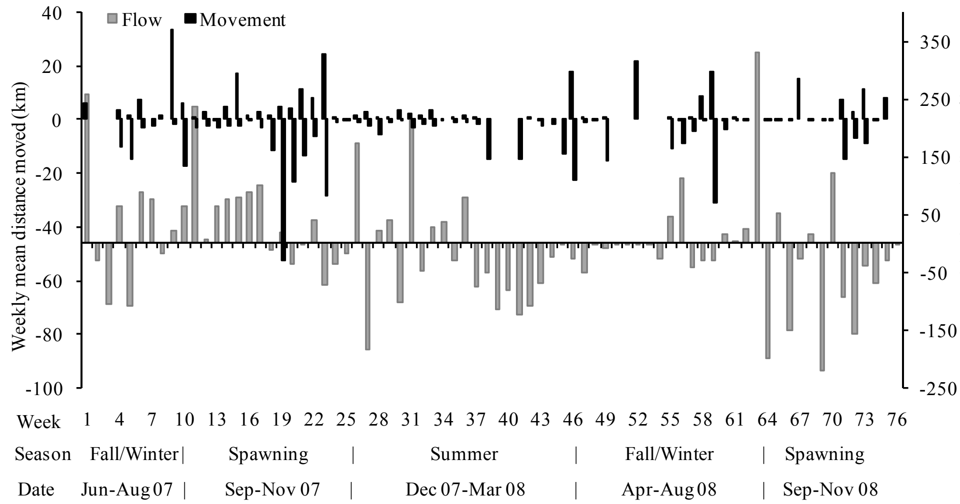

Figure 5.3.—Mean weekly up (+) and downriver (-) movements of koi carp implanted with acoustic transmitters with corresponding weekly change in flow of the Waikato River.

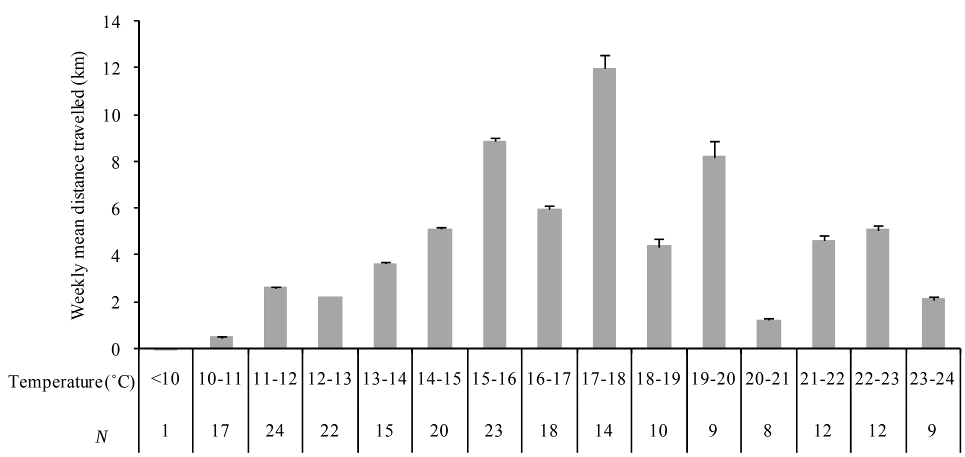

Figure 5.4.—Weekly mean distance travelled of koi carp implanted with acoustic transmitters and water temperature at the time of detection from 6 June 2007 to 16 November 2008. Error bars represent one standard deviation.

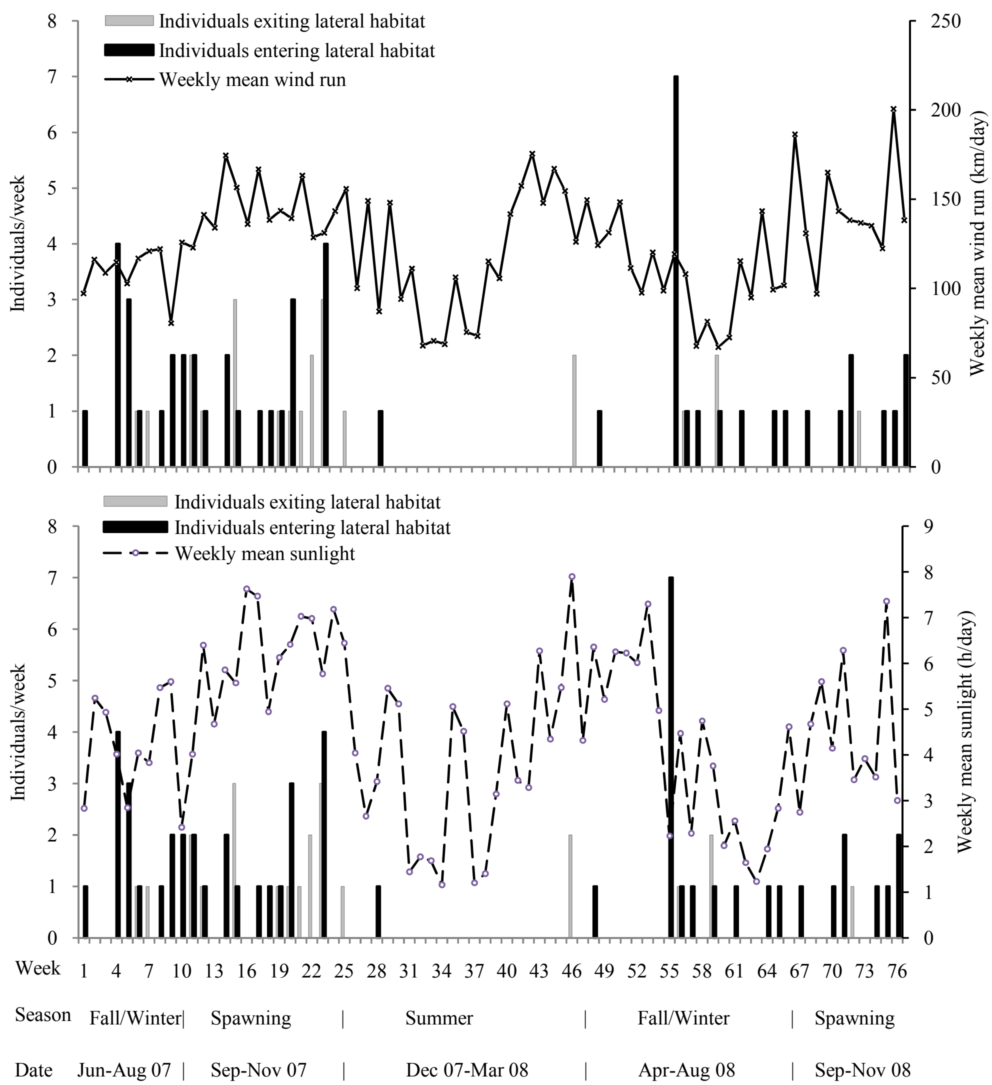

Figure 5.5.—Number of koi carp implanted with acoustic transmitters entering or exiting lateral habitat each week compared to weekly mean hours of sunlight and weekly mean windrun.

Figure 5.6.—Number of koi carp implanted with acoustic transmitters entering or exiting lateral habitat each week compared to weekly mean hours of sunlight and weekly mean windrun.

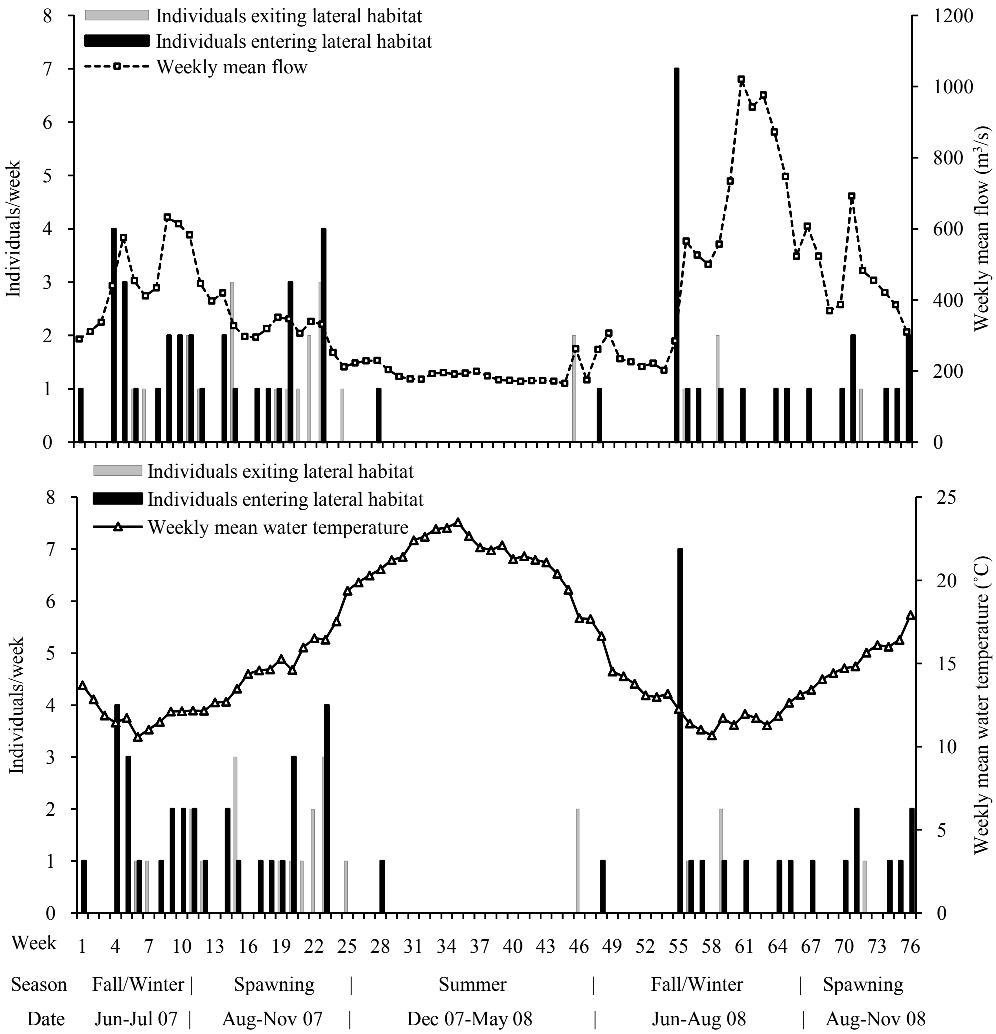

Figure 5.6.—Number of koi carp implanted with acoustic transmitters entering or exiting lateral habitat each week compared to weekly mean water temperature and weekly mean flow.

5.3.4 Habitat use

Radio fish were most often located near shore (57% of contacts, $N = 129$), but were found >50 m from shore on 36% of contacts ($N = 81$; Figure 5.7A). Seasonally, study fish were located more that 50 m off-shore more in the fall and winter than in summer or spring (Figure 5.7B).

Radio fish were located near emergent vegetation during 60% of contacts ($N = 126$, Figure 5.8A) and in less than 1 m of water during 82% of contacts (mean 0.8 m, $N = 166$; Figure 5.9A). During low water conditions, large groups of koi carp were observed feeding in shallow water (<0.2 m) over mudflats, void of vegetation or structure. Submerged macrophyte beds were only present in the Waikato River, and koi carp were only associated with submerged macrophytes (>5% of contacts) in the summer during low flow, when emergent vegetation was largely unavailable (Figure 5.8B).

Most radio fish contacts were near habitat structure consisting of woody debris or earthen banks (68 %, $N = 155$, Figure 5.10). Seasonally, the proportion of contacts associated with structure was less during the summer (37%, $N = 10$) compared to the spawning (71%, $N = 99$) and fall/winter (76 %, $N = 46$; Figure 5.10). During the fall/winter, radio fish contacts associated with wood were predominantly near waterfowl hunting blinds constructed in 1 to 3 m of water. Due to poor water clarity in riverine lakes, often less than 10 cm, detection of woody debris that was not exposed was not possible, therefore contacts associated with woody debris should be considered minimums and interpreted with caution.

