THE BIOLOGY AND GENERAL ECOLOGY OF THE BROWN BULLHEAD CATFISH (*AMEIURUS NEBULOSUS*) IN LAKE TAUPO

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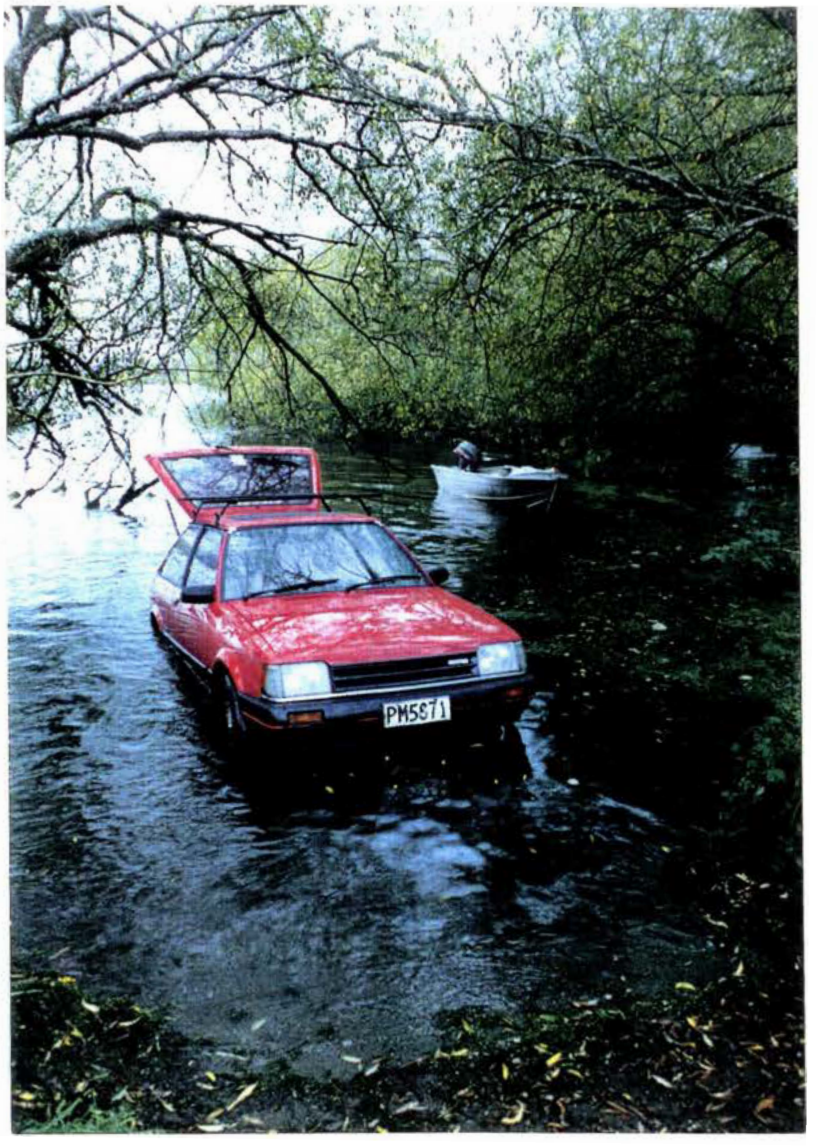

Frontispiece: The 13th fyke net (unlucky for some).

Abstract

The population structure, relative fish abundance, age, growth rate, and diet of the brown bullhead catfish (*Ameiurus nebulosus*) in Lake Taupo were examined. The study attempted to evaluate the possible impacts of catfish on the trout fishery in the lake. Fyke nets were set within the southern region of the lake at sites consisting of three distinct habitat types (weedy, rocky, and sandy), and left to fish overnight. Sampling was undertaken between 28 February 1995 and 15 December 1995 with catches grouped by season.

A total of 6226 catfish were caught from 273 fyke nets set at the southern sites, which gave a mean CPUE of 23 fish net^{-1} $night^{-1}$. A further 27 fish were captured in the northern regions of the Lake Taupo as part of the distribution experiment.

Abundance of catfish was greatest at the weedy sites followed by rocky and sandy sites respectively. Catch rates at sandy sites were consistently low. Macrophyte communities provide catfish with protection during daylight hours and spawning, and a large food source from associated macrophyte fauna. The abundance of catfish at Motuoapa Bay has remained relatively constant since 1986. Catfish are believed to have reached the carrying capacity of the bay forcing juvenile catfish to migrate in search of vacant territories. The availability of vacant habitats supporting dense macrophyte communities is a major factor restricting the maximum number of catfish in Lake Taupo.

The ages of catfish ranged from 1 to 8 years, with the majority of fish in their third season of growth. The conditions in Lake Taupo are favourable for rapid catfish growth. Somatic growth of catfish in this study was similar to that of Waikato and overseas catfish in the first two years and, whilst subsequently lower than the Waikato, was faster than other studies in the following years. The maximum length of catfish in Lake Taupo (359 mm F.L.) is less than that found in the Waikato (455 mm F.L.).

Catfish in Lake Taupo spawn between September and December at a similar season to fish from the northern hemisphere. The temperature threshold necessary for spawning to commence in overseas populations is considerably higher than that observed in Lake Taupo. Fecundity at Taupo appeared to be comparable with the Waikato and higher than overseas populations.

The diet of catfish was size and habitat dependent. Catfish from weedy sites fed upon gastropods, Trichoptera, cladocerans, and chironomids. Larger catfish were found to prey to a greater extent, koura, fish, and Odonata. Generally, catfish from rocky habitats had a similar diet to catfish from weedy habitats however, large catfish fed almost exclusively on koura and, to a lesser extent, gastropods.

At present population levels catfish are unlikely to influence trout size or numbers, however, there is potential for negative impacts to occur if catfish numbers increase significantly, particularly at depth. The degree of piscivory observed in catfish was not considered sufficient enough to cause a large decline in prey species, especially bullies. The predation of koura by large catfish will potentially decrease its abundance within the littoral zone of rocky and weedy habitats.

To my Parents,

Helen and Paul Barnes

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Chapter 1:
Introduction

1.1 Biology of the Brown Bullhead Catfish

The brown bullhead catfish (Figure 1.1) belongs to the following taxonomic groups:

Class	Osteichthyes
Subclass	Actinopterygii
Superorder	Ostareophysei
Order	Cypriniformes
Suborder	Siluroidei
Family	Ictaluridae
Genus	*Ameiurus*
Species	*nebulosus*

Until a few years ago this species was placed in the family Ameiuridae and the genus *Ictalurus*. Following a study on ictalurid catfishes and, more specifically, the Toothless Blindcat (*Trogloglanis pattersoni*), Lundberg (1982) concluded that the brown bullhead catfish belonged in the genus Ameiurus rather than *Ictalurus*. The change did not gain universal acceptance until the issue was again discussed in Mayden (1992) where Lundberg's 1982 paper was re-published. The family Ictaluridae is one of the smaller catfish families, containing only 40-50 species (McDowall, 1990).

The brown bullhead catfish *Ameiurus nebulosus*, hereafter referred to as catfish, originated from fresh and brackish water in North America. Catfish are native east of the Rocky Mountains from southern Canada south into Central America. They have been extensively introduced in the United States of America and are now well established as far east as California (McGammon and Seeley, 1961; Sinnot and Ringler, 1987). Catfish were released into Germany in the early 1900's and have been widely moved from there to England, many European countries, and the former Soviet Union (Scott and Crossman, 1973).

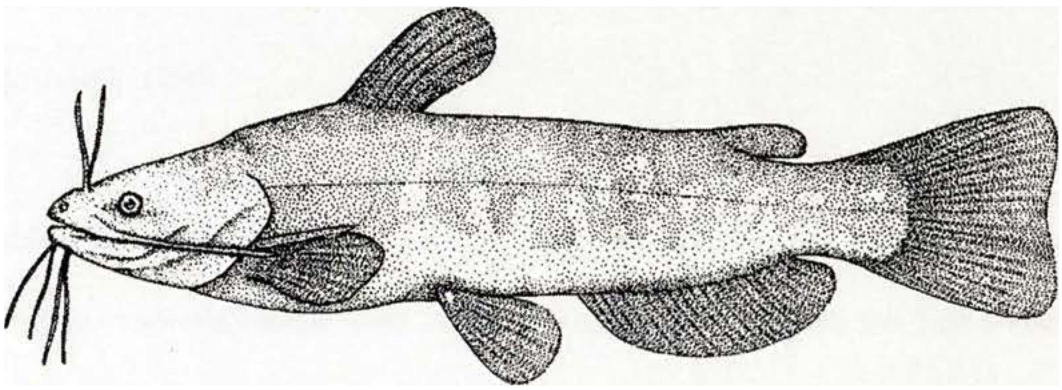

Figure 1.1 Brown bullhead catfish (*Ameiurus nebulosus*). F.L.=330 mm (McDowall, 1990).

Catfish are easily distinguished from other freshwater fish species in New Zealand by the presence of eight whisker-like barbels around the mouth, and also rigid spines in the dorsal and pectoral fins (McDowall, 1990). Catfish are a thick-bodied fish with a broad, sloping, dorso-ventrally flattened head. The eyes are extremely small relative to body size (Scott and Crossman, 1973). There are no scales and the skin has a thick mucous covering (McDowall, 1990). Catfish are dark brown to greenish olive, paling slightly on the sides. Small fish may be of similar colour to the adults, but some are wholly gold to greenish gold in colour (McDowall, 1990).

1.1.1 Life History

Catfish occupy sluggish, muddy and/or weedy streams and lakes. They are very robust and can endure wide ranges in environmental conditions which may be limiting for other fish species. In their native habitat they have been found to survive temperatures as high 36.1°C and oxygen levels as low as 0.2 ppm (Scott and Crossman, 1973). They are able to live out of water for long periods of time so long as they remain moist (McDowall, 1990).

Catfish have a highly developed social structure and communicate with one another by releasing chemicals into the water. They have a keen sense of smell and their bodies are covered with thousands of taste buds (Patchell, 1981).

1.1.2 Growth

Catfish normally reach a total length of 200-350 mm long, although it has been found to grow up to 500 mm in length and more than 3 kg in weight (Scott and Crossman, 1973).

In New Zealand, there are reports of catfish reaching 480 mm and more than 2 kg (McDowall, 1990). Growth rate studies in Ohio, United States of America, showed that growth is moderately rapid and four months after hatching the young range in length from 50-120 mm long (Keast, 1985). Growth rates in post 1+ age classes in the Waikato were found to be higher than in their native range (Patchell, 1977). Patchell (1981) found that most catfish in the Waikato were one to five years old, but may reach eight years of age.

1.1.3 Diet

Catfish are opportunistic food generalists, feeding nocturnally on or near the bottom. They rely heavily upon chemosensors to locate prey items and have been shown to detect food up to 25 body lengths away by taste alone (Keast, 1984). The young feed mostly on chironomid larvae, cladocerans, and amphipods (Scott and Crossman, 1973). The adults are truly omnivorous in that their food is composed of offal, detritus, molluscs, invertebrate larvae, terrestrial insects, leeches, crustaceans, worms, plant material, fish, and fish eggs (Scott and Crossman, 1973). In New Zealand catfish are known to prey predominantly upon invertebrate larvae and molluscs (Patchell, 1977; McDowall, 1990).

1.1.4 Reproduction

Sexual maturity is usually attained by age 3+ where females between 200-230 mm in length may have 2000-13000 eggs in their ovaries (Scott and Crossman, 1973). Spawning is thought to occur during late spring and early summer. Waikato populations are known to spawn more than once during this period (Patchell, 1981). Nests are constructed along the littoral zone in water depths ranging from 15 cm to 2 m and are well guarded during the incubation period. The young are shepherded by the parents, usually the male, for a couple of weeks immediately after hatching (Scott and Crossman, 1973). Catfish remain gregarious during most of the year except during mating when they will strongly defend their nesting site from other intruders (Patchell, 1977).

1.2 History of Catfish in New Zealand

Catfish were introduced into New Zealand in 1878 from the United States of America (Patchell, 1977). The first liberations consisted of 140 live catfish released into St. Johns Lake, Auckland (McDowall, 1990). Since the first release, catfish have been distributed via both intentional, and unintentional releases, into many rivers and lakes in both the North and the South Islands (Figure 1.2). Catfish are now present in the Waikato River, occurring as far upstream as Aratiatia. There are populations in the Wairoa River, north of Kaipara Harbour, in the Piako and Waihou Rivers, and there have been reports of catfish sightings from various parts of the Whanganui River (McDowall, 1990). Most recently, catfish have established viable populations in Lake Taupo, centered around the southern parts of the lake.