Radio fish were located in low-velocity habitat (0.07±0.30 m/s, $N = 223$, Figure 5.11) with mud substrate (62%, $N = 144$; Figure 5.12) during the majority of contacts. All fish contacted in water velocities of >0.30 m/s (n = 7) were located during boat electrofishing operations, and had previously been captured via boat electrofishing, potentially influencing their contact location. When radio fish were contacted in the vicinity of moving water, they were predominately found within 2 m of shore. Of the 13 fish contacted in rivers using standard boat tracking (no electrofishing boat in operation), the mean velocity at the point of contact was 0.08±0.10 m/s (range 0.0-0.3 m/s, $N = 51$ contacts).

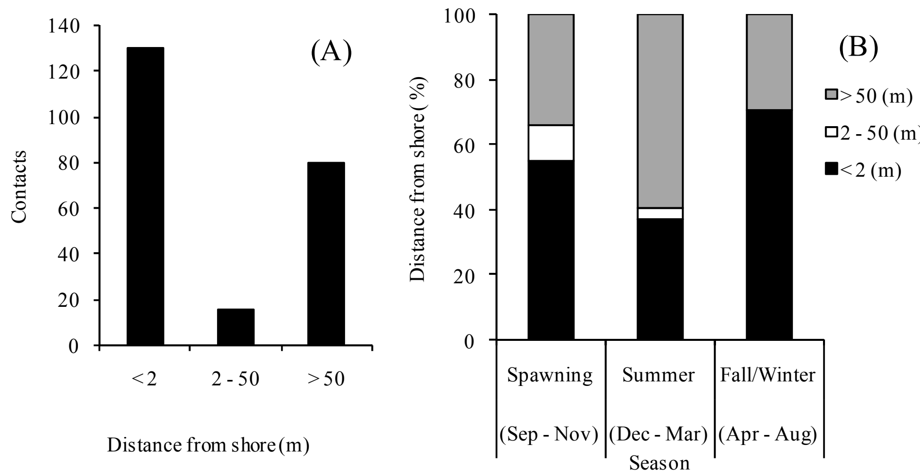

Figure 5.7—Distance from shore of koi carp implanted with radio transmitters from 8 August 2007 to 12 December 2008 (A) Histogram of all contacts in each distance from shore category. (B) Distance from shore as a percentage of all contacts during each season.

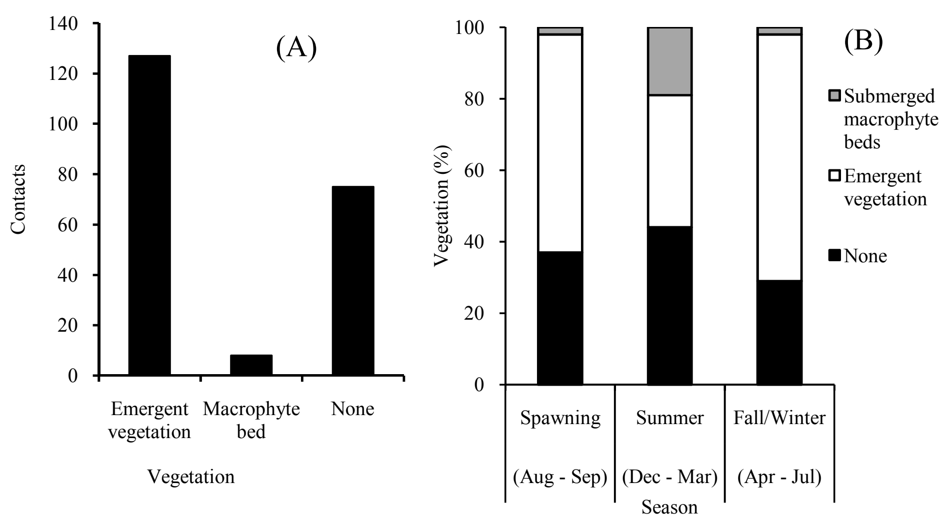

Figure 5.8.—Vegetation within 5 m of locations where koi carp implanted with radio transmitters were contacted from 8 August 2007 to 12 December 2008 (A) Histogram of all contacts in each vegetation category. (B) Vegetation categories as a percentage of all contacts during each season.

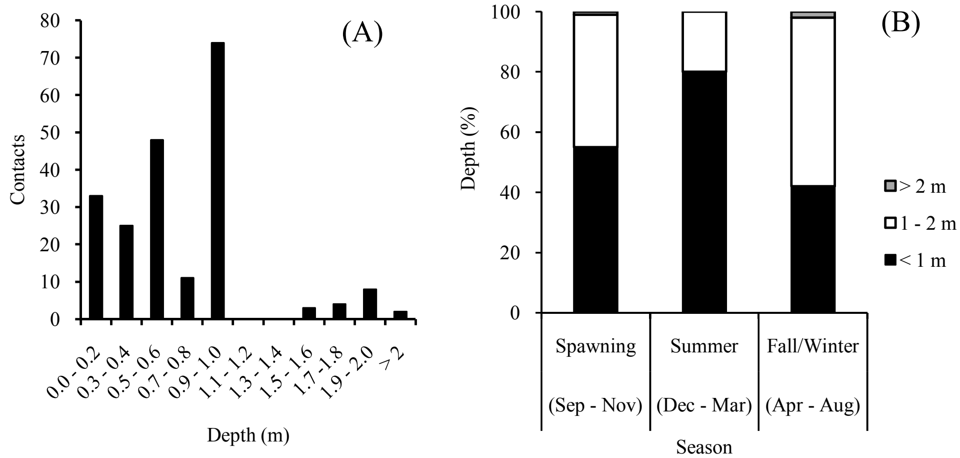

Figure 5.9.—Depths at locations where koi carp implanted with radio transmitters were contacted from 8 August 2007 to 12 December 2008 (A) Histogram of all contacts in each depth category. (B) Depth categories as a percentage of all contacts during each season.

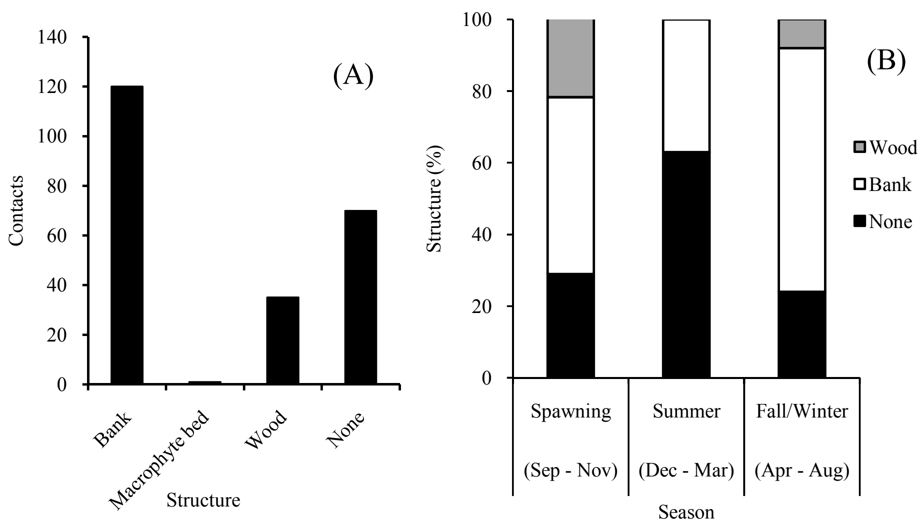

Figure 5.10.—Structure within 5 m of locations where koi carp implanted with radio transmitters were contacted from 8 August 2007 to 12 December 2008 (A) Histogram of all contacts in each structure category. (B) Structure categories as a percentage of all contacts during each season.

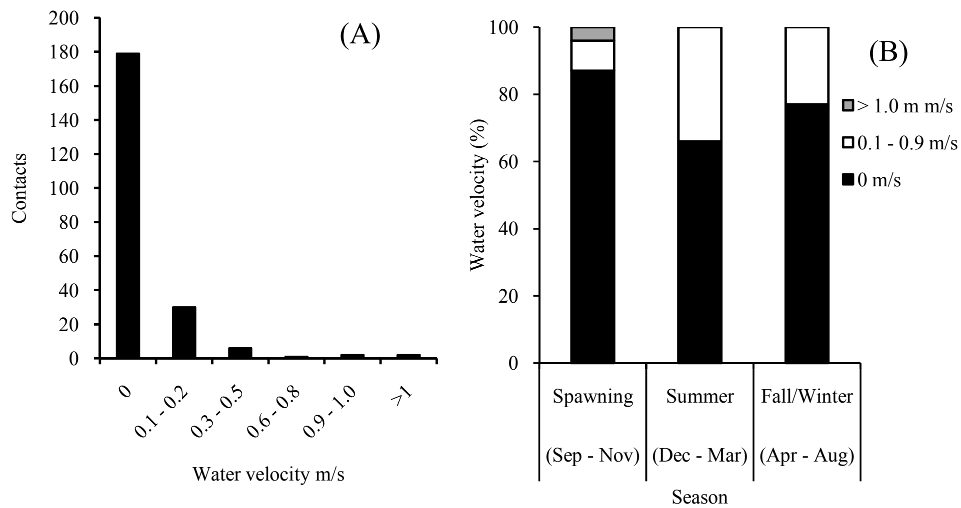

Figure 5.11.—Water velocity at locations where koi carp implanted with radio transmitters were contacted from 8 August 2007 to 12 December 2008 (A) Histogram of all contacts in each water velocity category. (B) Water velocity categories as a percentage of all contacts during each season.

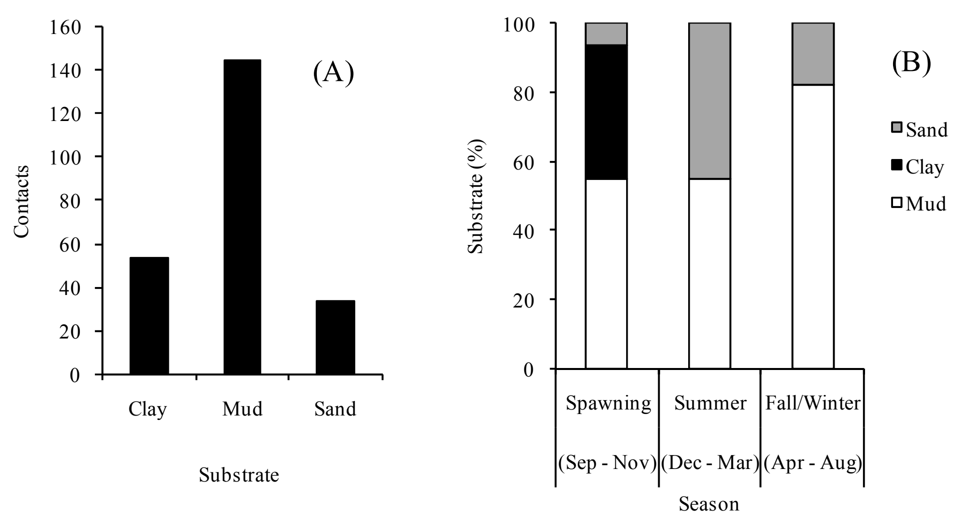

Figure 5.12—Substrate at locations where koi carp implanted with radio transmitters were contacted from 8 August 2007 to 12 December 2008 (A) Histogram of all contacts in each substrate category. (B) Substrate categories as a percentage of all contacts during each season.

5.4 Discussion

Koi carp in the Waikato River have extreme invasive potential, occupying 71% of the potential in river TLR in just 7 months. This highlights the need for early detection where possible. Koi carp also showed considerable site fidelity in both lake and river habitats, as described by other authors (Crook 2004; Jones and Stuart 2009; Osborne et al. 2009). Radio fish were observed returning to previously occupied habitat after periods of up to one year.

Possible social cohesion was observed during this study and was reported to potentially occur amongst koi carp on the Waikato River by Osborne et al. (2009). However, site fidelity was so strong for some koi carp it is unclear if individuals occupy and return to the same habitat or if they intentionally form lasting groups. Individuals observed occupying habitat within close proximity of one another were often observed with other conspecifics but were never observed with other study fish, suggesting that they were simply coexisting in the same habitat. Radio fish migrated to the same locations but were not found in the immediate proximity of one another suggesting that individuals were simply occupying productive habitat at the same time as other conspecifics. From this we concluded that koi carp captured and released together did not tend to stay in social groups.

Social cohesion, as defined in the methods of this paper (70% of contacts within 20 m of another study fish) was not observed, but long-term associations could exist amongst koi carp that were not compatible with our definition. Common carp have highly developed hearing and sound recognition (Chase 2001) indicating that sound could potentially be used as a form of communication. We have recorded feeding sounds (clicking of pharyngeal teeth) of koi carp using hydrophones (unpublished data). These sounds could be a means of communication between individual koi carp in social groups, over distances far greater than 20 m, and should be investigated as a means of attracting koi or common carp for removal.

High site fidelity and little or no social cohesion would suggest that identifying and targeting optimal habitat through habitat modeling (Iguchi et al. 2004) would be more effective than using fish implanted with radio transmitters to locate conspecifics ("Judas" fish, Diggle et al. 2004). However, our data and the experiences of established common carp removal programs (Diggle et al. 2004) suggest that the use of "Judas" fish can be extremely effective during the spawning season. Outside the spawning season a "Judas" fish would likely direct removal efforts towards their preferred habitat. Without evaluating the available habitat it would be difficult to determine if the high-use areas of "Judas" fish represented the only preferred habitat available or were one of many potential locations occupied by conspecifics.

Movement into and out of lateral habitat was more frequent during flows between 250 and 400 m^3/s. Some lateral habitat was disconnected from the Waikato River during flows less than 250 m^3/s, and when access to lateral habitat was restored, large numbers of koi carp were observed migrating into riverine lakes. Movements of study fish into lateral habitat were positively correlated with weekly hours of sunlight and wind run. Although sunlight and low wind run can increase water temperature in lateral habitat triggering spawning events, early in the spawning season, these correlations were likely influenced by the restricted movement of koi carp that occurred during low flows. Similarly, the correlation between cool water temperatures and study fish exiting lateral habitat could have been influenced by restricted movement during the warmest portion of the year. However, there are clear peaks in movement into and out of lateral habitat corresponding to increases in flow reinforcing that flow influenced koi carp movement as described in Chapter 4. Lateral movements, similar to those made by koi carp that were observed during this study, have been utilized for the removal of common carp in Australia (Stuart et al. 2006) and could be a useful tool for detecting or removing koi carp in New Zealand

Meteorological conditions were poor indicators of koi carp movement overall however responses to temperature and flow were observed. Dramatic reductions in movements and large aggregations of common carp have been observed in North America at water temperatures below 12°C (Bauer and Schlott

2004; Penne and Pierce 2008). Winter aggregations in regions with seasonal ice cover, have been reported, near warm water inputs (Cooke and McKinley 1999), aeration devices (Penne and Pierce 2008), and deep water (Johnsen and Hasler 1977). We observed reduced movement at water temperatures below 11°C, but did not find large aggregations of fish during the winter. Water temperatures on the North Island of New Zealand rarely drop below 10°C, making winter aggregations unlikely.

Unlike common carp in Canada (Brown et al. 2001), koi carp in the Waikato River basin did not move downriver in response to high flow events. This is likely due to the difference in habitat type, water temperature, and the nature of the flood events. Access to low velocity habitat is greatly increased during high flow events in the Waikato River allowing fish to move laterally. Flash flood events caused by ice break-up are nonexistent on the lower Waikato River due to elevated water temperatures.

Habitat use was consistent with other long-term studies conducted at similar latitudes, fish were predominantly found in shallow water, associated with emergent vegetation or woody debris and low water velocity (Crook et al. 2001; Stuart et al. 2006; Jones and Stuart 2007). Mean depth and distance from shore were less than half that of common carp described by Penne and Pierce (2008) in a North American lake. However, mean depth and association with vegetative cover were similar to common carp described by Otis and Weber (1982) in a North American lake.

Koi carp contacted in rivers were predominantly found in slow moving water (<0.3 m/s) within 2 m of the shoreline. Common carp appear to avoid high water velocity (>0.6 m/s; Edwards and Twomey 1982), this behavioral attribute could be exploited by placing traps along shorelines adjacent to high water velocities in high use areas. Installing a barrier from the shoreline to direct migrating fish into traps, such as fish wheels (Hayes et al. 1996), could be an effective means of removing koi carp from in river habitat.

Due to the extreme mobility of koi carp response plans that concentrate removal efforts at the site of introduction are likely to be ineffective. Reacting swiftly and concentrating detection and removal efforts in preferred habitat (giving priority to preferred habitat near suspected liberation points) is likely to increase the probability of successful removal efforts. Determining the date of the introduction and reviewing environmental conditions (habitat availability, flow, season, and water temperature) that were present post release could help prioritize search areas. For example, short time at liberty, ample preferred habitat in the vicinity of the introduction, and high water levels would warrant a small search area. A model of koi carp habitat preference similar to the ecological niche model described by Iguchi et al. (2004) would be a valuable tool for prioritizing removal efforts and could potentially be adapted for use in other countries.

The response to new liberations and final removal efforts (i.e., removal of a residual population after bulk removal efforts are complete) should be based on the same principles including: A) all target animals must be put at risk by removal efforts, B) target animals must be removed at a rate that exceeds recruitment, C) immigration must be prevented, and D) Small populations must be detected and targeted (Owen 1998; Cromarty 2002).

We found high site fidelity and infrequent movement of New Zealand koi carp thus requiring a strategy that attracts fish to a capture location or covers all available habitats. An effective attractant for koi carp (such as artificial pheromones or sound attraction) is not yet available and adequately monitoring all available habitats is often unrealistic. Focusing removal efforts based on habitat preference is likely to be the most effective strategy to encounter all members of a remnant population.

New Zealand koi carp are highly fecund (Tempero et al. 2006) thus exceeding recruitment would require the prevention of all spawning. Barrier netting has been used to successfully prevent spawning by blocking common carp from accessing spawning sites (Diggle et al. 2004) and could be an effective means of preventing koi carp spawning in New Zealand.

Preventing immigration or liberation of koi carp into areas where removal efforts have been successful may prove to be the most difficult variable to control. We have demonstrated that koi carp frequently access lateral habitat and are highly invasive making recolonization likely unless it can be physically prevented. Installing electric barriers (Verrill and Berry 1995), hydraulic barriers (R. Norrgard, pers. com.) or screens (Chow-Fraser 2005, Parks 2006) can be effective for excluding most common carp, but are not always 100% effective. More importantly the reintroduction of invasive fish by humans is a real threat that can be reduced through public awareness and education.

The detection of small populations of koi carp may be possible with the use of both "Judas" fish (Diggle et al. 2004) and habitat preference modeling (Iguchi et al. 2004). The successful eradication of koi and common carp introductions are feasible if spawning can be completely eliminated as highlighted by the near success of the Lake Sorell carp management program in Tasmania (Inland Fisheries Service 2008). The consequences of non detection or a poorly planned response can be devastating to aquatic ecosystems (King et al. 1997; Zambrano et al. 2001; Parkos et al. 2003).

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Chapter 6: Conclusions and recommendations

6.1 Major findings

Common carp in the lower Waikato River Basin are highly invasive during low water years and comparatively less invasive during high water years. Fish released at Lake Whangape occupied a total linear range (TLR) of over 120 km in just 218 days, which represents 71% of the potential in river TLR within the lower Waikato River basin. Koi carp frequently used lateral habitat when it was available. At least 74% of fish, that were monitored for at least 250 days, migrated through the waterways between riverine lakes or wetlands and the Waikato River. Waterways connecting riverine lakes and wetlands to the lower Waikato River are ideal locations to intercept migrating koi carp. Adult koi carp were found to be active year-round, but peak movements occurred during spawning season (October) during both years of the study.

The detection of small populations of koi carp may be possible with the use of both "Judas" fish (Diggle et al. 2004) and habitat preference modeling (Iguchi et al. 2004). The use of "Judas" fish will likely direct removal efforts to spawning sites and high productivity habitat but is unlikely to identify all remnant populations. Locating remnant populations should be a top priority of future research.

It may be possible to exploit the habitat use of koi carp to facilitate their removal. Koi carp contacted in rivers were predominantly found in slow moving water (<0.3 m/s) within 2 m of the shoreline. This finding would suggest that koi could be targeted along shorelines in areas of relatively high velocity water in the main stem Waikato River and connecting waterways.

Although unrelated to the overall objective, the data collected in the field study revealed important findings that may influence the design of future telemetry studies. For example, travel speeds calculated using fixed telemetry were influenced by data resolution and total linear range calculations were influenced by the length of time fish were monitored. Movement speeds calculated from elapsed times of more than 10 hours (0.2±0.4 km/h, N = 237) were significantly lower than those calculated from travel times of less than 10 hours (2.0±1.6 km/h, N = 31; $P < 0.001$, Mann-Whitney U-test; Figure 5). The mean TLR of radio and acoustic fish, in the lower Waikato River, monitored for less than 250 days (16±26 km, N = 52) was under half that of fish monitored for greater than 250 days (39±30 km, N = 38; $P = 0.01$, Mann-Whitney U-test).

Tank trials conducted in preparation for the movement monitoring were inconclusive, but yielded some valuable information that influenced the success of the field studies. Most notably, transmitter rejection was high making it necessary to plan for additional tagging during the second year of the study. In addition, the use of a pelvic girdle attachment procedure was not successful and could have lead to a disastrous outcome if it had been used in the field trial.

6.2 Study justification and progression

This thesis was designed to assist end users in reducing koi carp populations that are perceived to be detrimental to water quality in the lower Waikato River Basin. To achieve the desired goal of finding exploitable stages in the life history of koi carp two separate telemetry studies were conducted simultaneously. A total of 107 adult koi carp were implanted with radio or acoustic transmitters and were monitored for up to 18 months. Both studies yielded valuable information that is summarized below.

During the preparation for the field telemetry studies a literature review was conducted that revealed alarmingly high transmitter rejection rates reported for common cap in water temperatures approaching 20°C. A tank trial was conducted to verify these findings and estimate the loss of transmitters that could be expected in the field. Results from the first tank trial suggested bacterial infection might have influenced transmitter rejection. This led to a second tank trial intended to test the use of a single dose antibiotic to reduce transmitter rejection.

6.3 Transmitter retention

Retention of both radio and acoustic transmitters by koi carp in New Zealand was low when transmitters were implanted in water temperatures above 20˚C, with losses at or above 50% within 150 days (Chapter 2). Transmitter coatings such as beeswax and KISS concentrated gel may have slightly improved transmitter retention by creating a sterile transmitter surface (Chapter 2 and 3). However, the cost of KISS concentrated gel and the added volume of beeswax may outweigh the minimal benefits of both coatings for most applications.