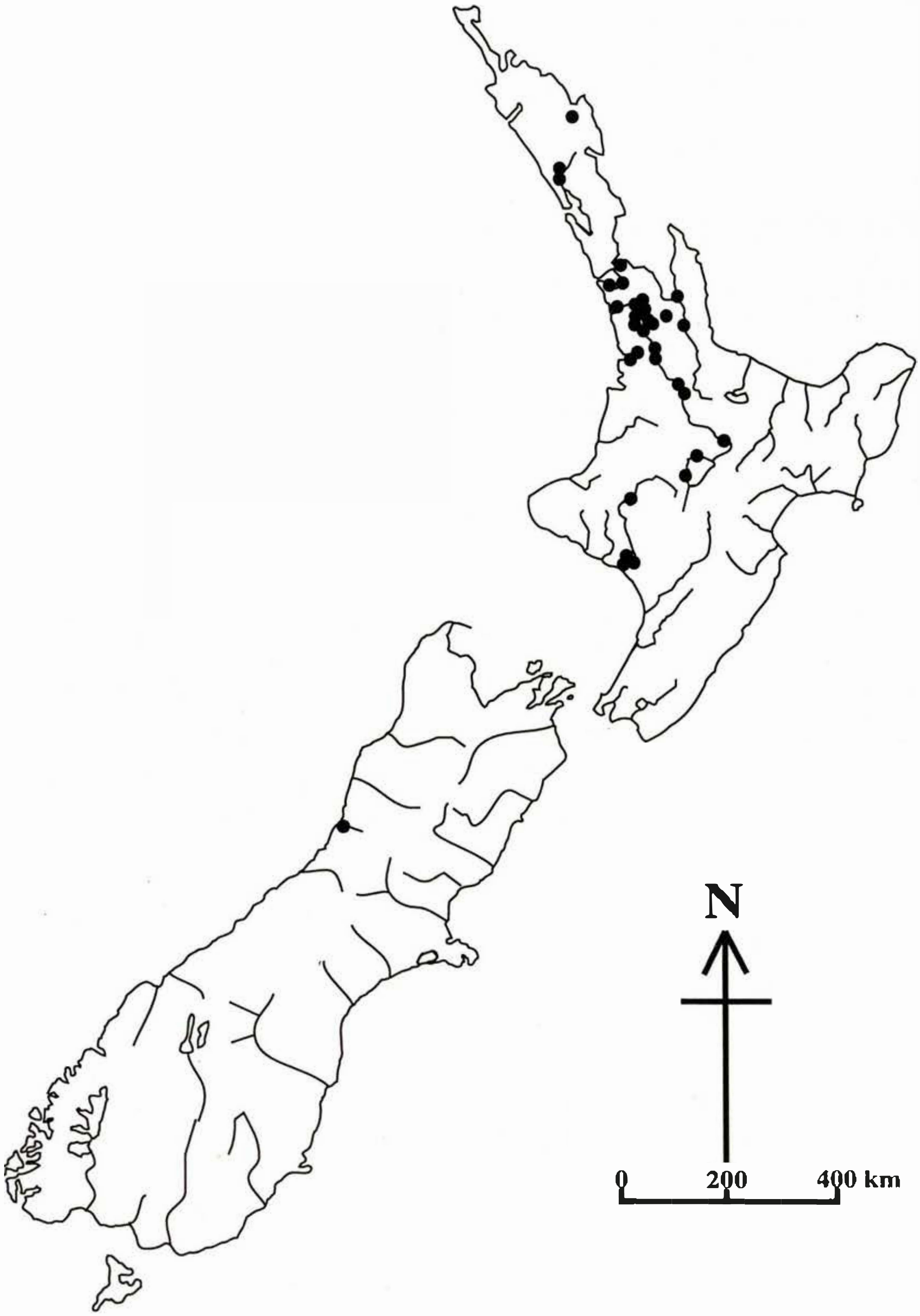

Figure 1.2 Distribution of brown bullhead catfish in New Zealand. Eaeh black dot represents a record of presence (adapted from McDowall, 1990).

There exists a degree of conjecture as to the length of time catfish have been present in Lake Taupo. Official documents (Fechney, 1986), first noted their presence in 1985 in Motuoapa bay and the first preliminary study on their abundance was carried out the following year.

This initial study was prompted by public concern as to the possible impacts the presence of catfish would have on the lake ecosystem and, specifically, on the trout fishery. Results from that study carried out in 1986 by Dr. Theo Stephens of the Department of Conservation, suggested that catfish were illegally released into the lake during the late seventies or early eighties.

1.3 Study Design

Since the introduction of catfish into Lake Taupo no extensive research has been carried out on their biology, general ecology, and the potential impacts on the trout fishery. This study attempted to investigate the above aspects by adopting the following objectives:

1) to evaluate spatial and seasonal feeding of bullhead catfish in different habitats at different times of the year through dietary analysis.
2) to investigate catfish abundance, fecundity, growth, and habitat use.
3) to investigate aspects of catfish spawning including where and when spawning occurs.

This study was restricted to the littoral zone of Lake Taupo to depths of less than 5 metres. No attempt was made to capture fish outside this area.

1.4 Site Description

1.4.1 Lake Taupo

Lake Taupo, with an area of 616 km^2 is Australasia's largest lake (Lister, 1978). It occupies a natural land catchment of 286 515 ha which ranges in altitude from 357 m to 2800 m above sea level. A further 67 110 ha of artificially diverted catchment, resulting from the Tongariro hydro-electricity scheme, increases the total catchment area to 353 625 ha (Lister, 1978). Lake Taupo is drained by the Waikato River.

One or more large lakes have been a feature of the centre of the North Island for possibly 1 million years. The formation of Lake Taupo was attributed to large downfaulting of the Taupo-Rotorua depression and uplifting of land to the east and west (Timperley, 1983a). Rhyolite eruptions from the Taupo volcanic zone produced huge flows of ignimbrite which remain the dominant feature of the western bays shoreline. Development of the lake since that time has been dominated by eruptions producing pumice and ash (Timperley, 1983a).

Approximately half the water entering the lake does so at the southern end, together with large quantities of sediment carried by the Tongariro river from the eroding slopes of the volcanoes to the south. The soils are recently derived from rhyolite pumice. Soluble phosphorus concentrations in groundwater and springs are high, with nitrogen the limiting nutrient during summer stratification (White, et al. 1980).

The structure, position, and elevation of the Lake Taupo catchment are major factors influencing the climate of the area. Continuous mountain ranges in the east and south-east rising to over 1500 m, with relatively low (1000 m) ranges in the west and south-west, leave the catchment open to the prevailing westerly winds, with winter slightly less windy than summer (Timperley, 1983b). West and north-west winds flowing over the National Park volcanoes are largely responsible for the high rainfalls in the southern catchments (Lister, 1978). Rainfall is evenly distributed throughout the year, with high intensity rainfalls characteristic in the southern catchments (Lister, 1978).

Lake Taupo is classified as warm monomictic, being thermally stratified in summer and temperatures not falling below 4°C in winter (Hutchinson, 1957). Surface temperatures in summer only briefly rise above 20°C (Figure 1.3). The bottom waters of the lake are virtually constant in temperature throughout the year. Maximum phytoplankton biomass occurs in late winter when surface temperatures are 10-11°C and secchi disc readings may drop from ca. 18 m to 10-12 m at this time of year (Jolly, 1968). Maximum crustacean zooplankton biomass occurs during early spring (Forsyth and McCallum, 1980).

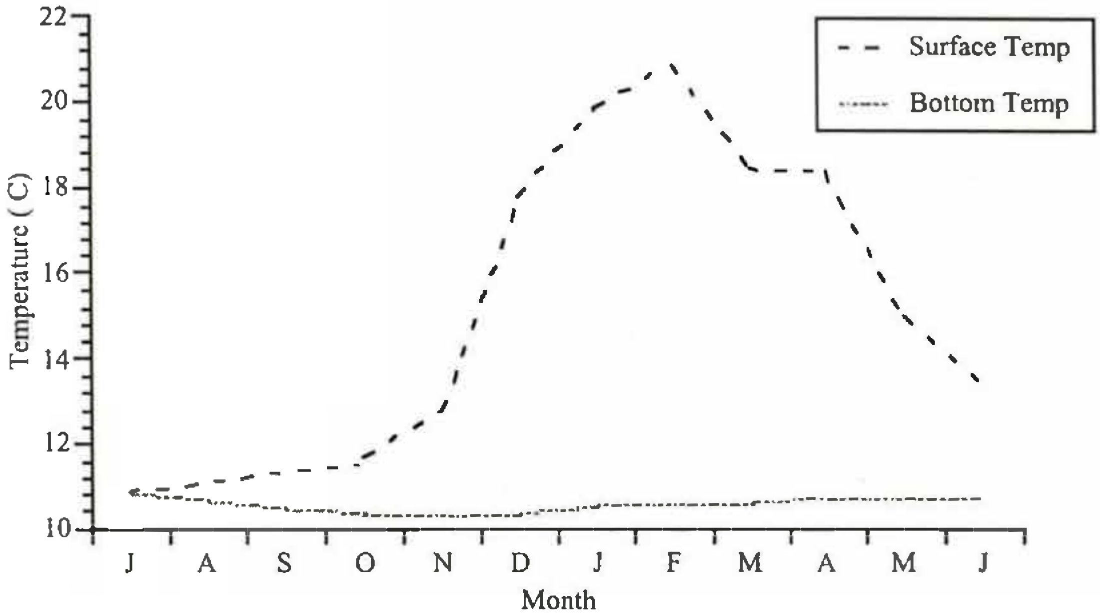

Figure 1.3: Annual temperature range of surface and bottom waters in Lake Taupo during 1994-1995 (Gibbs, M.M. unpublished data).

The species and abundance of plants in the littoral zone of Lake Taupo are closely related to the type of shoreline and lake sediment. The extent to which cliffs dominate the shoreline limits the degree to which rooted plants can become established in these areas (Howard-Williams and Vincent, 1983). In sandy areas exposed to vigorous wave-action there is little or no plant growth and much of the lake's eastern shore is like this. Along less-exposed sandy shores (37% of Lake Taupo's shoreline) large communities of native and exotic macrophytes dominate (Howard-Williams and Vincent, 1983).

In recent years these native macrophyte communities have largely been smothered by introduced oxygen weeds *Elodea canadensis* and *Lagarosiphon major* (Howard-Williams and Vincent, 1983). At one time native communities of milfoils (*Myriophyllum triphyllum* and *M. propinquum*) the water grass (*Ruppia polycarpa*) curly leafed *triphyllum* and *M. propinquum*) the water grass (*Ruppia polycarpa*) curly leafed pondweed (*Potamogeton crispus*) and one of the water buttercups (*Ranunculus fluitans*) would have dominated (Howard-Williams and Vincent, 1983).

These introduced macrophytes generally form single species communities with closed canopies (Brown, et al, 1973; Brown, 1975). *Lagarosiphon* grows at depths of 2-6 m generally, although it may be found at shallower depths in sheltered areas (Chapman et al, 1971). Up to the late seventies its domination was largely restricted to the inner zones of Waihi Bay, Acacia Bay, Stump Bay, and Motuoapa Bay (Wilson and Turner, 1977). Coffey (1975) believed that *Lagarosiphon major* would eventually displace all submerged communities within its depth range. This seems to largely be the case now in the southern areas of the lake, especially at Motuoapa and Waihi Bays (pers. obs.).

Crustacean zooplankton comprise 50% of the zooplankton present in the lake with rotifers comprising the rest. The crustaceans are dominated by the copepod *Boeckella propinqua* (31%), the cladoceran *Ceriodaphnia dubia* (8.5%), and the cyclopoid copepod *Macrocyclops albidus* (1%) (Vincent and Forsyth, 1980). There also exist smaller populations of the cladoceran *Simocephalus* around the littoral fringes of the lake (M. A. Chapman, pers. comm.). The most common rotifers were *Polyarthra vulgaris,* which makes up 36% of total zooplankton numbers, *Conochilus coenobasis* (10.3%) and *Asplanchna brightwelli* (2.2%). (Vincent and Forsyth, 1980).

There are three species of native fish in Lake Taupo, the koaro (*Galaxias brevipinnis*) the common bully (*Gobiomorphus cotidianus*), and the common smelt (*Retropinna* rainbow trout (*Onchorynchus mykiss*)), and are therefore important to the Lake Taupo fishery. The native fish population of Lake Taupo differs from other North Island lakes that are directly accessible to the sea, by the absence of eels (*Anguilla dieffenbachii, A. australis*), inanga (*Galaxias maculatus*), and mullet (*Mugil cephalus*). Their absence from Lake Taupo is due to the Huka Falls which forms an effective barrier against their entry into the lake (Stephens, 1983).

1.4.2 Site Characteristics

The field base was located at Turangi and, for logistical reasons, routine sampling was confined to the southern end of Lake Taupo. Principle sampling sites were at Motuoapa, Pukawa, and Waihi Bays (Plates 1.1 - 1.3); secondary sampling sites were located at Acacia bay, Motutere point and Kinloch Harbour (Figure 1.4) From each of the principle sites three sub-sites were chosen, each corresponding to a dominant habitat type of, sandy, rocky, and weedy. Sites were also chosen for their ease of access by boat and trailer and, if possible, their seclusion from the public.