Transmitter expulsion was reduced with the use of CONVENIA™ (cefovecin sodium), a slow-release antibiotic (Chapter 3). The use of cefovecin sodium improved transmitter retention by 50% over 176 days, was cost effective (CONVENIA™ NZ$200 to treat 1000 kg of fish; transmitter cost NZ$300) and easy to use. The reduction of transmitter expulsion observed when fish were treated with a slow-release antibiotic suggests that bacterial infection is a major factor of transmitter expulsion. The loss of some transmitters in fish treated with cefovecin sodium suggests that the dose could be refined or that cefovecin sodium may not have adequately reduced bacterial infection for the duration of the healing process. It is also possible that there is another cause of transmitter expulsion that was not addressed by antibiotic treatment. The results of the cefovecin-sodium tank trial were a major step forward in reducing transmitter expulsion in water temperatures above 20°C. Cefovecin sodium should be used in future laboratory and field trials, where appropriate (non food fish), to improve transmitter retention and reduce animal suffering. Future work could include a larger cefovecin sodium tank trial held at high (>20˚C) water temperatures, testing transmitter retention of new species treated with cefovecin sodium, experimenting with dose rates of cefovecin sodium and testing the effect of small incisions on wound healing time.

6.4 Removal strategies

Removal efforts generally fall into one of three categories, one time removals, ongoing or annual removals and complete eradications. One time removals of pest fish can yield important scientific data but are of little long-term value as water quality will return to the pre-removal state as fish biomass increases post removal (Meijer *et al.* 1994; Meijer *et al.* 1999). If complete removal is not an option, annual removals can be effective for reducing biomass of common carp similar to commercial fishing operations at Moira Lake, Australia (Jones and Stuart 2009). By utilising commercial fishers it could be possible to remove a sustainable and biologically significant harvest of koi carp from riverine lakes in the Waikato River basin that could allow recovery of native biodiversity.

Complete removal of koi carp from the Waikato River basin would be the preferred long-term option for preserving water quality and native biodiversity. Although this would be a difficult task the near removal of common carp from two Australian lakes, Lake Sorell (4,770 ha) and Crescent (2,365 ha), proves that common carp removal from large lakes is possible (Inland Fisheries Service 2008). Common carp were identified in Lake Sorell and Lake Crescent in 1995 and an intensive removal programme has resulted in current estimated populations of less than 100 fish (Inland Fisheries Service 2008).

Successful eradication strategies for invasive alien species of plants and mammals have similar criteria that will also apply to koi carp removal in New Zealand (Chadderton 2001): A) all target animals must be put at risk by removal efforts, B) target animals must be removed at a rate that exceeds recruitment, C) immigration must be prevented D) Small populations must be detected and targeted, E) the eradication must be politically and financially supported (Owen 1998; Cromarty 2002).

Common carp removal programmes have three distinct stages discovery (the initial detection), bulk removal (the elimination of fish from high use areas), and final removal (the detection and removal of remnant populations after successful bulk removal). The management response during the discovery and final removal stages are very similar (Chapter 5). Low densities of fish potentially dispersed through a large area require attracting or locating fish. At the bulk removal stage removal efforts focus on aggregations and high use areas. In my opinion, it is essential to properly plan both bulk and final removal strategies prior to beginning a removal project with the goal of eradication.

The amount of koi carp biomass that must be removed (biomanipulation) to restore lakes to a stable macrophyte-dominated state has not been studied in New Zealand. However, in a study of 18 such biomanipulations, in shallow Dutch lakes, Meijer *et al.* (1999) found that a reduction of >75% of fish biomass coincided with a significant increase in water clarity and substantial macrophyte regeneration that was unaffected by wind resuspension. Similarly, Zambrano *et al.* (2001) modelled the removal of common carp in shallow Mexican ponds, and found a 70% reduction in biomass was necessary, to restore water clarity. Pinto *et al.* (2005), reported a 10-fold reduction in cyanobacterial counts, and a 20% increase in Secchi disc transparency, after catches of common carp were reduced from 97 kg day^{-1} to 50 kg day^{-1}. A multiple technique approach would be necessary to achieve a 75% reduction in koi carp biomass or a significant reduction of catch in the lower Waikato River or connecting water bodies.

6.5 Exploitable behavioural attributes of koi carp

The following section describes removal techniques that are likely to be effective for New Zealand koi carp. Koi carp in the Waikato River basin have several exploitable behavioural attributes including: A) spawning aggregations (Chapter 5), B) spawning migrations (Chapter 4), C) migrations in response to low flows (Chapter 4 and 5), D) in-river migration routes close to shore or structure in low velocity water (Chapter 5), E) koi carp are attracted to bait.

6.5.1 Spawning aggregations

Targetting spawning events by netting koi carp can reduce koi carp biomass and is an effective bulk removal strategy, but is not an effective long-term solution to eradicate koi carp unless spawning can be completely eliminated. Spawning was observed in the Waikato River and lateral habitat during the spawning season

(August-October) and summer (January). Temperature is accepted as the key factor in the timing of common carp spawning timing (Davies and Hanyu 1986) and although the Waikato River temperature was monitored during this study, it is often unrelated to the water temperature of shallow flooded margins where spawning takes place during high water levels. Monitoring water levels and the temperature of floodplains during spawning season could allow managers to predict the timing of spawning events in known spawning locations. However, this would only be useful for targetting large spawning areas and there are many widely dispersed spawning sites that were used by koi carp within the study area. Due to the high fecundity of koi carp in the Waikato River (Tempero *et al.* 2006), targetting spawning koi carp is unlikely to permanently reduce the overall number of fish in any one area unless spawning can be prevented. As a simple example, assuming a population of 1,000 koi carp, if 95% of all spawning fish are captured and the remaining 5% spawn successfully, and 50% were female with a mean of 299,000 eggs per female (Tempero *et al.* 2006), a 0.1% survival rate the cohort would yield 7,475 fish.

Preventing spawning in lakes is possible using fixed or floating barriers, as show in Lake Sorell and Lake Crescent (Inland Fisheries Service 2008) and should be the first management action taken during an eradication programme. However, this method would require considerable initial investment and yearly maintenance. Lake Waikare, for example, would require a minimum of 20 to 30 km of barrier to eliminate spawning habitat during high water. Modifications to existing stock exclusion fences could drastically reduce the cost of excluding koi carp from preferred spawning sites.

By eliminating access to spawning habitats it may be possible to predict and exploit the spawning locations of koi carp and trap or poison spawning fish. During this study koi carp were observed spawning in many suitable locations when water levels were high making monitoring of spawning sites difficult. When optimal spawning habitat was not available, due to low water levels, koi carp were observed spawning at only one location where a small amount of plant matter (peat) was exposed. Similarly common carp in Lake Sorell were observed spawning on any available surface including barrier nets when excluded from all available spawning habitats (C. Wisniewski, pers. com.). By excluding most suitable spawning locations in an area it may be possible to use the remaining spawning sites as bulk removal points (ambush locations) thus reducing monitoring sites and increasing the chances of encountering the entire population. Ambush sites could be used as trap or netting locations and would be ideal for electronic surveillance to alert managers of spawning events. To prevent eggs from hatching after successful spawning events, ambush locations could be regularly treated with rotenone.

6.5.2 Migrations

The small waterways that connect the Whangamarino Wetland, Lake Whangape, Lake Waikare and Lake Waahi to the Waikato River are suitable locations to trap migrating adult koi carp during bulk removal efforts (Chapter 4). At least 74% of fish that were sufficiently monitored travelled through the waterways between riverine lakes or wetlands and the Waikato River (Chapter 4, Appendix B). Study fish tended to migrate out of riverine lakes during falling water levels between (250-400 m^3/s, Rangiriri gauging station), when emergent vegetation was unavailable and returned when water levels returned to normal levels (Chapter 5). Similar connecting waterways have been exploited for capturing adult common carp in Australia using the Williams cage (Stuart *et al.* 2006) and push/jump traps (L. Thwaites, pers. com.). These traps have been proven effective in habitat comparable to the Waikato River basin. Both traps separate common carp from native fish by exploiting the jumping and pushing behaviours of common carp. Jumping and pushing traps separate native fish from common carp as native fish remain in an initial holding cage and common carp push or jump into a secondary cage. These traps would have to be tested to see if the same behavioural responses apply to native New Zealand fish and koi carp.

Koi carp tended to move during periods of low water when lateral habitat was unavailable (Chapter 4 and 5). This behaviour could be exploited by manipulating water levels in lakes and wetlands to initiate koi carp movement (Verrill and Berry 1995) to facilitate their capture. Koi carp were observed moving out of Lake Whangape and Waikare during dropping water levels in this study (Chapter 5). Water level manipulation could also be used to reduce spawning habitat or dry eggs after successful spawning events (Stuart and Jones 2002; Yamamoto *et al.* 2006).

Preventing juvenile koi from re-entering lakes, as described by Boubée *et al.* (2004), would also be necessary. High densities of juvenile common carp can reduce the abundance of large-bodied zooplankters causing a bottom up trophic cascade that may reduce water clarity and minimise the effects of adult carp removal (Schrage and Downing 2004). Preventing juvenile carp from re-entering riverine lakes will require physical barriers, such as small-mesh screen systems or hydraulic barriers (R. Norrgard, pers. com.) to be installed (Parks 2006). Rotating drum screen would be the most suitable option for preventing juvenile carp from re-entering riverine lakes. Rotating drum screens are perforated drums installed perpendicular to flow that sit 65% to 85% submerged and rotate via a paddle wheel (Bell 1991). The rotating motion of the screen deposits debris over the screen while preventing fish passage (Bell 1991). Rotating drum screens are commonly used in Washington State, USA to exclude downstream migrants from irrigation diversions (Neitzel *et al.* 1991).

Installing weirs, traps, and screens to reduce koi carp biomass in riverine lakes and wetlands will create physical barriers for native fish (Joy 2001). Manipulating water levels may also reduce spawning and rearing habitat for native fish in riverine lakes (Yamamoto *et al.* 2006). However, these disadvantages may be outweighed by the possibility of restoring riverine lakes to a stable macrophyte-dominated state.

It may also be possible to capture migrating koi carp with fish wheels similar to those used in North America to capture adult salmonids (Hayes *et al.* 1996). Fish wheels are current powered nets that scoop up migrating fish directed into the device by weirs or nets. Captured fish are automatically deposited into holding tanks that could be modified to separate or release native fish. Koi carp migrating in the Waikato River predominantly travelled within 2 m of the shoreline and would be susceptible to capture from such a device.

6.5.3 Radio telemetry

The use of "Judas" fish (Diggle *et al.* 2004; Inland Fisheries Service 2008) should be tested to improve netting efforts and could be combined with pheromone attraction. "Judas" fish, in this case, would be koi carp implanted with radio transmitters for the purpose of locating spawning sites and conspecifics. "Judas" fish have been used successfully to aid removal of common carp in Lakes Sorell and Crescent, Australia (Inland Fisheries Service 2008). It is feasible that this procedure could be advanced by using desexed female carp injected with pituitary gland extract to induce spawning pheromone production (hypophysation; Weil *et al.* 1980). If sterile females could be artificially stimulated to produce spawning pheromones and induce spawning behaviour they could potentially seek out suitable spawning locations and attract conspecifics. This procedure would be similar to using hypophysation traps (Inland Fisheries Service 2008) with the added mobility of a liberated fish. Hypophysation traps would be a less labour intensive alternative to "Judas" fish and would likely be effective during the prespawning and spawning season.

6.5.4 Bait and poison

Koi carp were observed actively feeding on bait laid by coarse fishers during this study and are thought to be vulnerable to attractants. A koi carp implanted with a radio transmitter was found feeding, with conspecifics, on corn laid by a coarse fisher, and had moved approximately 10 km from its last know position after not moving for over a month. The bait and trap technique has been used for commercial common carp removal for over 50 years and has been reported to increase catch by 3 fold (Cahoon 1953). This technique could also be used in conjunction with boat electrofishing to increase catch efficiency.

The use of the currently available poisons and poison baits are likely to kill non-target species (Gehrke 2001) and have limited effectiveness for controlling common carp (Koehn *et al.* 2000; Frederieke *et al.* 2005; Gilligan *et al.* 2005). Poisons such as rotenone can be effective for treating ponds and isolated aggregations such as spawning events but are not practical for eradications of pest fish in large lakes due to cost (Chadderton *et al.* 2001).

Common carp actively avoid rotenone baits (Bonneau and Scarnecchia 2001) and their use for removing grass carp in New Zealand was only partially effective (Rowe 1999). Poison baits could be useful during final removal efforts where boat electrofishing and netting are not practical. The efficacy of poison baits for removing New Zealand koi carp and their effect on non-target species should be tested (Rowe 2001).

6.5.5 Sound attraction

Koi carp make sounds that could be used to attract conspecifics. Common carp have highly developed hearing recognition and have even been trained to distinguish between blues and classical music (Chase 2001). It is likely that such a developed sense of sound recognition is heavily utilized by koi carp and could be used to attract fish by replaying feeding or spawning recordings in locations with low background noise. Koi carp were recorded using a hydrophone before, during and after being presented with food in the tank trial portion of this study. Before food was presented to study fish little or no noise was recorded, after food was presented numerous rapid clicking sounds were recorded. The sounds were presumably the percussion of pharyngeal teeth grinding or smashing food and were clearly audible using a hydrophone. These sounds could attract other koi carp and should be tested during appropriate field conditions. Common carp hearing is easily disrupted by background noise such as wind waves (Amoser and Landich 2005) potentially limiting the effectiveness of sound attraction. If carp are attracted to spawning sites via sound cues this could partially explain why large spawning aggregations were only observed on days of little or no wind (low background noise) during this study. Lack of wind could have also increased the water temperature of shallow spawning habitat compared to days when mixing, caused by wind waves, occurred.

6.6 Initial response and final removal

The response to new liberations of koi carp and the final stages of removing an established population should be based on the same principles (Chapter 5). First and foremost spawning must be eliminated, a single spawning event can potentially produce thousands of additional fish. Due to high site fidelity and infrequent movements, koi carp will have to be attracted or located. Developing a well thought-out removal plan based on preferred habitat will greatly improve the chances of removing small populations of koi carp and is a small investment compared to full-scale removal efforts.

Developing a model, as described in Chapter 5, of koi carp dispersal and preferred habitat would be a valuable tool for koi carp removal and rapid response planning. The data collected in this study is insufficient for building a habitat preference model. The appropriate data could be obtained in conjunction with "Judas" fish trials during removal efforts and should be collected using transplanted fish to mimic the response of koi to a new introduction. Data collected in North America (Edwards and Twomey 1982; Penne and Pierce 2008) could be used to construct a general model of common carp habitat preference, but would have to be validated for use with New Zealand koi carp. A well-designed model could be adapted for use with other species within New Zealand and could potentially be used in other countries.

To date there has been no confirmed report of koi carp above Karapiro Dam on the Waikato River. It is likely that koi carp could be liberated into upriver hydropower reservoirs and could potentially be introduced into the Rotorua lakes. Continuing public education programmes, monitoring for new introductions, and preparing a pest fish rapid response plan will decrease the likelihood of such introductions becoming successful breeding populations.

6.7 Conclusion

Although the threshold for returning the riverine lakes of the lower Waikato River basin to a stable macrophyte-dominated state is unknown, overseas literature suggest a reduction in biomass of at least 70% is necessary (Meijer *et al.* 1999; Zambrano *et al.* 2001). The mobility of koi carp and their use of lateral habitat, described in this thesis, suggest that targeting migrants may allow managers to remove a significant proportion of the Waikato River Basin adult koi carp population with trapping alone. Koi carp removal alone may not return riverine lakes to a macrophyte-dominated state. Like most natural systems other confounding factors such as sediment resuspension by wind (Perrow *et al.* 1997; Lougheed *et al.* 1998) and nutrient inputs from agriculture (Jeppesen *et al.* 1999) must be addressed simultaneously to increase the likelihood of successful lake restoration. Regardless of the removal method, a long-term commitment is required to reduce koi carp biomass to a biologically significant level. Koi carp in the lower Waikato River are highly fecund (Tempero *et al.* 2006) and will require total eradication or continual removal efforts to improved water quality in the long term. However, with adequate funding and a long-term commitment I am confident that koi carp biomass can be significantly reduced in the riverine lakes and wetlands of the lower Waikato River basin.

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Appendix A: A novel use of ArcGIS Network Analyst to process river based telemetry data

Appendix A: Introduction

Telemetry data for animals confined to a restricted habitat, such as water, are typically processed manually by connecting fish locations on a base map. Manual processing is time consuming and introduces inconstancies caused by inaccurate tracing of base maps. Previous GIS-based tools simply draw straight lines between points and cannot be confined to boundaries like a river or lake edge resulting in underestimates of travel distances. Network Analyst (ArcMap 9.2, ESRI, Redlands, CA, USA), a GIS-based programme typically used to analyse data based on road networks, can be used by creating a network based on the available habitat of the study animal to confine the potential movement resulting in precise estimates of travel distance. The following is a step-by-step description of the procedure used to create a network, enter telemetry data, and interpret the results of Network Analyst output. This procedure will link and measure the distance between points in chronological order based on a network of available habitat.

Appendix A: Methods

1 Create a line file (shape file) that covers your study area. Consider this a road network for your study animals to travel on. For this study, a line file was used that connected rivers, lakes and wetlands. For a lake, this could be as simple as a line down the middle with fingers to the different portions of the lake.

1.1 Make sure each segment of the line has a distance field. For example, if your line file is X shaped you should have 4 segments, and each segment must have a field with its length.

Appendix A:

1.2 You must also make sure all the segments connect. If the line segments do not connect the analysis will stop at the gap, resulting in an error.

2 You can now convert the line file of your study area into a network using ArcCatalog.

2.1 First turn on the Network Analyst extension in ArcGIS by selecting the "Tools" menu, then "Extensions" and selecting "Network analyst".

2.2 Open ArcCatalog and right click the shape file of your study area you have made, and then select "New Network Dataset".

2.2.1 When you are be prompted to enter a file name, do so.

2.2.2 Then you will be asked to pick a connectivity setting; choose "Default" and do not modify connectivity.

2.2.3 Select "Yes" for "Do you want to model U turns?".

2.2.4 You will be prompted to "Specify the attributes for the network dataset". Select "Add" and type the name of the heading you used for distance on your shape file in the "Name" box. Then set the units to match the units of your distance measurement in the shape file. Leave "Usage type" and "Data type" as the default.

2.2.5 You will be prompted "Do you want to establish driving directions..."- select "No".

2.2.6 You should now see a summary page -select "Finish".

2.2.7 Now you should see "The new network has been created would you like to build it?" select "Yes".

2.2.8 If you get an error here about the file it is probably because you are using relative paths with your file names and it has found a similar network in the folder so you can either make a new folder, for each network you build from a shape file or change the name of the shape file you start with.

3 Now you add the network you created and associated files to a ArcMap layer.

3.1 This should add three files, the original line file, a "_Junctions" point file and an "Edges" line file.

4 Select "New Route" under the network analyst menu.

4.1.1 If you don't see the Network Analyst tab you need to turn on the Network Analyst extension, see 2.1.

5 You should have just created a route tree in your active layer with the label "Route 1"

6 Now you can add your telemetry data, but to do this you need to have your fish locations in a shape file.

6.1 The file must indicate the order you would like your data connected. You can use the date and time or you can make a new column and chronologically number each consecutive point.

6.2 You can import your data as one file by placing the X positions, Y positions and chronological order of points in separate work sheets for each individual in an Excel workbook.

6.2.1 ArcMap will not recognise the new Excel 2007 so you have to save the workbook in the Excel 1997-2003 format.

6.3 When you have made your Excel file, open ArcCatalog, navigate to the workbook, left click the workbook, right click a worksheet you would like to add, select “Create Feature Class” and “From XY table”.

6.3.1 Add your fish points to the layer you have set up the network in. If the points do not appear on or near your network check to make sure the points and network, are in the same datum.

7 Now that you have created your shape file you can right click on “Stops (0)” in the new window next to your layers window and select “Load locations”.

7.1 . If you do not see a Network Analyst window with “Stops (0)” “Routes (0)” and “Barriers (0)”, left click the “Show/Hide Network Analyst Window” box next to the “Network Analyst” pull-down tab.

7.2 Use the folder in the upper right to navigate to a shape file with your telemetry data.

7.3 Use the “Select Field” pull down tab to select the field that you used to order your data.

7.3.1 You can now select a “Search Tolerance” this is the distance from a point to your network that the programme will accept. For aircraft data, set the set “Search Tolerance” to high (5000 m), but you can set “Search Tolerance” to whatever suits your situation to filter points to far from the network you have created.

7.3.2 Select “OK” and Network Analyst will draw a line perpendicular to the network you have created to the points you loaded. You should see the point appear as numbered points on the network.

7.3.3 Points that cannot be found or are outside the your “Search Tolerance” will appear as “?” and will not be included in the analysis.

7.3.4 Left click on “Solve” to the right of the “Network Analyst” pull-down tab or right clicking “Route” under your layer and selecting “Solve”.

8 You should now see a 1 instead of a 0 next to “Routes” and the route should be drawn on your network.

8.1 If you have stops that are not included in the route you will see an error; this indicates that you have a disconnection or gap in your network.

8.1.1.1 To find the location a gap in your network you can create stops along the suspect portion of the network and rerun the route to find the approximate location of the problem.

9 To view the distance travelled, just right click on “Stops” (just under “Route” on the far left in the layers window) and then “Open Attribute Table”. You should have a coulomb with cumulative length (Cumul_LENGTH) at each point entered on the route.

10 The attribute table can be exported as an Excel workbook, left click “Options” then “Export”. In Excel the cumulative length column can be used with an existing date-time column to calculate distance moved at each location and velocities.

11 To load the next fish left click on “Stops (1)” in the Network Analyst window then “Delete All”. Then do the same with “Route (1)” in the same window. They should both read “(0)”.