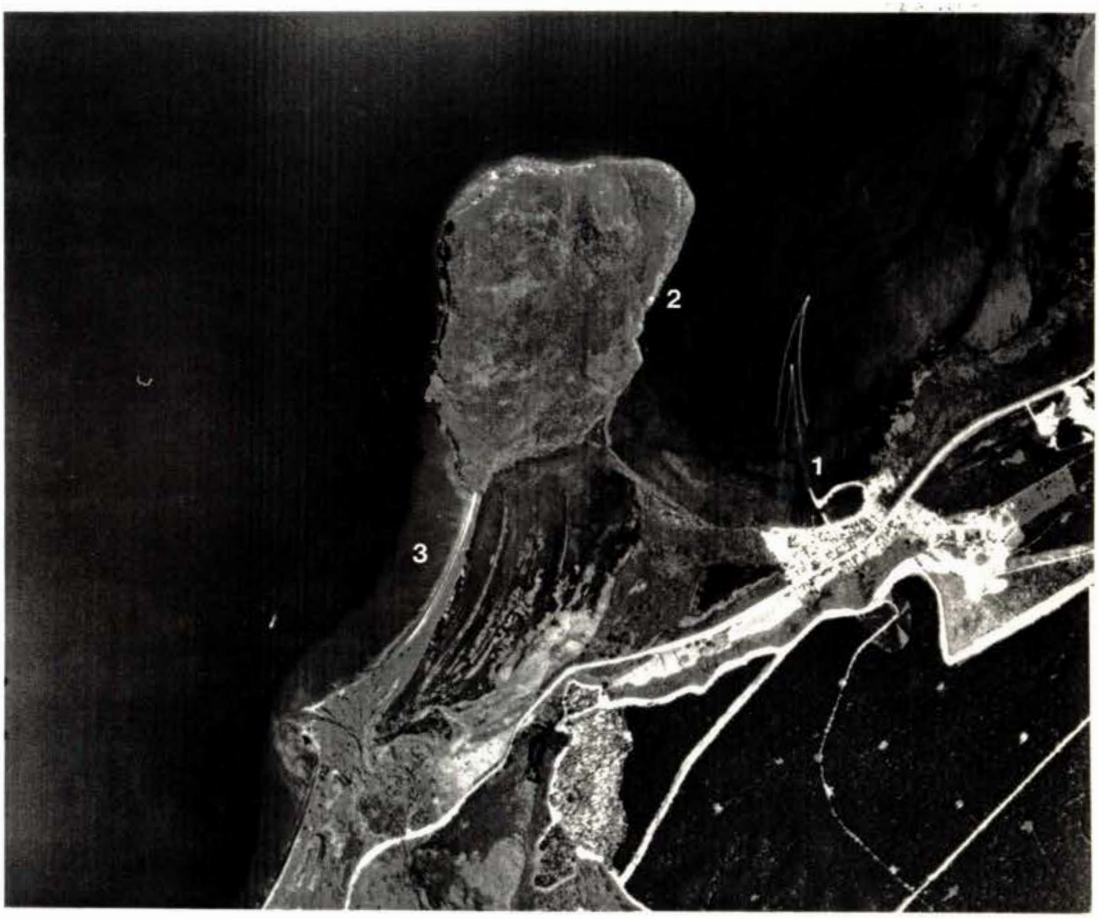

Plate 1.1: Aerial photograph of Motuoapa, including Motuoapa Headland and Stump Bay. MotW, MothR, and StumpS are labeled 1, 2, and 3, respectively. Reproduced courtesy of the Department of Lands and Survey Information.

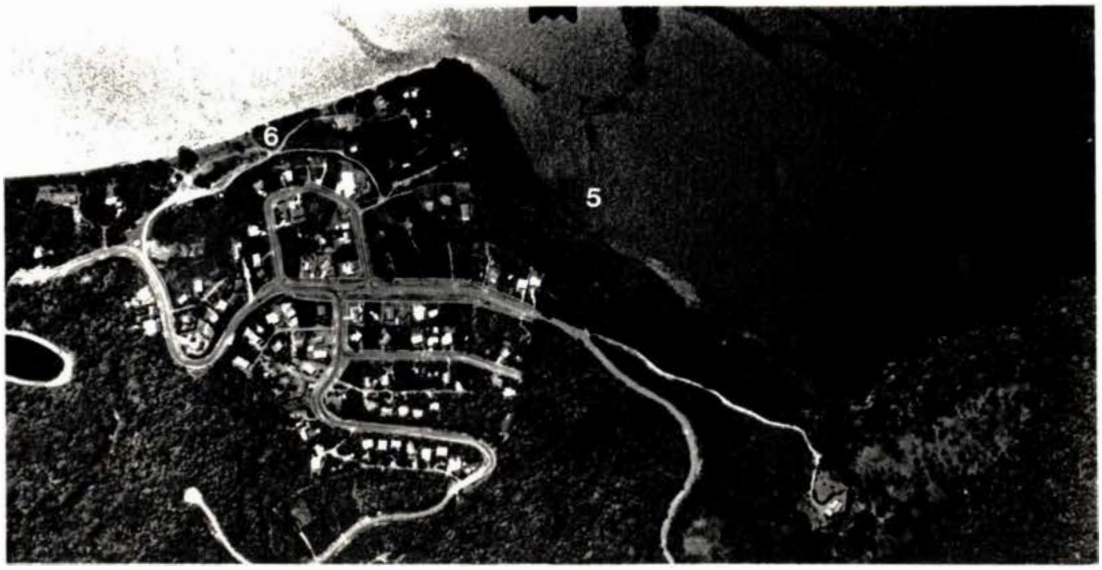

Plate 1.2: Aerial photograph of Pukawa bay showing the sampling sites PukR and PukS, labeled 5 and 6 respectively. Reproduced courtesy of the Department of Lands and Survey Information.

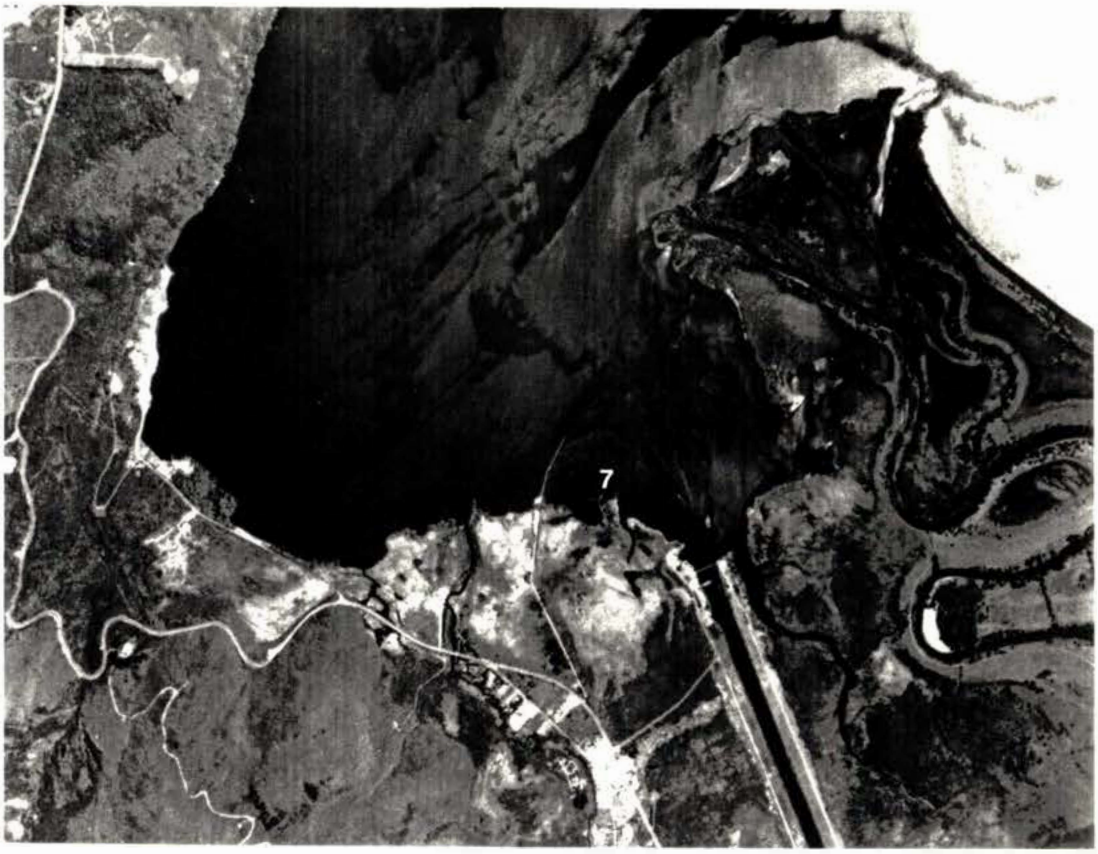

Plate 1.3: Aerial photograph of Waihi Bay showing the sampling site WaihiW (7). Reproduced courtesy of the Department of Lands and Survey Information

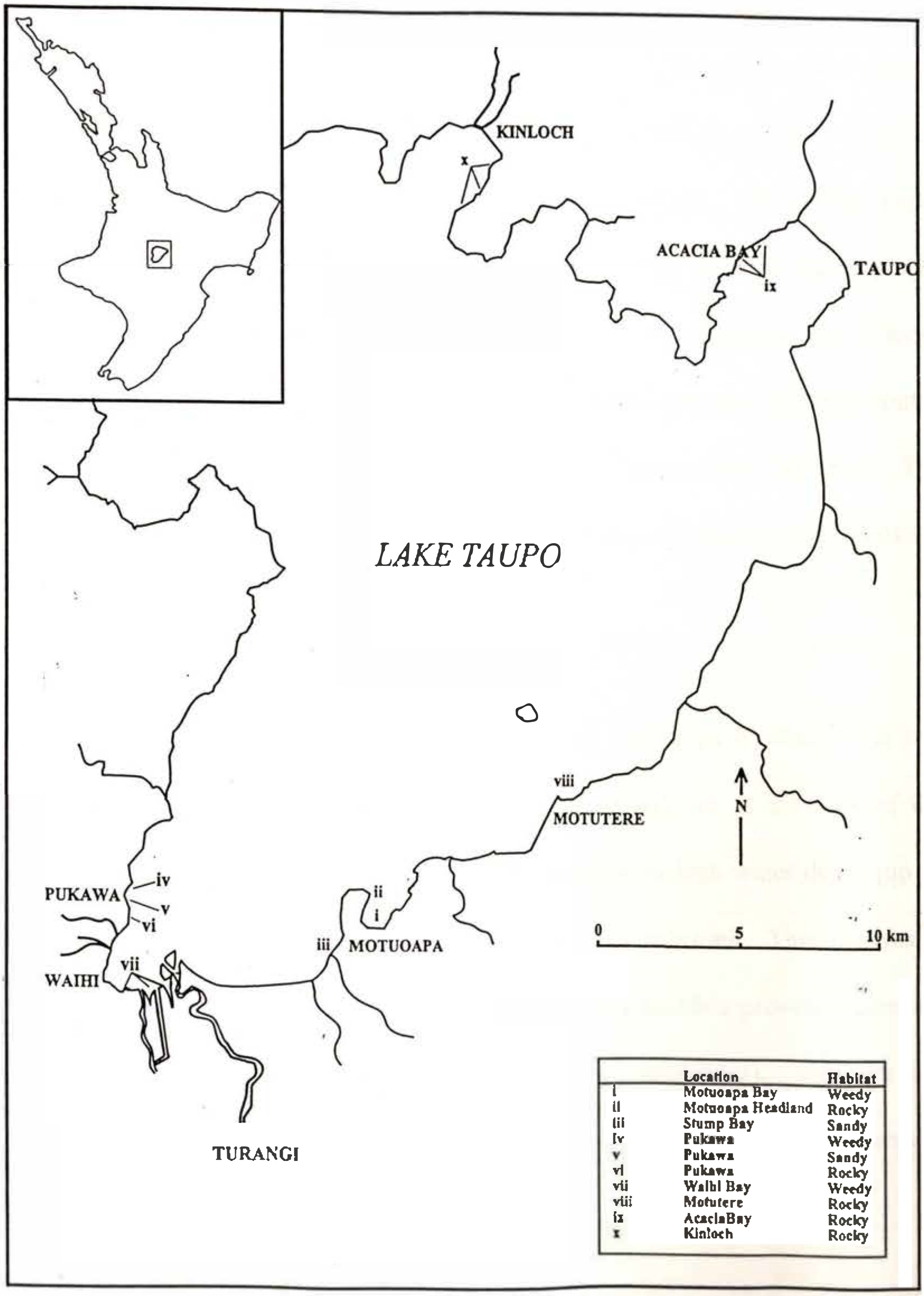

Figure 1.4: Map of Lake Taupo showing the location of the primary sampling sites (i-vii) and the secondary sites (viii-x). (adapted from Forsyth and Howard-Williams, 1983).

1.4.2.1 Motuoapa

The weedy site was located directly out from the Motuoapa marina in water depths between 0.5 and 2m. This site was characterized by being relatively sheltered from the prevailing wind due to the presence of the Motuoapa headland. The exotic weeds (*Lagarosiphon* and *Elodea*) formed clumps up to a metre high amongst native plants such as pondweeds, milfoils, and water buttercups (Howard-Williams and Vincent, 1983). This site was subject to dense macrophyte blooms over the summer months followed by an extended period of dieback over the cooler winter months. The macrophyte stands supported a large biomass of invertebrate larvae and gastropods for most of the year.

The rocky site was located along the western shores of Motuoapa headland in an area approximately 1 km long, extending from the stand of willows at the base of the headland to the northern tip. This site was characterized by its high water depth (up to 30 m deep within 50 m of the northern tip), and large rocky substrate. This site was in a similar sheltered position as the weedy site and the large boulders provide protection for large numbers of freshwater crayfish (*Paranephrops planifrons*). This site had extensive growths of *Lagarosiphon*, between 3-6 m deep, within the southern shores of the headland, close to the willows.

The sandy site was located at Stump bay between the Waimarino River mouth and Motuoapa Headland. This site was characterized as a high energy site, because of its exposure to most wind directions. The site exists as a sandy shelf, in 1-2 m of water, continuing out into the lake for 500 m before dropping away. There was little macrophyte growth along this site, with the most common species (*Myriophyllum triphyllum*) found only in sparse patches. Two other small plants, *Glossostigma* and *Lilaeopsis*, may occur with the *Myriophylum* patches. Where combined, they often bound the sand and formed small mounds on the substrate. (Forsyth and Vincent, 1983).

1.4.2.2 Pukawa

The weedy site was located on the western shore of Pukawa bay situated to the landward side of the boat moorings. The site was characterized by intermittent patches of *Lagarosiphon* and *Elodea* between 2 to 4 metres deep and was different to Motuoapa Bay in the extent of macrophyte growth and the degree of shelter from the prevailing winds. There exists an extensive wave-wash zone typical of a moderate energy shoreline. (Forsyth and Vincent, 1983). While the assemblage of macrophytes was of a similar composition to Motuoapa Bay, the extent to which they dominated the habitat were greatly reduced.

The rocky site extends around to the east of the Pukawa boat ramp on the western shore of a large ignimbrite outcrop extending from Waihi bay through to Pukawa. Water depths, and substrate type, and invertebrate biomass are similar to that encountered at Motuoapa Headland, however this site was found to be almost devoid of large macrophytes. This site is a high energy littoral zone with direct exposure to the prevailing winds and thus macrophyte growth was likely to be restricted to depths not sampled at in this study.

The sandy site runs along the full extent of Pukawa Bay, from the rocky outcrop at the east of the boat ramp to the mouth of the Pukawa Stream. This site was characterized as a high energy littoral zone and was similar to characteristics encountered at Stump Bay (Forsyth and Vincent, 1983).

1.4.2.3 Waihi Bay

Extensive macrophyte growth is encountered through much of the southern part of the lake during the greater part of year. There does exist dieback over the winter period to some degree, however it is not to the extent of the Motuoapa or Pukawa sites. Macrophyte assemblages are similar to Motuoapa and are typical of other low energy littoral zones around the southern part of the lake (Forsyth and Vincent, 1983). However the degree to which these plants dominated the lake-bed at Waihi bay was far greater than other areas. *Lagarosiphon* and *Elodea* dominated at depths greater than 1 m while the remaining macrophyte species consisted of native milfoils, pondweeds, water buttercups and water grass. Associated with the high biomass of aquatic plants was a similar high biomass of invertebrate larvae and gastropods.

Chapter 2:
Methods

2.1: Fish Capture

Fishing for catfish was carried out on a seasonal basis from February 1995 to December 1995. Sampling was conducted over a period of four nights during which four fyke nets were set at each different habitat type, just prior to dusk, and retrieved the following morning. Sampling began at Motuoapa Bay on night one with Pukawa being sampled on the following night (Table 2.1). This procedure was repeated over the third and fourth evening. Two remaining nets were set at Waihi bay each evening giving a total of fourteen nets set over each night and 56 nets per trip. Trapped fish were bagged and placed on ice immediately following capture.

Distribution experiments were conducted during August outside the primary sampling area in order to evaluate the extent to which catfish have become established within the lake. Anecdotal evidence suggests catfish were first liberated into the southern part of the lake and catfish present within the northern regions would suggest they are, or have been, migrating to these areas. 39 nets were set over a period of three days with 13 nets being set at each site and left to fish overnight. Motutere, Acacia Bay, and Kinloch were chosen as all these sites had rocky and weedy habitats within close proximity.

Table 2.1: Principle sampling sites used for the capture of catfish between February and December 1995. This procedure was repeated over nights 3 and 4.

Habitat Type	Night 1	Number of Nets	Night 2	Number of nets
Weedy	Motuoapa bay	4	Pukawa bay	4
	Waihi Bay	2	Waihi bay	2
Rocky	Motuoapa headland	4	Pukawa bay	4
Sandy	Stump bay	4	Pukawa bay	4

Each fyke net comprised 25 mm stretched mesh and consisted of three interconnected funnels, with a total net length of 6 m, including a 4 m long wing, extending from the net mouth, to intercept and guide fish into the enclosure (Plate 2.1) (Kane, 1995). The nets were set within two metres of the shore in water no greater than five metres deep and secured with two concrete blocks, one at the end of the funnel and one at the end of the leader. At sites exposed to strong winds the leader was set facing the wind with the end of the funnel pointing towards the shore. This procedure was reversed at sheltered sites with the leader being set perpendicular to the shore.

Although regular sampling was attempted during each trip there were occasions when, due to poor weather, sampling was abandoned for the evening. It was found that during periods of high winds and corresponding high waves the fyke nets fished inefficiently and/or subsequently collapsed.

Plate 2.1: Fyke nets containing over 10% of the total number of catfish captured during the course of the study.

2.2: Fish Processing

Fish were weighed, measured, and sex established under laboratory conditions either in Turangi or in Hamilton. Weight was taken to the nearest 0.1 g using an electronic balance and fork length measured to the nearest millimetre. Sex was identified by making a mid-ventral incision to the visceral cavity of each fish from the anal pore forward and gonads examined. The stomach was removed from approximately every tenth fish and preserved in a 10% formalin solution. Ovaries were removed from selected mature female fish, weighed, and preserved in Gilson's Fluid (Simpson, 1951). The fish were then placed in plastic bags and frozen. Vertebrae were removed from approximately 5% of the catfish captured between September and December for ageing and stored frozen until required.

2.3: Fish Ageing

The ageing of Ictalurids has been extensively examined (Frank, 1955; Layher, 1981; Marzolf, 1956; Sneed, 1950). Sneed (1950) used vertebrae and pectoral spines to age *Ictalurus punctatus*. Marzolf (1956) and Frank (1955) aged *I. punctatus* using vertebrae. They both concluded that ageing based on vertebral annuli offered a more accurate assessment of growth history. Saggital otoliths have been used to age Ictalurids in the past, however due to the small size of the otolith (3 mm diameter) they often burn too rapidly obscuring the growth marks (Patchell, 1977).

Determination of age and growth rate of catfish from vertebrae depends upon the correlation of growth marks with passage of time and increased body size (Appelget and Smith, 1950). The centra of a vertebrae from *A nebulosus* showed a series of dark bands that were thought to represent annular markings formed during a period of slow growth (Figure 2.1). The markings were of a similar appearance to those encountered by Patchell (1977) and from authors overseas (Hensel, 1966; Marzolf, 1956; Lewis, 1948).

The number of annuli were counted and a series of measurements were taken from the centra to the final annuli (Rn) and from the centra to the vertebral rim (Rn+1).

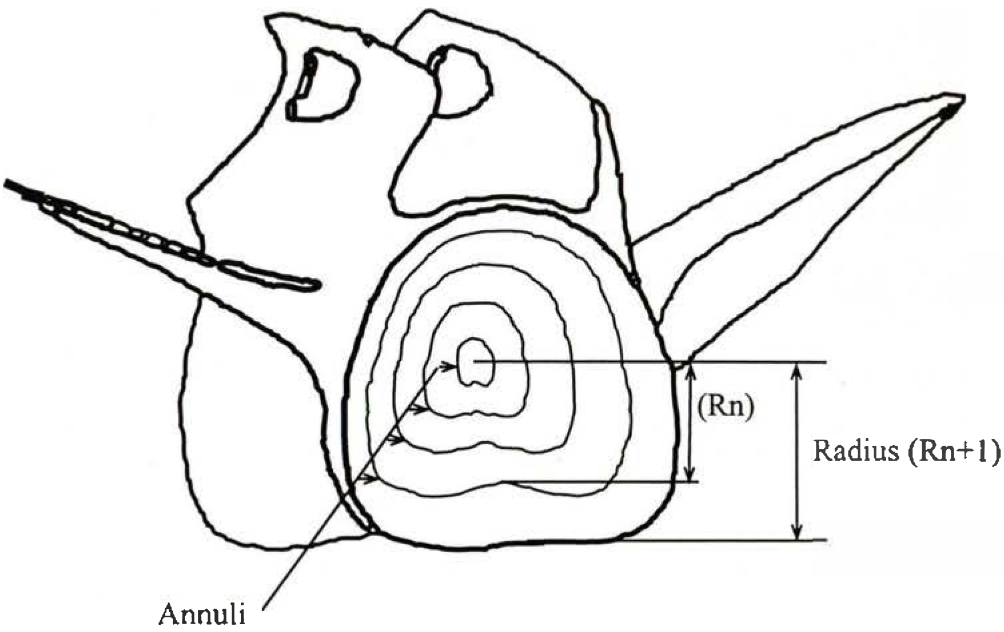

Figure 2.1: Diagram showing the region of the catfish vertebrae used in ageing.

Vertebrae were removed from fish caught during spring and summer sampling and grouped into 10 mm size classes. Two incisions were made to completely sever the head and tail regions of the fish. The first incision was made to the anterior half of the vertebral column through the fused cervical vertebrae. The second incision was made at the posterior end of the dorsal fin. The samples were then placed in labeled plastic bags and boiled for approximately 30 minutes. The column was scraped clean of tissue and allowed to dry over night at room temperature. When dry, the vertebrae were easily separated by disjointing, and the fifth vertebrae, as chosen by Appelget and Smith (1950), was removed for ageing.

Vertebrae were placed in glycerol, analysed under a stereo microscope, and the number of annuli counted. Two measurements were obtained, one from the origin to the final annuli and the second from the origin to the edge of the vertebrae (Figure 2.1).

A vertebra which is satisfactorily cleaned shows wide, light-coloured bands alternating narrower, dark bands. Dark bands are interpreted as annula marks and the light bands, are considered to represent annual growth increment. Some vertebrae, however, have dark bands which cannot be interpreted as true year marks. A true year mark consists of a complete dark ring concentric with the rim of the vertebra (Appelget and Smith, 1950).

2.4: Spawning Behaviour

Diver surveys were conducted on three occasions during November to document individual cases of nesting behaviour. Motuoapa Bay was surveyed during darkness using SCUBA equipment in water 0.5 m to 3 m deep. Transects were set up extending from the shore to 150 m out into the bay. An attempt was made to cover as much of the littoral zone in Motuoapa Bay as was possible.

On the first occasion three teams of paired divers conducted searches from the shore to the outer limit and back again. Any sign of nest guarding behaviour was noted. A second attempt at documenting nesting behaviour was conducted by myself during daylight. The number of diver surveys attempted was thought to be inadequate, however factors outside this studies control, including weather and personnel, limited the number of dives to three.

2.5: Fecundity

Ovaries were removed from fish at the fifth stage of maturity as determined by Nilkosky (1963). These were then weighed to the nearest milligram, split longitudinally, turned inside out, and placed in a solution of Gilson's Fluid (Simpson, 1951). They were shaken vigorously and left to harden for up to three months. Periodic shaking during this period helped to loosen the eggs from the ovarian tissue.

The eggs were then separated from the ovarian tissue and placed in a filter system through which cold distilled water was allowed to run. The eggs were washed for two hours to remove all traces of ovarian tissue. Samples of approximately 10% of the total number of eggs were separated, placed in small glass dishes and allowed to harden at room temperature for 24 hours. The total number of eggs was calculated from the following formula:

$$F = \frac{n \times W}{w}$$

Where F = fecundity, n = number of eggs in the sample, w = weight of the ovary in grams, and W = fish weight (g).

2.6: Diet

Study of the diet of fish based upon analysis of stomach contents is now standard practice in fish ecology (Hyslop, 1980). The method used was established from a critical review of stomach content analysis by Hyslop (1980) and allowed for the examination of the diet of a fish population with a view to assessing the species nutritional standing in the context of the aquatic community.

Samples were taken randomly from every tenth catfish captured between February and August and fixed in 10% formalin. Before analysis the stomachs were neutralized in a solution of sodium sulphate and sodium sulphite before being rinsed in cold water. The stomach samples were examined under a low power stereo microscope and food items present were identified to species level where possible. Data from the enumeration of food items was treated in two ways. Firstly, the number of stomach samples in which one or more of a given food item was found was expressed as a percentage of all non-empty stomachs examined. Secondly, the number of food items of a given type found in all specimens examined was expressed as a percentage of all food items from all specimens to estimate the relative abundance of that food item in the diet.

Comparisons of diet were made based on habitat type. Time and resources did not allow for a full comparison of diet over all seasons at each site. Fish caught in the sandy sites were not included in the study of diet due to the low numbers captured and the high incidences of empty stomachs.

Chapter 3:

Abundance, Size Distribution, Reproductive Biology, and Diet

3.1 Abundance

A total of 6226 catfish were caught from 273 fyke nets set at the southern sites between February and December 1995, which gives a mean catch per unit effort (CPUE) of 23 fish night^{-1} (Appendix I). A further 27 fish were captured in the northern regions of Lake Taupo as part of the distribution experiments. 1044 fish were captured in nets and processed in late summer (February/March), 754 in autumn (April), 1337 in winter (June/July), 1113 in spring (September/October), and 2005 in early summer (December).

The relative abundance of catfish at various locations was indicated by CPUE (Figure 3.1). Assuming an unchanging level of activity in catfish, the CPUE of fyke netting should be directly proportional to fish abundance (Hubert, 1983). Mean CPUE varied between locations depending upon the type of habitat sampled (Appendix II).