11.1 Now repeat the steps above starting at 7.

Appendix B: Koi carp migrations by release site

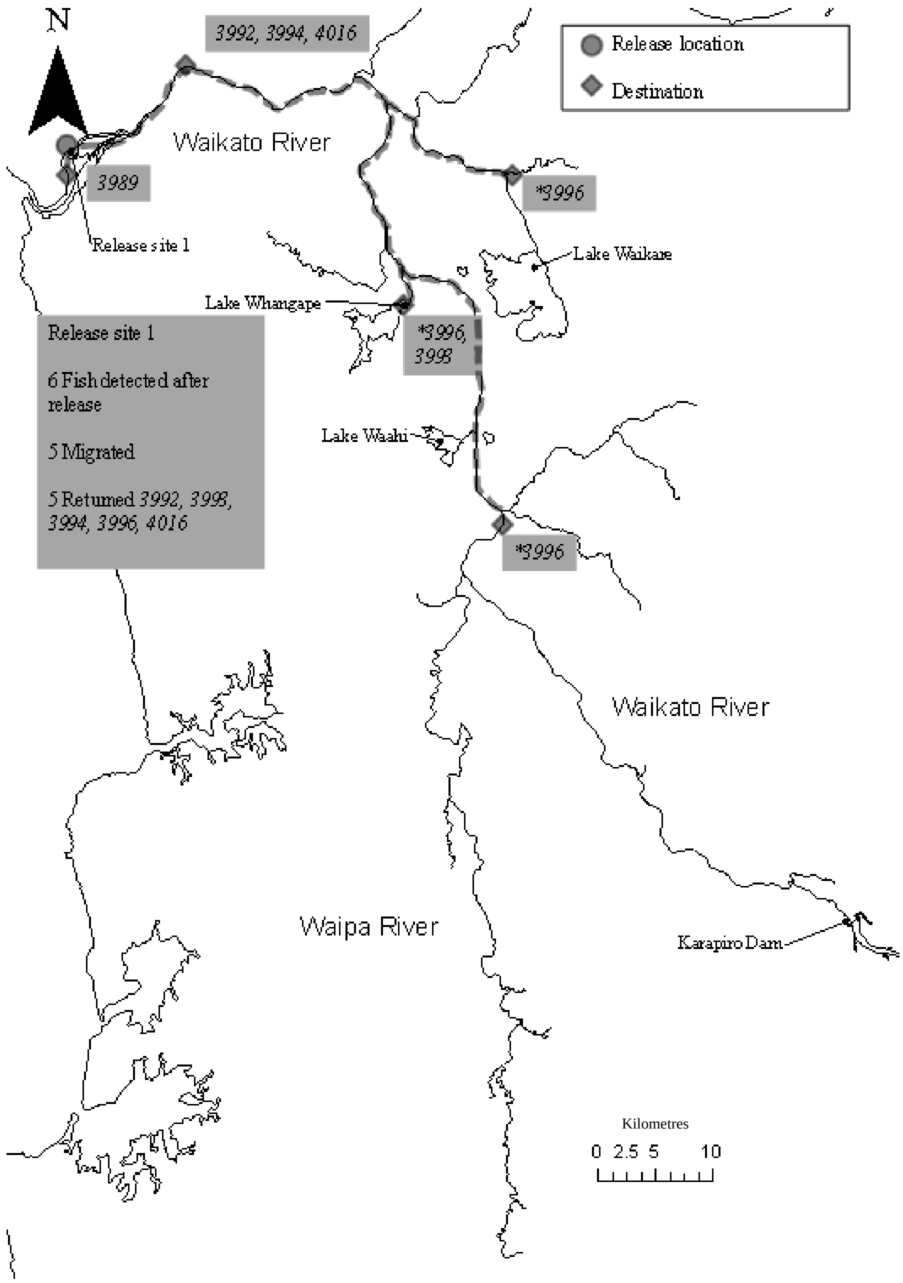

Fig. B.1. Migration locations of koi carp implanted with acoustic transmitters released at site 1 in May 2007. See Tables 4.1 and 4.3 for release site locations and release dates. Identification numbers of fish implanted with acoustic transmitters are shown in italics. * identifies fish that migrated to multiple water bodies. Dashed lines indicate likely migration paths.

Appendix B:

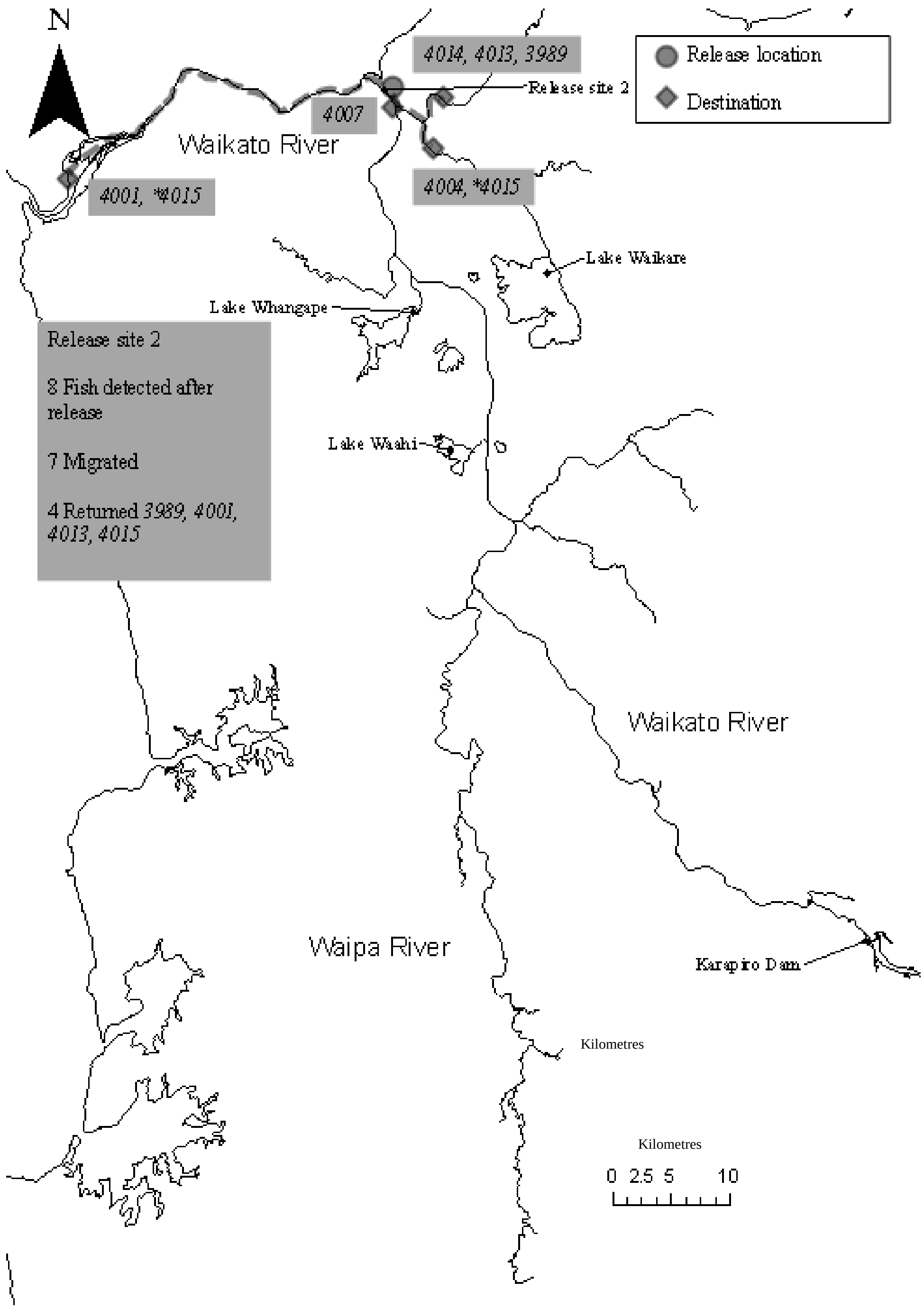

Fig. B.2. Migration locations of koi carp implanted with acoustic transmitters released at site 2 in May 2007. See Tables 4.1 and 4.3 for release site locations and release dates. Identification numbers of fish implanted with acoustic transmitters are shown in italics. * identifies fish that migrated to multiple water bodies. Dashed lines indicate likely migration paths.

Appendix B:

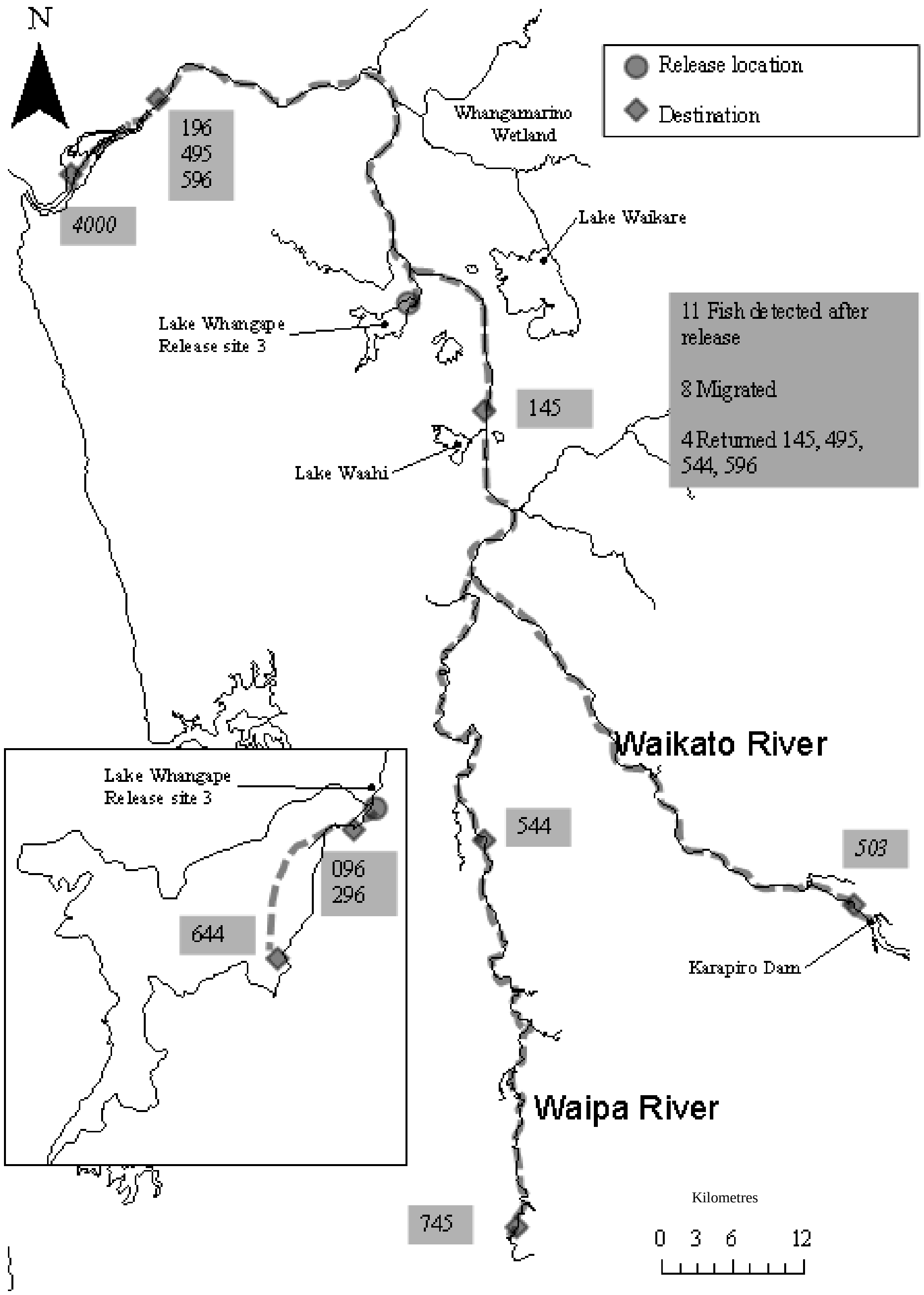

Fig. B.3. Migration locations of koi carp implanted with radio and acoustic transmitters released at site 3 in August 2007. See Tables 4.1, 4.2 and 4.3 for release site locations and release dates. Identification numbers of fish implanted with acoustic transmitters are shown in italics. Dashed lines indicate likely migration paths.

Appendix B:

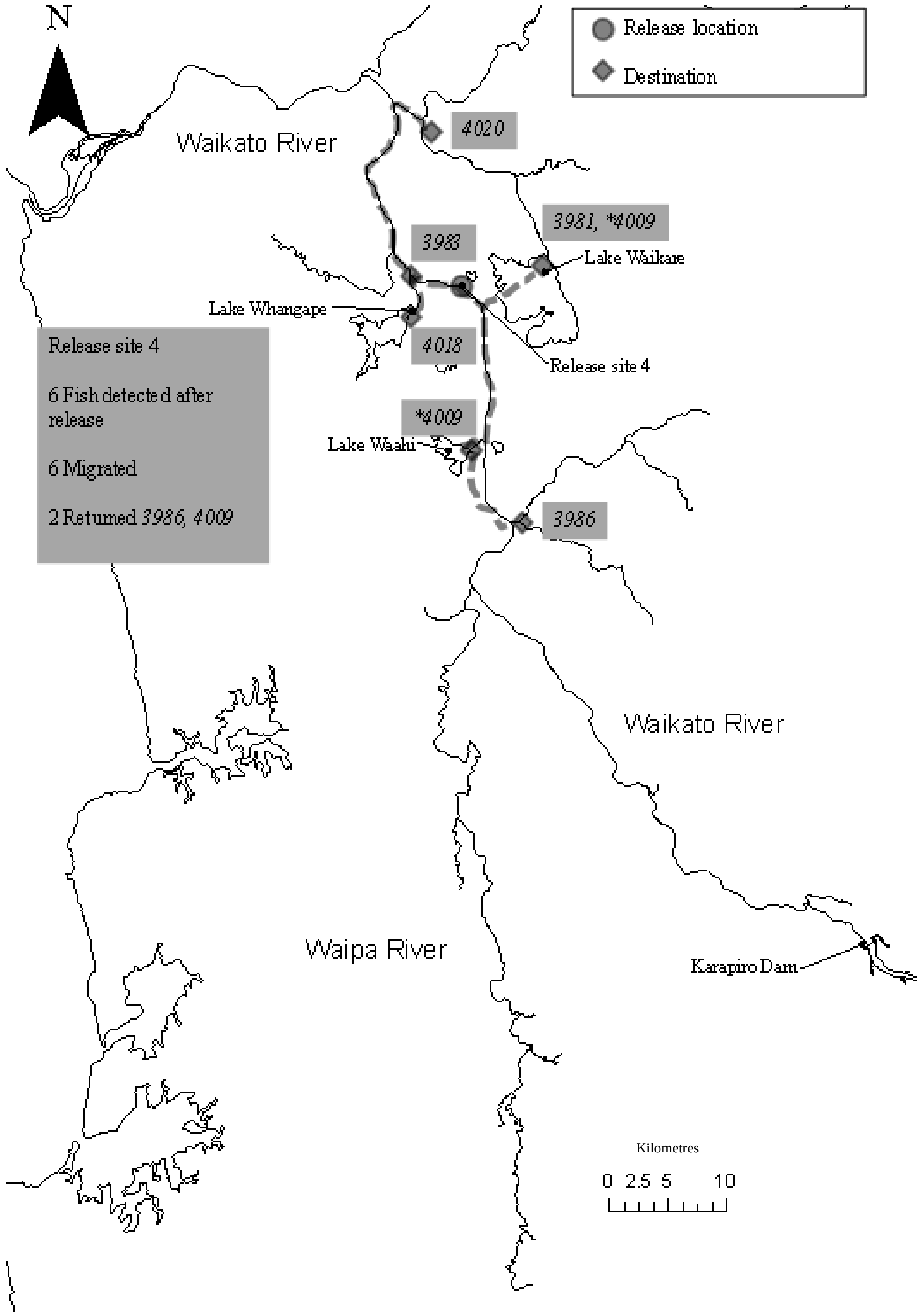

Fig. B.4. Migration locations of koi carp implanted with acoustic transmitters released at site 4 in May 2007. See Tables 4.1 and 4.3 for release site locations and release dates. Identification numbers of fish implanted with acoustic transmitters are shown in italics. * identifies fish that migrated to multiple water bodies. Dashed lines indicate likely migration paths.

Appendix B:

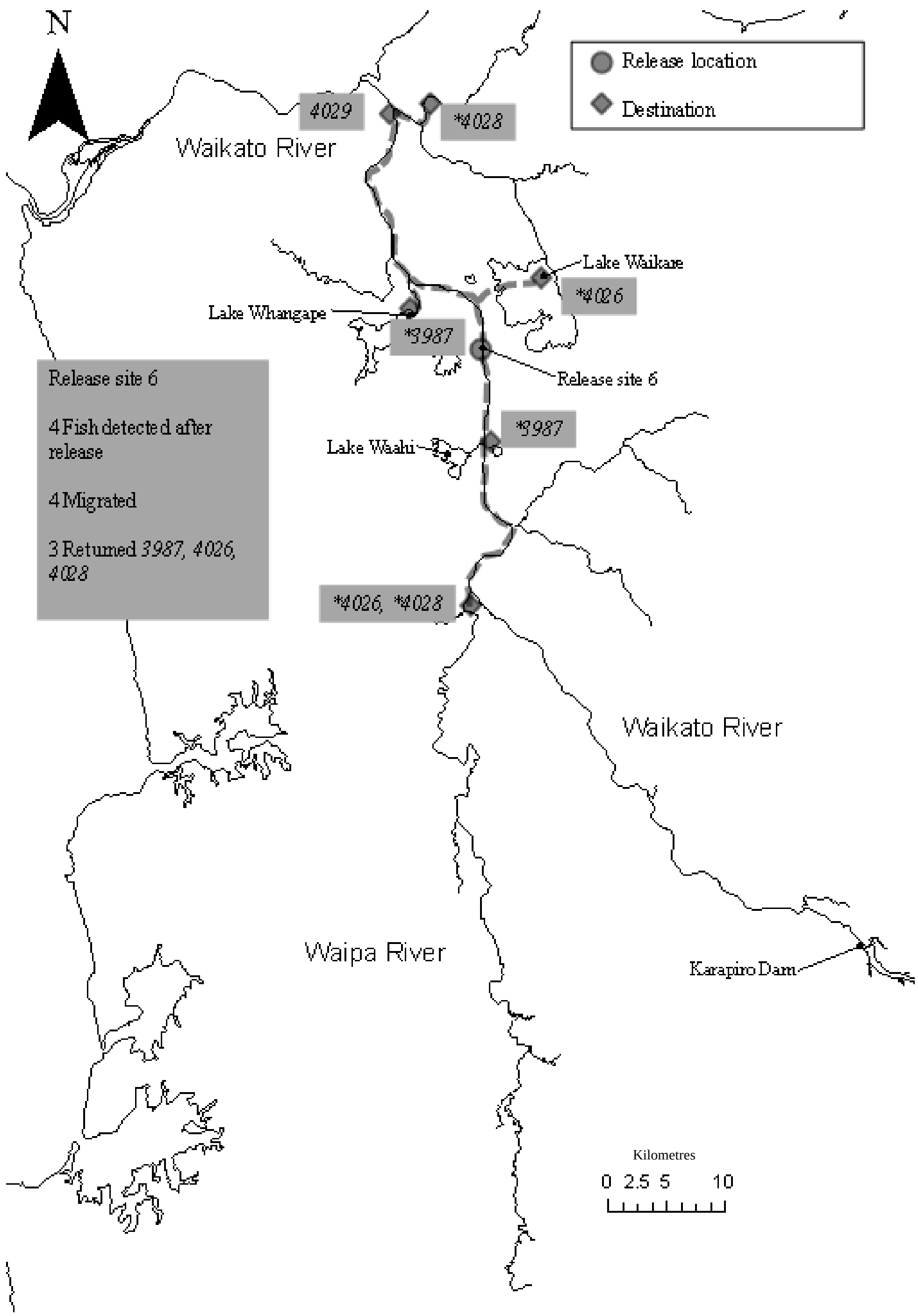

Fig. B.5. Migration locations of koi carp implanted with acoustic transmitters released at site 6 in May 2007. See Tables 4.1 and 4.3 for release site locations and release dates. Identification numbers of fish implanted with acoustic transmitters are shown in italics. * identifies fish that migrated to multiple water bodies. Dashed lines indicate likely migration paths.

Appendix B:

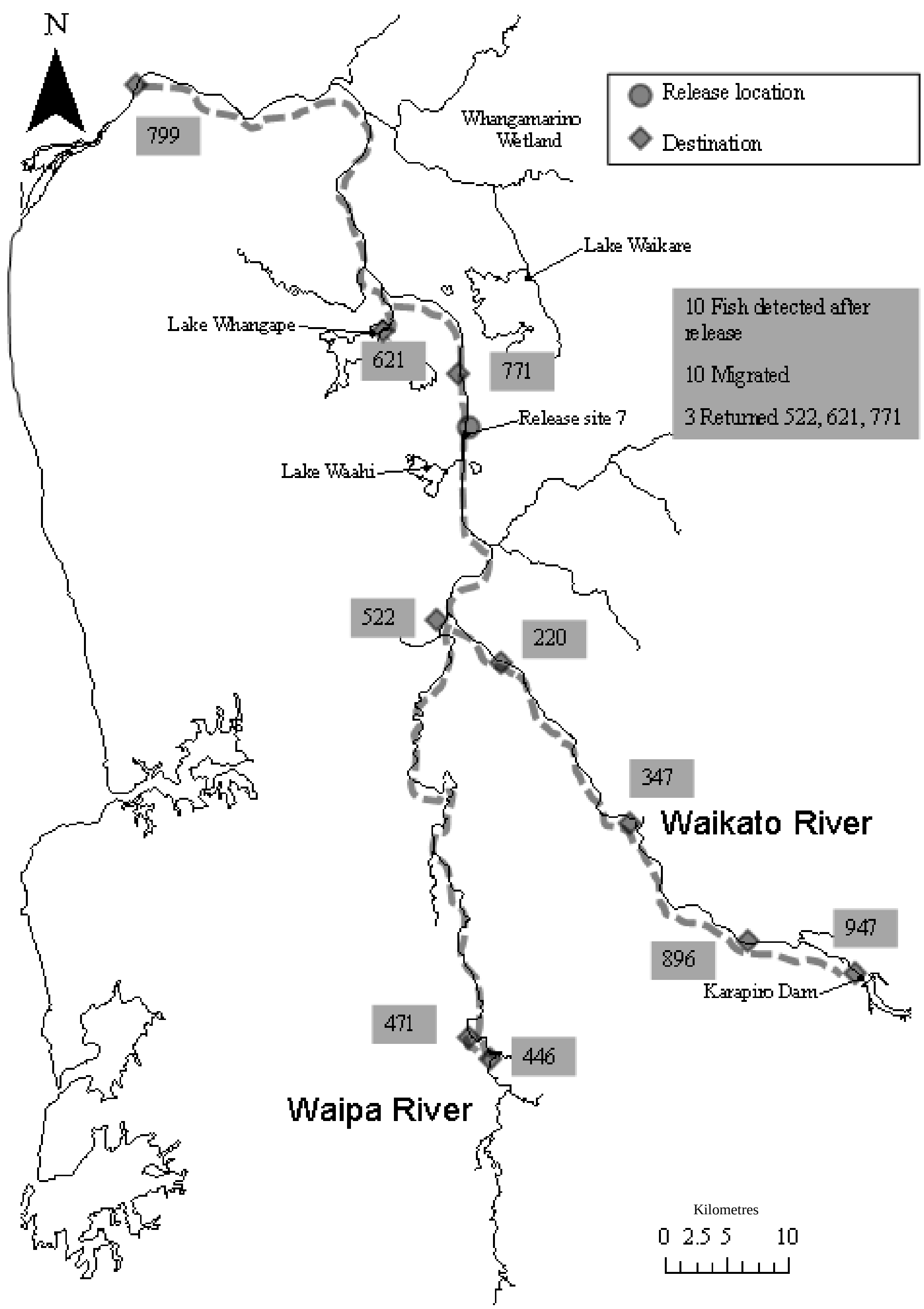

Fig. B.6. Migration locations of koi carp implanted with radio transmitters released at site 7 in July 2007. See Tables 4.1 and 4.2 for release site locations and release dates. Dashed lines indicate likely migration paths.