Mean CPUE in rocky habitats increased from 5.48 fish net^{-1} night^{-1} in late summer to 44.0 fish net^{-1} night^{-1} in winter before decreasing to 34.3 fish net^{-1} night^{-1} in early summer. Mean CPUE in weedy habitats decreased from late summer to winter before increasing to 92.1 fish net^{-1} $night^{-1}$ in early summer. Seasonal variation in catch rates between rocky and weedy habitats were generally within 95% confidence intervals. Mean CPUE was consistently low in sandy habitats with no catfish captured at either sandy site sampled during winter. Standard deviations for both weedy and rocky areas were high, indicating large variation among catch rates of individual nets within the same area. For example, one net set in Waihi Bay during December, captured 639 fish in one night (Plate 2.1).

Mean CPUE was calculated for individual sites in an attempt to account for the variation in catch rates (Table 3.1). Catch rates at Waihi Bay were consistently higher than at the other weedy sites. During spring mean CPUE at Waihi Bay was six times higher than at either Pukawa or Motuoapa Bay. Differences in catch rates at all weedy sites followed similar seasonal variations, decreasing from February to July, before increasing to December. Seasonal catch rates at the Pukawa weedy site were low with no fish captured during Winter and Spring.

Catch rates were considerably higher at the Motuoapa Headland rocky site than at the Pukawa rocky site and seasonal mean CPUE at Motuoapa Headland was higher than at the Motuoapa Bay weedy site during every season except Summer. Differences in seasonal catch rates followed an opposite trend to that observed at the weedy sites where mean CPUE increased from late Summer to Spring before decreasing to early Summer.

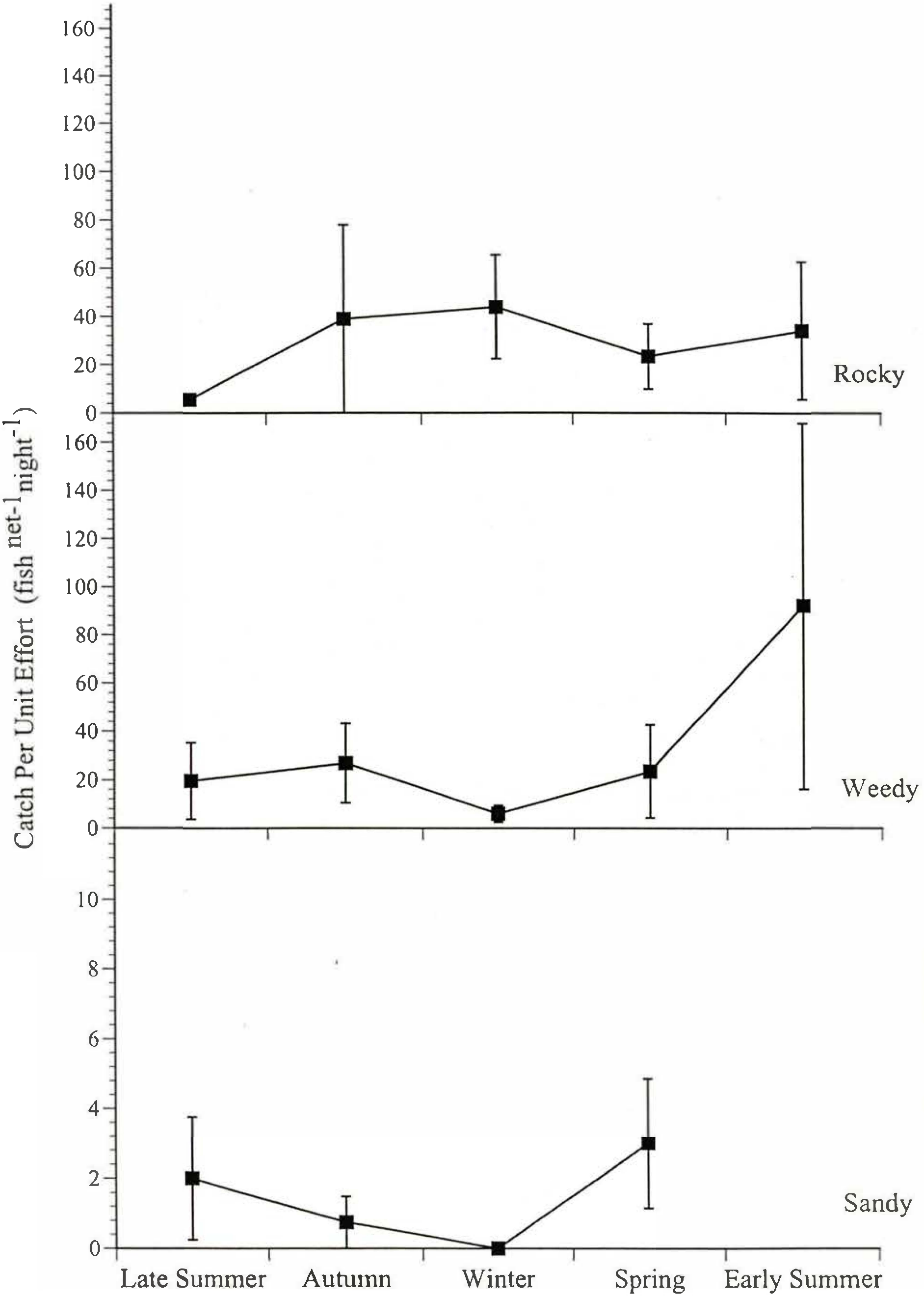

Figure 3.1: Mean catch rates of catfish (fish net^{-1}night^{-1}) caught at three habitat types between February and December 1995. Error bars are 95% confidence intervals.

Table 3.1: Catch rates of catfish caught at all primary sites sampled between February and December 1995. (-) denotes nets not set.

Site Type	Location	Mean catch per unit effort (fish net^{-1} $night^{-1}$)				
		Late summer	Autumn	Winter	Spring	Early summer
Rocky	Motuoapa	13.16	22.50	6.25	10.13	34.33
	Waihi	31.19	35.86	9.29	65.20	129.46
	Pukawa	2.75	0.00	0.00	9.13	-
Weedy	Motuoapa	8.33	39.00	62.92	42.50	19.33
	Pukawa	4.17	-	23.5	6.63	-
Sandy	Stump Bay	1.16	1.00	0.00	4.38	-
	Pukawa	3.00	0.50	0.00	4.38	-
		Mean catch per unit effort (kg net^{-1} $night^{-1}$)				
		Late summer	Autumn	Winter	Spring	Early summer
Rocky		0.74	7.66	6.02	1.71	1.02
Weedy		1.23	4.56	1.07	3.32	11.40
Sandy		0.25	-	-	0.26	-

Weedy habitats were found to have the highest mean yield of catfish (4.31 kg net^{-1} $night^{-1}$) reaching a peak of 11.4 kg net^{-1} $night^{-1}$ during early summer (Table 3.1). The yield of catfish from the weedy habitats was approximately 1 kg net^{-1} $night^{-1}$ greater than the mean yield recorded at the rocky habitats. Catfish yield at rocky habitats was greatest during autumn and winter at 7.66 and 6.02 kg net^{-1} $night^{-1}$, respectively. The yield of catfish from sandy habitats was, as expected, consistently low (0.26 kg net^{-1} $night^{-1}$).

3.1.1 Catfish Distribution

The distribution of catfish in the northern regions of the lake was investigated over a period of three days during August 1995. A total of 27 fish were captured from 39 net sets: 2 in Acacia Bay, 11 at Motutere, and 14 at Kinloch. This resulted in CPUE figures of 0.15, 0.84, and 1.08 (fish net^{-1} $night^{-1}$), respectively. In comparison to the CPUE figures obtained during regular sampling these results are extremely small.

3.1.2 Sampling By-Catch

The numbers of other species caught whilst fyke netting were low. I believe the positioning of the fyke net along the littoral margins of the lake foreshore, and the associated low water depth, prevented many trout being captured. A total of 7 rainbow trout were caught whilst netting; four were less than 150 mm long with the remainder ranging between 250 - 400 mm. All captured trout were released back into the lake after length measurements had been recorded.

Significant catches of koura were obtained in the Pukawa area. These peaked during spring as adults migrated to shallower areas to breed (Forsyth, 1983). Goldfish (*Carassius auratus*) and the common bully were the only other species to be captured whilst sampling, with numbers being greatest in weedy habitats.

3.2 Population Attributes

3.2.1 Length Frequency Distributions

Fish were allocated to 10 mm size classes and graphed according to site and habitat type. The three habitat types were compared over four seasons with the clearest modes occurring between 110 - 130 mm and 280 - 320 mm (Figure 3.2). Differences in mean length of catfish from each habitat type were calculated using analysis of variance (Table 3.2)

There were no significant differences ($p < 0.05$) in the mean lengths of catfish between rocky, weedy, and sandy habitats. Catfish from rocky and weedy sites were found to have a mean lengths of 173 and 171 mm F.L respectively, and approximately 10 mm less than found in catfish from sandy sites.

Table 3.2: Mean lengths of catfish from rocky, weedy, and sandy habitats, caught between February and December, 1995.

Site type	LS Mean	S.E.	N
Rocky	172.9	0.008	2137
Weedy	182.4	0.037	98
Sandy	170.9	0.006	4018

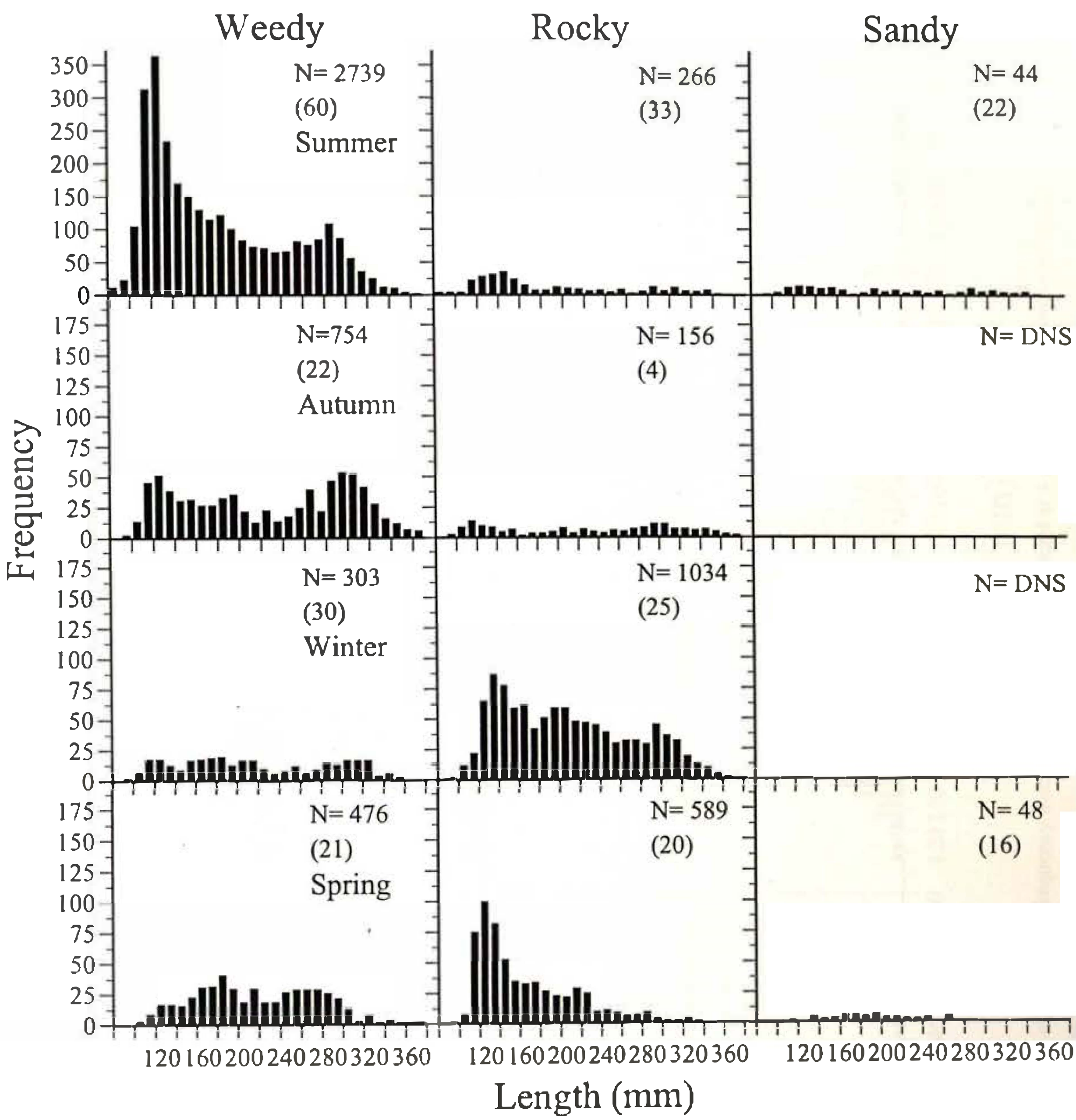

Figure 3.2: Comparison of the length frequency distribution of all catfish caught at 3 habitat types between Motuoapa and Waihi bay from February through to November 1995. ( ) total number of nets set.

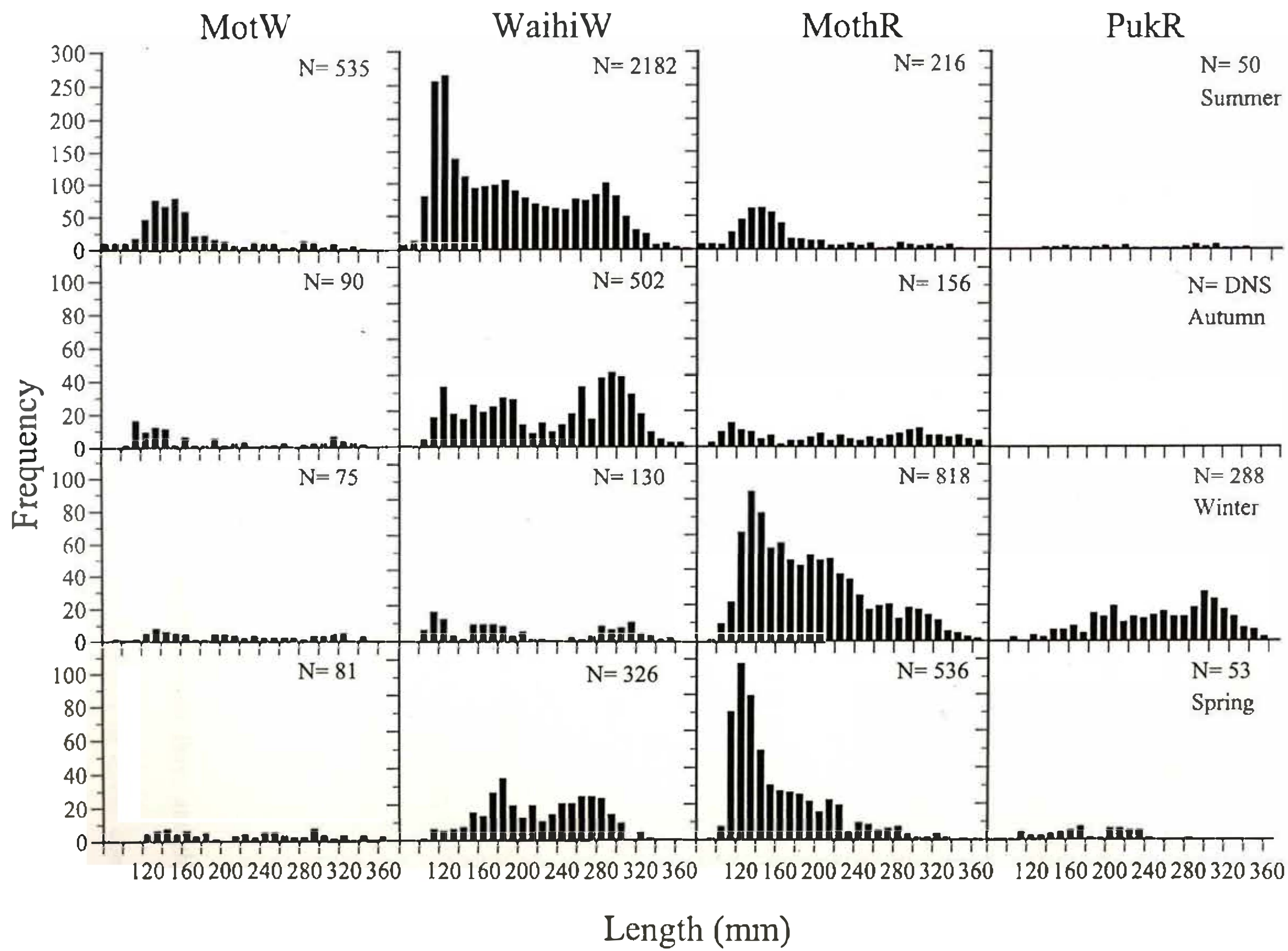

Figure 3.3: Comparison of the length frequency distribution of all catfish caught at 4 different sites between Motuoapa and Waihi bay from February to November 1995

In summer the weedy sites dominated the total catch, with a strong modal size class evident between 110-130 mm. This mode accounted for 70% of the total catch at the weedy sites during summer but decreased in frequency over the following seasons. There does not appear to be a seasonal increase in the mean length of the 110 - 130 mm size class that would indicate growth of individual catfish within this mode. The second dominant mode observed in the weedy habitats appears to undergo a seasonal increase in length from 280 mm in summer to 300 mm in winter before decreasing 10 mm in spring.

In rocky habitats a strong modal size class was evident between 120 - 150 mm during winter. This size class appeared to decrease to 110 - 130 mm in spring. The second modal size class evident in weedy sites during all seasons was not replicated at the rocky sites. Relative low catches in rocky habitats during summer and autumn made interpretation of dominant modes difficult.

The first dominant mode evident at both rocky and weedy habitats was thought to consist of age 2+ catfish. Accurately ageing further modes through length frequency analysis was not believed to be possible due to the poor distinction of separate size classes.

The fishing effort between the weedy sites, Waihi and Motuoapa Bay, and the rocky sites, Pukawa Bay, and Motuoapa Headland were similar, making direct comparison possible. The length frequency data are dominated by fish captured at just two sites (Figure 3.3). Waihi bay contributes 76% of the total catch in the weedy sites, whilst Motuoapa Headland exhibits a similar domination of total catch in the rocky sites.

There were no fish captured less than 80 mm in length, except in summer, where the minimum size captured was 74 mm,. This lack of representation can be attributed to the sample method employed. The fyke net mesh size actively discriminated against fish <100 mm in length.

3.3 Age and Growth

3.3.1 Age Assessment

Of the 101 fish that were aged, the greatest age obtained (8+), came from the largest catfish captured (359 mm F.L.) (Table 3.3). Vertebrae prepared for ageing and measurement are shown in Plate 3.1. Figure 3.4 graphically illustrates the mean length at each age.

The largest number of catfish sampled during ageing were aged 2+. This age class showed a similar dominance in catfish numbers during length frequency analysis. There existed no overlap in ages for catfish less than 140 mm F.L., suggesting catfish from the first and second age classes consisted of individuals with similar growth rates. Catfish older than two years of age exhibited a large range in size indicating the population consists of both fast and slow growing individuals.

Table 3.3: Mean age by size class of catfish caught in Lake Taupo between September and December 1995.

Size Class (mm)	No. of Specimens	Mean Age (years)	Standard Deviation	Minimum Age	Maximum Age
<100	6	1	0.00	1	1
110-120	4	2	0.00	2	2
120-130	11	2	0.00	2	2
140-150	12	2.08	0.30	2	3
150-160	12	2.17	0.40	2	3
170-180	10	2.70	0.50	2	3
200-210	4	2.50	0.58	2	3
230-240	15	3.93	1.33	2	6
260-270	8	5.38	1.51	3	7
290-300	13	5.69	0.85	4	7
320-330	5	5.40	1.14	4	7
>330	2	7	1.41	6	8

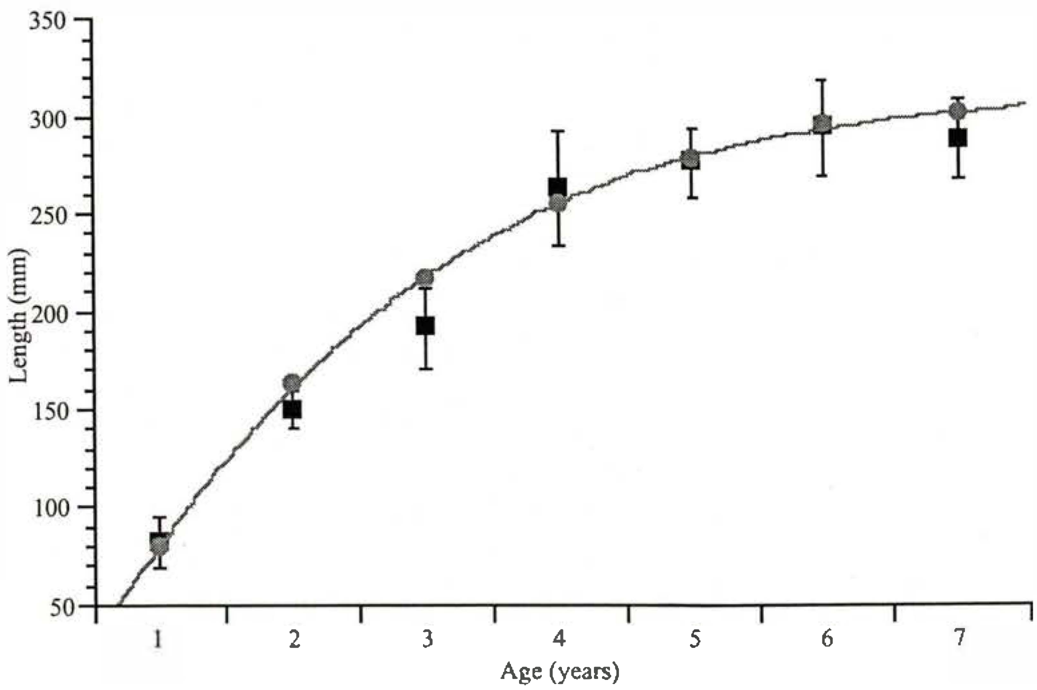

Figure 3.4: Mean length at age data fitted with the von Bertalanffy growth equation for catfish caught in Lake Taupo between September and December 1995. Error bars are 95% confidence intervals. Mean length at age data (squares), von Bertalanffy (circles).

The mean lengths for age 1+, 2+ and 3+ catfish were 82 mm, 150 mm and 196 mm respectively. Mean length in catfish increased in decreasing increments from age 1+ to age 3+. The mean length of age 4+ catfish was found to be 264 mm, a greater increase in length from age 3+ than was expected. Mean length ranged from 277 mm to 294 mm for catfish between 5 and 6 years of age. Catfish in their eighth season of growth were found to be on average 5 mm smaller than age 7+ catfish. Mean length remained within 95% confidence intervals for catfish aged 5+ and greater.

Calculation of growth history of a fish from measurements of a skeletal part depends upon the establishment of a definite relationship between growth of the part and growth of the entire body (Appelget and Smith, 1950). In this study the diameter of the fifth vertebra was compared to the body length of the fish throughout the range of sizes represented in the entire ageing subsample (Figure 3.5A).

A logarithmic transformation gave the straight line relationship:

$$\ln(L) = -6.35 + 1.25R$$

where L equals fork length in mm and R equals vertebral radius in mm (Figure 3.5B).

A comparison of the calculated line with the empirical data indicates that the curve fits the data satisfactorily ($r^2 = 0.935$), except at the mid point of the size range (between 200 - 325 mm) where the empirical points lie above the line. These fish represent individuals with a growth rate less than fish at the mean length at age.

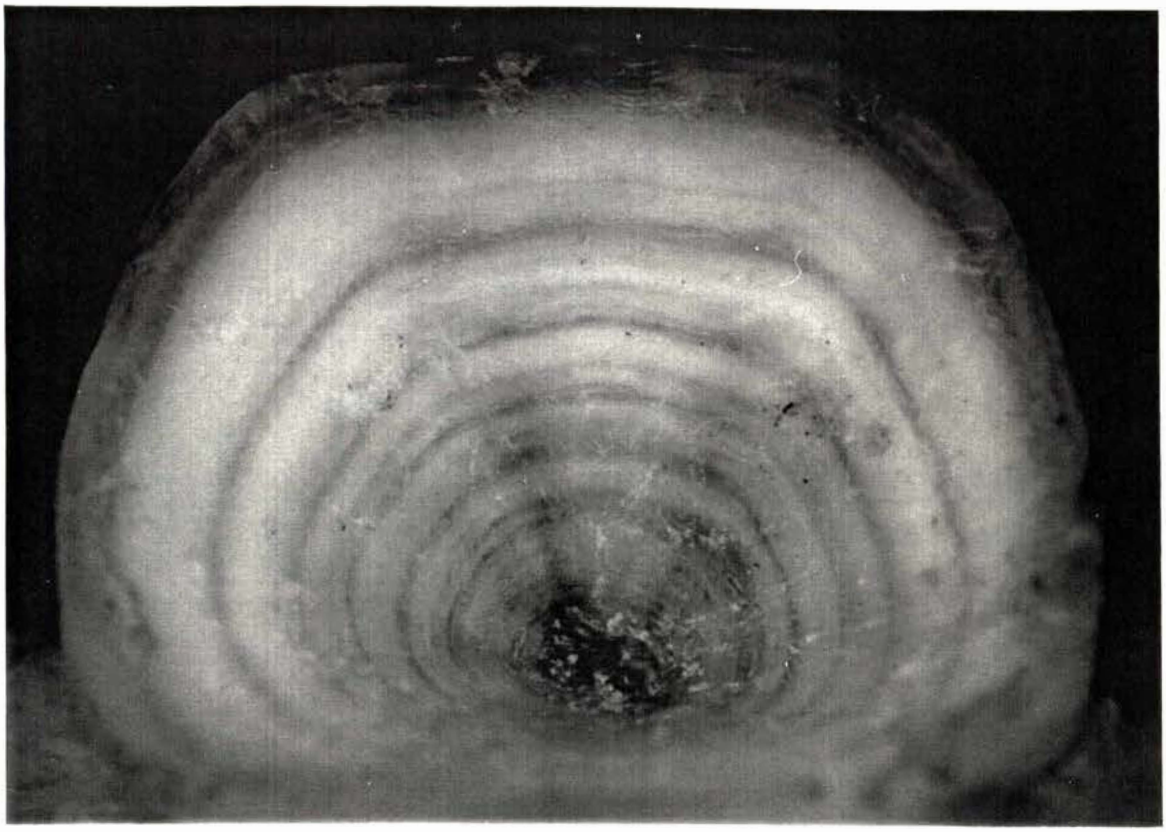

Plate 3.1: Stereo-microscope view of the fifth vertebra from an age 6+ catfish. Where vertebral radius = 1.95 mm, and fork length = 290 mm.