Appendix B:

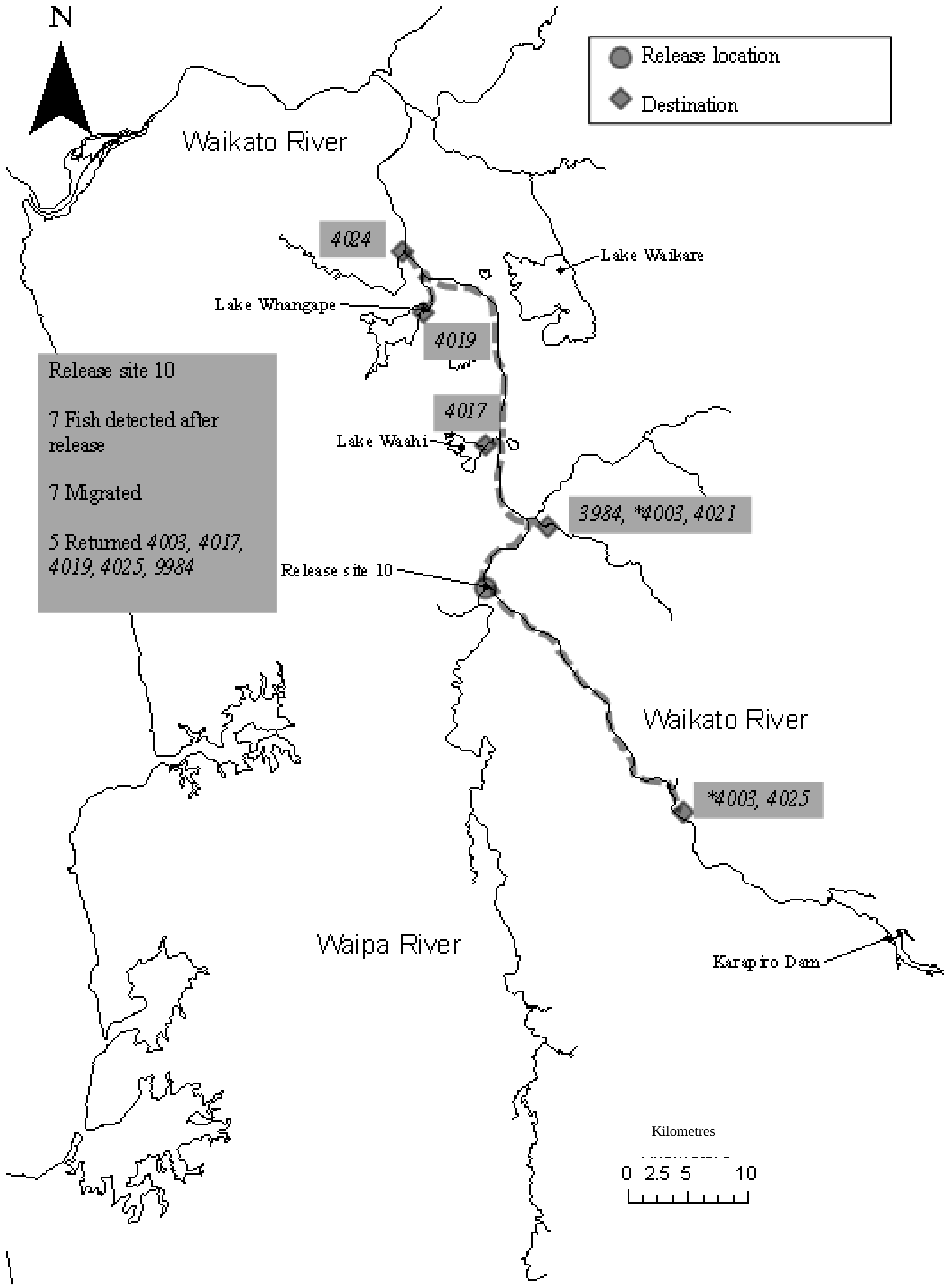

Fig. B.7. Migration locations of koi carp implanted with acoustic transmitters released at site 10 in May 2007. See Tables 4.1 and 4.3 for release site locations and release dates. Identification numbers of fish implanted with acoustic transmitters are shown in italics. * identifies fish that migrated to multiple water bodies. Dashed lines indicate likely migration paths.

Appendix B:

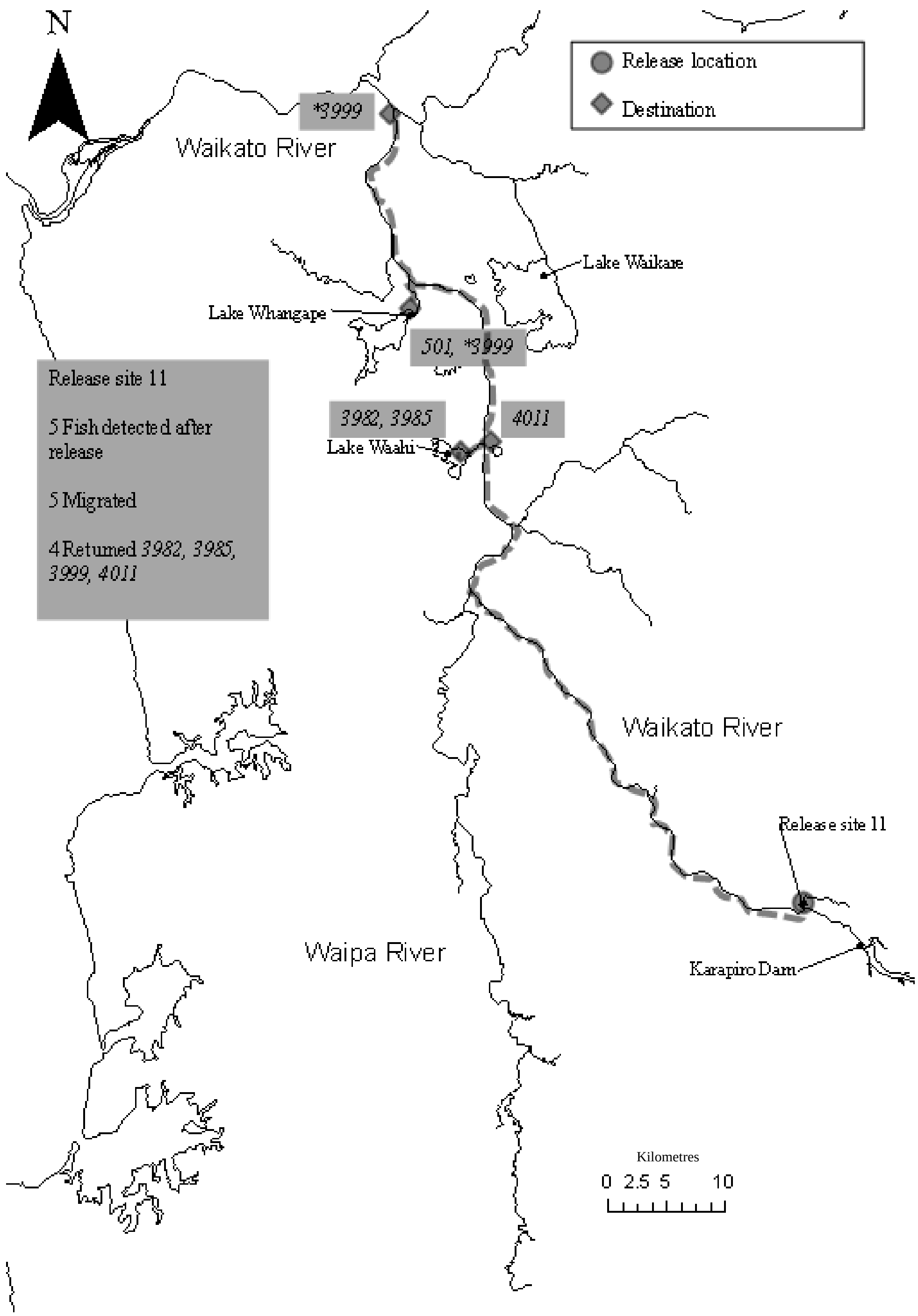

Fig. B.8. Migration locations of koi carp implanted with acoustic transmitters released at site 11 in May 2007. See Tables 4.1 and 4.3 for release site locations and release dates. Identification numbers of fish implanted with acoustic transmitters are shown in italics. * identifies fish that migrated to multiple water bodies. Dashed lines indicate likely migration paths.

Appendix B:

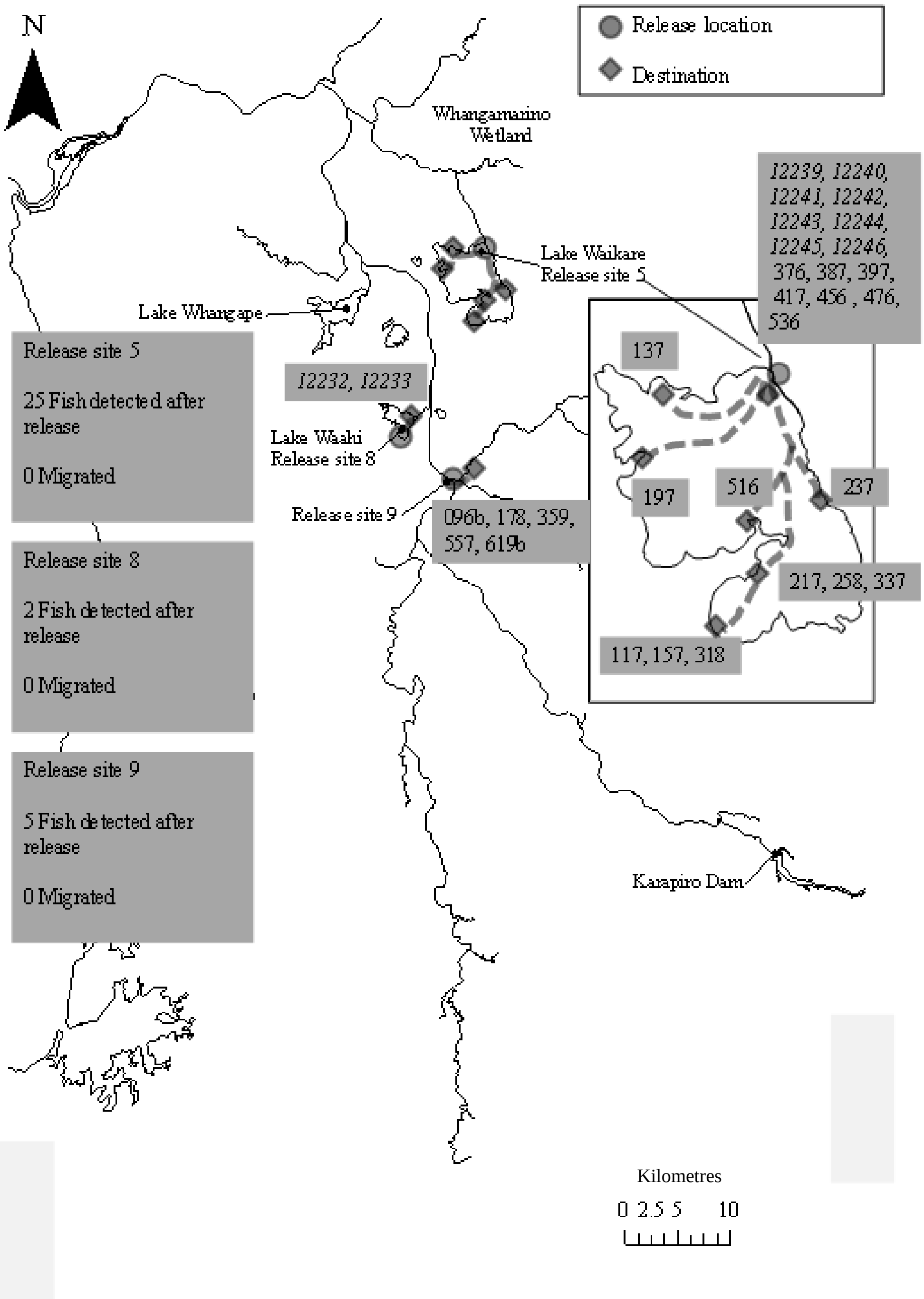

Fig. B.9. Migration locations of koi carp implanted with radio and acoustic transmitters released at sites 5, 8, and 9 in July and August of 2008. See Tables 4.1, 4.2, 4.3, and 4.4 for release site locations and release dates. Identification numbers of fish implanted with acoustic transmitters are shown in italics. Dashed lines indicate likely migration paths.