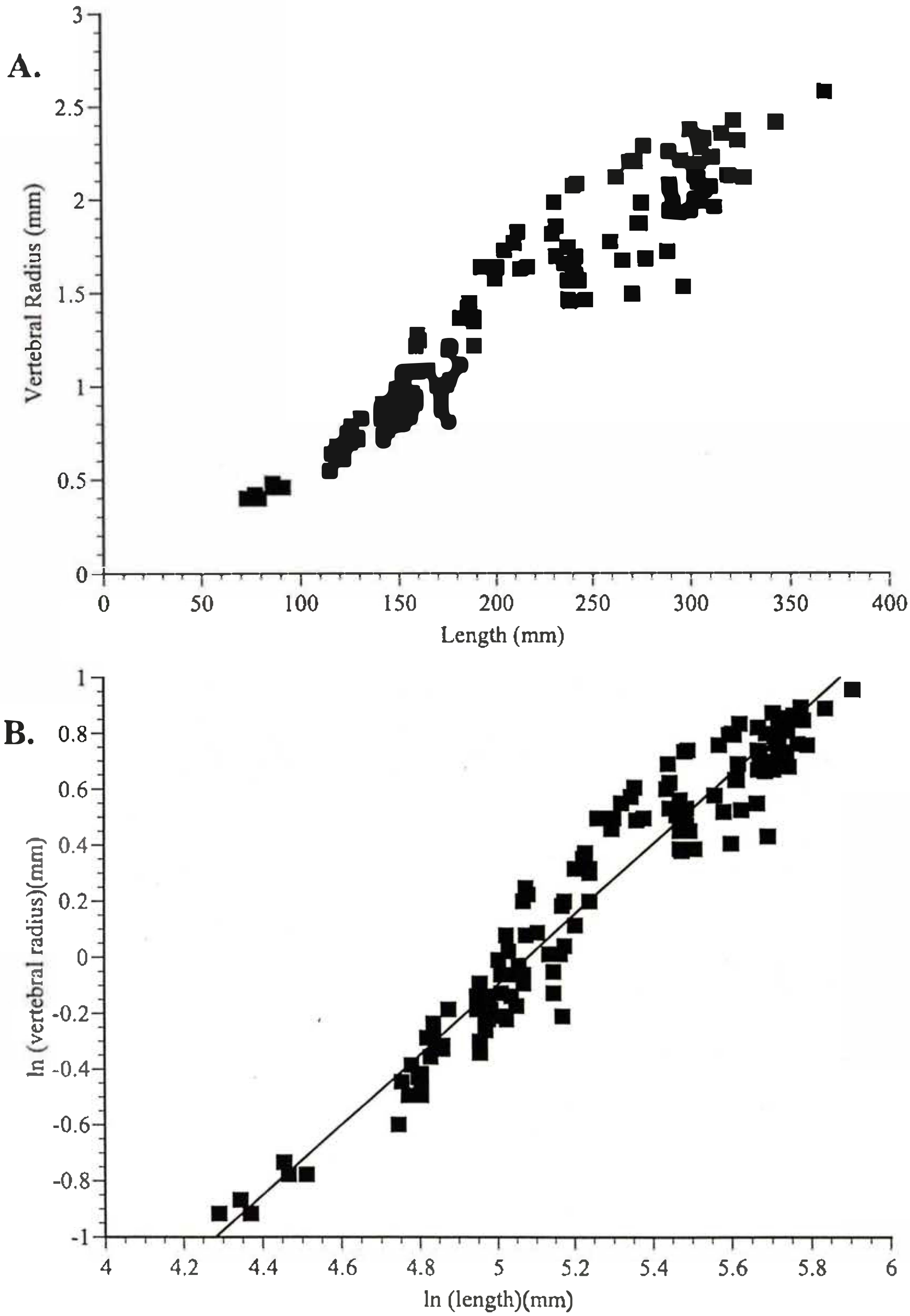

Figure 3.5: Comparison of fork length and vertebral radius of catfish caught in Lake Taupo between February and December 1995. A. Plot of vertebral radius versus fork length. B. Plot of natural log of vertebral radius versus natural log fork length.

3.3.2 Validation of Ageing Method

The deposition of growth rings can form an observable annual pattern in temperate fishes (Appelget and Smith, 1950; Patchell, 1977). However, it was considered necessary to verify that the rings on vertebrae of the Taupo population were in fact annual to justify their use in ageing.

This followed the method established by Patchell (1977), where the distance between the final annuli (R_{n+1}) and the vertebral margin (R_n) was graphed against fish length (Figure 3.6) If it could be shown that the rings were laid down at approximately the same time each year they then could be used for age determination. Fish captured and analysed for ageing at the end of winter should have had a greater difference between (R_{n+1}) and (R_n) than fish captured in December, where the newly formed annuli had only recently become visible.

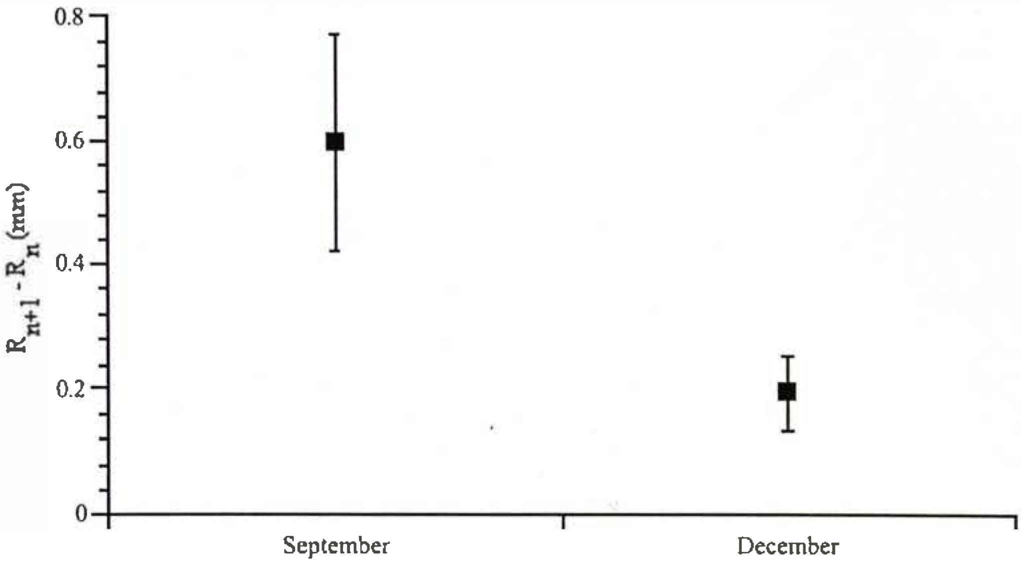

Figure 3.6: Changes in the mean distance from the ultimate annulus (R_{n+1}) to the vertebral margin (R_n) of 2^+ catfish caught in Lake Taupo between September and December 1995. Error bars show 95% confidence intervals.

There exists an apparent difference in R_{n+1}-R_n between the two months. Mean R_{n+1}-R_n values of 0.6 mm. and 0.2 mm were observed for September and December respectively. This result is similar to that encountered by Patchell (1977) where the pattern apparent was of high R_{n+1}-R_n values during the winter months of June through August, followed by a rapid decrease in early spring (September/October), and a slow increase during the following summer/autumn period (January though May).

3.3.3 Growth in Length

A Walford graph of length at age t+l versus length at age t was plotted for mean length at the end of each year (Figure 3.7). The single age 8+ fish did not conform to the linear series so was omitted from length analysis.

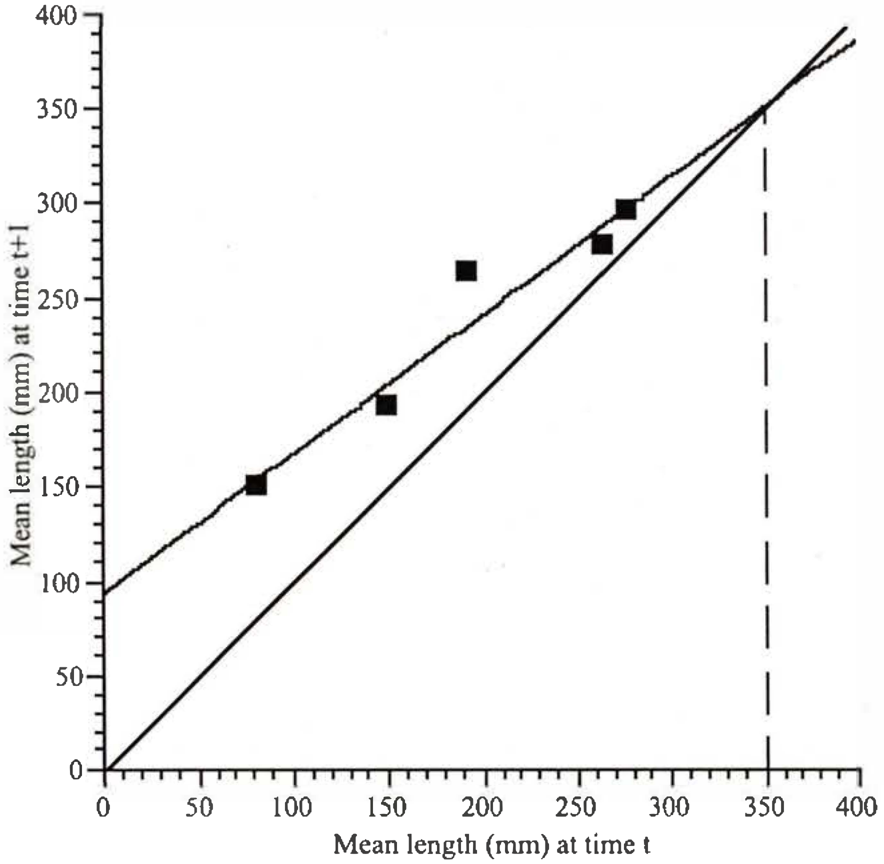

Figure 3.7: Walford plot of length (mm) at age $t + 1$ against length at age t, for all catfish aged between September and December 1995. The 45 degree line represents y = x. L = 350 mm (dashed line = regression line intercept with y=x line).

From the slope of the line (k = 0.734) and the ordinate intercept (90.82), L_∞, or the maximum length attainable, could be calculated using the von Bertalanffy (1938) growth equation. The von Bertalanffy equation is one of the most widely used growth curve models and expressed as;

$$L_t = L_\infty(1 - e^{-K(t-t0)}) \quad \text{(Tesch, 1971)}$$

Where: L_∞ = the mathematical asymptote of the curve.

L_t = the length at time t.

K = a measure of the rate at which the growth curve approaches the asymptote.

t_0 = a time scalar equivalent to the hypothetical starting time at which the fish would have been zero-sized if they had always grown to the above expression.

To obtain the Bertalanffy equation different values for L_∞ were trailed. Trial values for $L_\infty - L_t$ were computed and their natural logarithms plotted against age for ages 1-6 (Figure 3.8). Upper and lower values of $\log_e(L_\infty - L_t)$ were determined using least squares regression analysis. It was thought that values of $\log_e(L_\infty - L_t)$ that gave the highest r^2 and lowest standard deviation would accurately predict L_∞. For the upper and lower limits the line was somewhat curved. It was found through regression analysis that $L_\infty = 330$ gave the highest r^2 value of 0.98, and lowest standard deviation of 0.12.

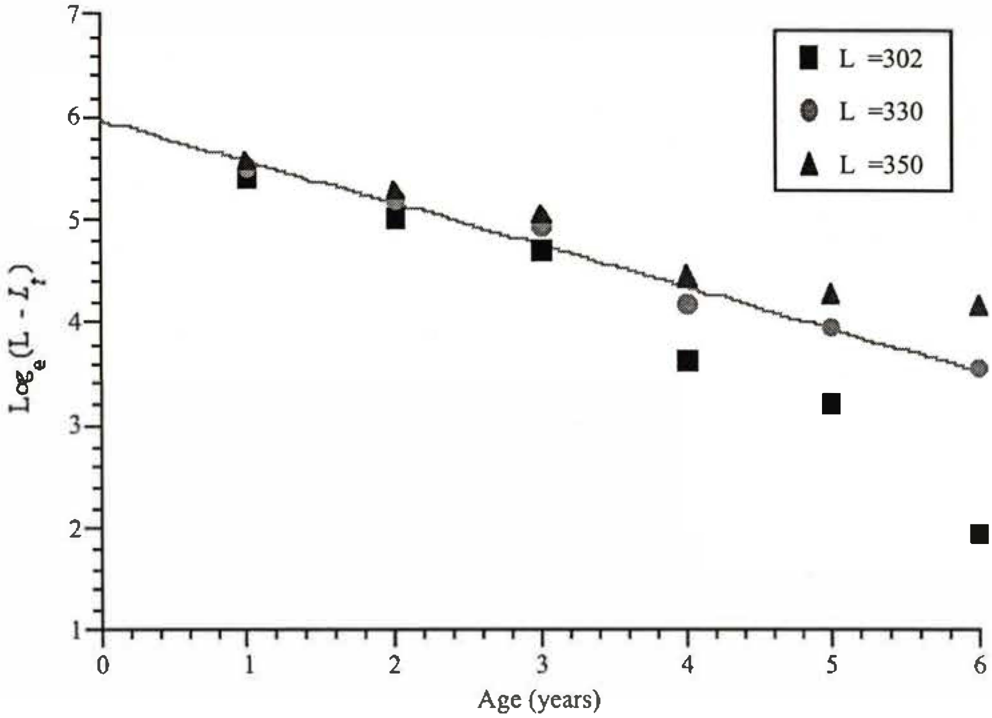

Figure 3.8: Log$_e$(L - L_t) plotted against age for trial values of L . Regression line equals line of best fit L = 330.

For this value of L_∞, the slope of the $\log_e$ line was K = 0.4 and the Y-axis intercept was 5.98. Time at t_0 was equated using the procedure developed by Ricker (1975) where the y-axis intercept was equated to $\log_e L_\infty + Kt_0$, with $\log_e L_\infty = \log_e = 350 \text{ mm} = 5.86$:

$$t_0 = \frac{5.98 - 5.86}{0.4} = 0.3$$

The von Bertalanffy equation became:

$$L_t = 330(1 - e^{-0.4(t-0.3)})$$

The von Bertalanffy growth equation was found to accurately reflect the mean length at age data (Figure 3.4). All points were contained within the 95% confidence intervals of mean length at age. An apparent inflection of mean length at age occurs between age 2+ and age 4+. This is reflected in the von Bertalanffy equation where the growth curve under-estimates mean length of catfish at age 4+.

The asymptotic length of 330 mm was below the length of the longest fish captured (359 mm F.L.). It is pertinent to realise that the von Bertalanffy growth equation calculates the mean length of catfish and thus it is expected that maximum lengths of selected older catfish will fall outside the asymptote.

3.3.4 Growth in Weight

The relationship between length and weight was compared for all fish captured. The comparison extended to site, season, and sex. The functional regression used the standard form $W=aL^b$ (Tesch, 1971) The parameters *a* (intercept) and *b* (slope) are most easily estimated by linear regression based on the logarithmic transformation:

$$\log_e W = \log_e a + b \log_e L$$

Significant differences in slope and intercepts were found utilising covariate analysis to compare length-weight regressions according to site and season ($P < 0.001$) (Table 3.4). Due to the low sample size of sandy sites (N= 98), compared to N= 2137 and N= 4018 for rocky and weedy sites respectively, sandy sites were removed from the analysis. Slope (*b*) was found to increase from summer to winter for both habitat types, before decreasing to summer levels again. An increase in *b* was accompanied by a decrease in the y-intercept. Slope was the same for both sites during each month sampled except July and October. The weedy sites had a greater slope than the rocky sites in July (weedy b = 3.16: rocky b = 3.14), but had a lower slope during October (weedy b = 3.16: rocky b = 3.18).

Growth in weight of catfish was found to be greater than the cube of increase in length (b=3) in all cases except during early summer where the high proportion of spent females and the associated loss of condition brought the regression coefficient below 3 (Appendix III).

Table 3.4 Coefficients of linear equations [Ln(weight in g)=a+b(Ln(length in mm))] for all catfish caught at Motuoapa, Waihi Bay, and Pukawa between February and December 1995.

Month	Habitat Type	No. of Catfish	Sex combined		
			a	b	r^2
February	rocky	150	-11.56	3.05	0.991
	weedy	156	-11.52	3.05	0.990
April	rocky	1126	-11.93	3.12	0.995
	weedy	589	-11.95	3.12	0.993
July	rocky	116	-12.02	3.14	0.987
	weedy	850	-12.23	3.16	0.995
October	rocky	592	-12.26	3.18	0.989
	weedy	211	-12.10	3.16	0.985
December	rocky	476	-11.65	3.06	0.994
	weedy	1889	-11.56	3.06	0.983

An effort was made to compare seasonal changes in the mean of the squared residuals (least squares) for each habitat type (Figure 3.9). The natural log of weight was found

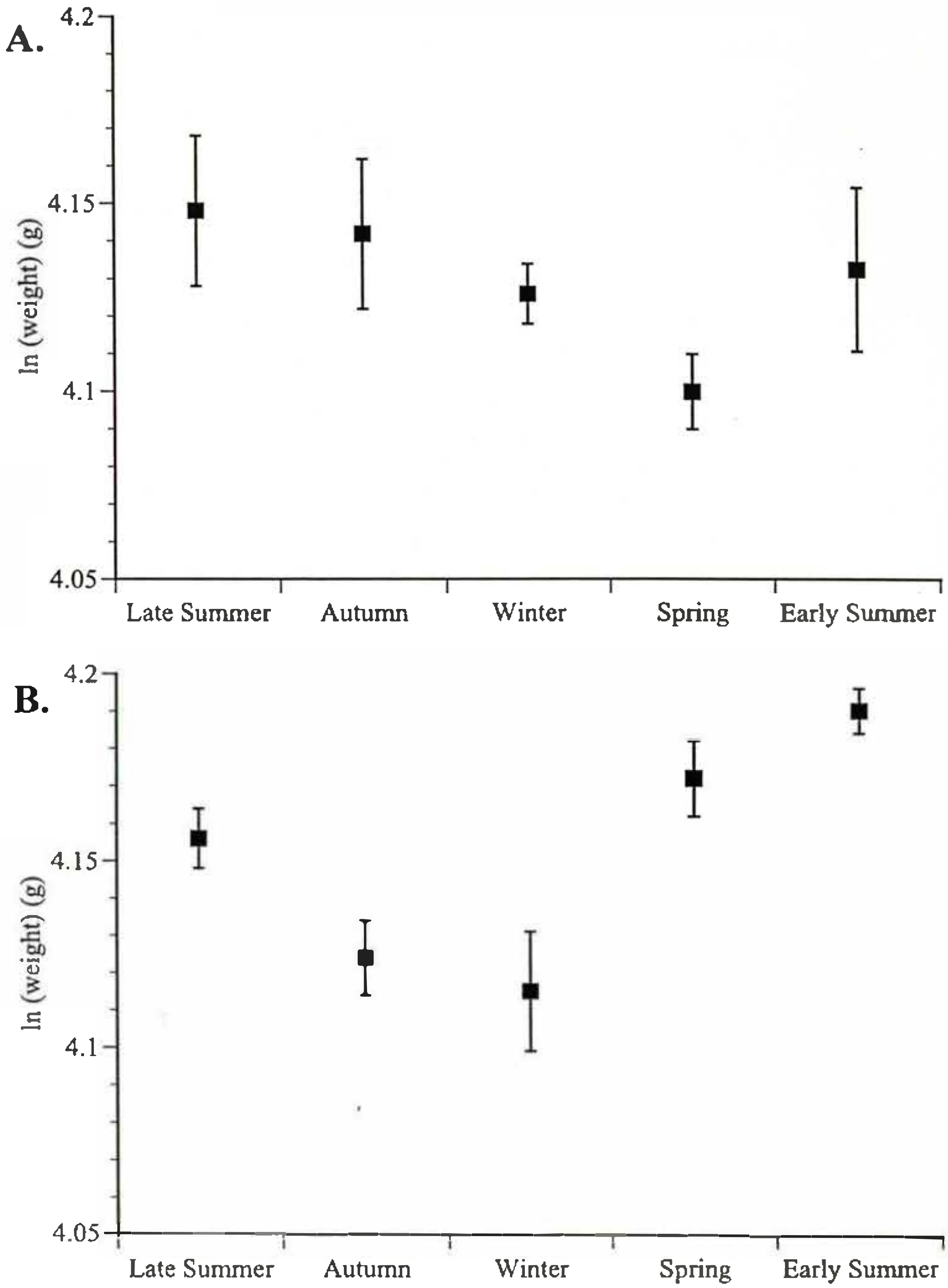

Figure 3.10: Seasonal changes in the least squares mean of $\log_e$ (weight) (g)
A. Rocky habitat. B. Weedy habitat.

to exhibit cyclical fluctuations between summer and winter. Log_e of weight in the weedy sites, reached a minimum of 4.12 during winter before beginning to increase. The rocky sites did not begin to ascend from a minimum of 4.10 until spring. The ascent of weight was found to be steeper and reaching a higher level (log_e of weight = 4.19), in the weedy sites.

3.4 General Reproductive Biology

3.4.1 Age and Size at Maturity

There exists no practical means of externally assessing sex of large numbers of catfish. It was found that all catfish greater than 90 mm long could be sexed after dissection by noting the physical appearance of the gonads lying directly behind the intestine. The smallest sized fish with mature ova (as determined using the scale developed by Nilkosky (1969)), was 171 mm long and at age 2+. Whilst the size of this fish was small, the ovary was considered to be mature due to the rich colouration and the domination of large ova (up to 0.5 mm diameter).

The heaviest ovary encountered was 72.7 g from a fish 288 mm long and 427.7 g in weight. This ovary was distended to the extent of encompassing most of the visceral cavity leaving little room for an extended stomach and hence making the consumption of food near impossible.

3.4.2 Sex Ratios

The ratio of male to female fish captured was approximately 1:1. Of the 2088 fish sexed, 1029 (49%) were male and 1059 (51%) were female. When broken down into habitat types; 57% were female in the sandy areas, 49% female in the rocky areas, and 55% female in the weedy areas (total number of sample was 64, 906, and 1218, respectively).

3.4.3 Seasonal Reproductive Cycle

Diver surveys were conducted on three occasions to locate nesting catfish, but none were found. This has largely been attributed to the presence of dense macrophyte beds offering significant cover to nesting catfish, making direct observation impossible. Diving beneath the cover proved futile.

Due to the territorial nature of catfish during spawning an attempt was made to note changes in catch rates and population structure during what was thought to be the spawning period (Figure 3.2 and 3.3) Catfish caught during July at Motuoapa Bay, Motuoapa Headland, and Waihi Bay were compared with fish caught at the same sites during December. If mature fish were absent from the December sample this would indicate that spawning was currently occurring. However, this was not the case. Only

Motuoapa Headland showed any absence of larger fish, particularly in the 220 - 280 mm size class, although this could be attributed to the low number of catfish caught in this area during December. Another attempt was made to evaluate the extent to which spawning was occurring by calculating the percentage of fish running ripe. The number of fish which had large, fully yolked ova peaked in November, however, no incidences of fish running ripe were recorded.

Changes in ovarian weight throughout the year have often been used as an indicator of gonad maturity and spawning time (Blumer , 1985). The mean GSI value peaked in spring, before declining in early summer (Figure 3.10). Mean GSI peaked at 5.28 in October before declining rapidly to 1.35 by mid December. This suggested that the duration of spawning was approximately four months, from September to December. The gonadosomatic index (GSI) was used as diver surveys failed to elucidate the time of spawning.

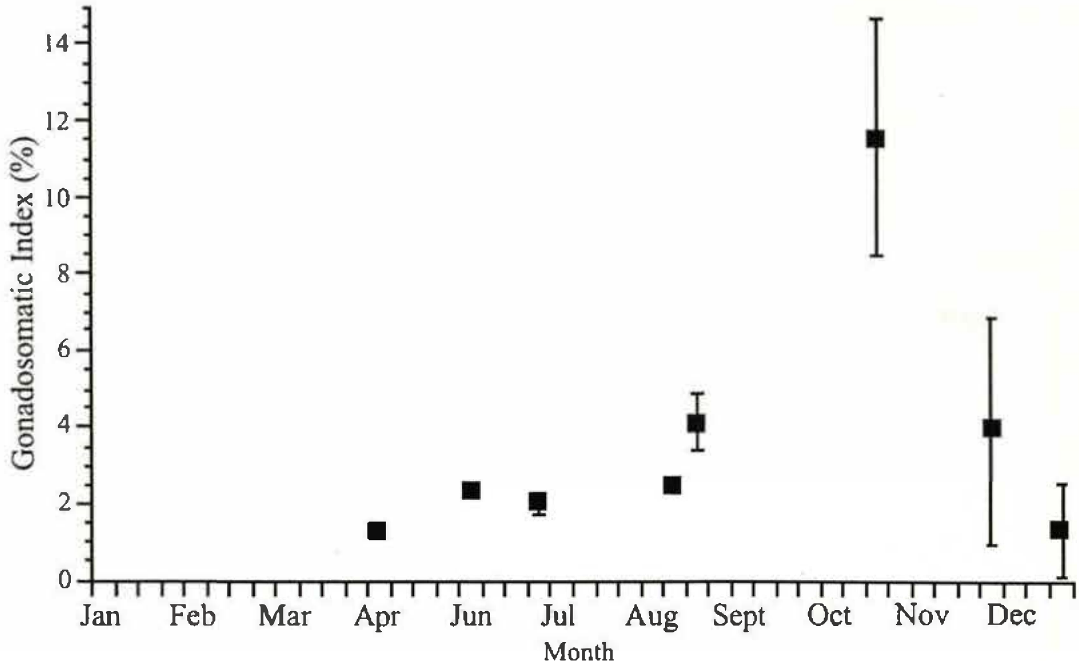

Figure 3.10: Gonadosomatic Index (GSI) of catfish caught in Lake Taupo between February and December 1995

3.4.4 Fecundity

Fecundity is defined here as the total number of secondary oocytes present in the ovaries prior to the first spawning of the season (Patchell, 1977) (Appendix III). The relationship between egg numbers and fish weight is illustrated in Figure 3.11. The linear equation gave the straight line relationship:

$$y = ax^b$$

where y = the number of ova, x = weight (g), a = 959, and b = 12.250.

The slope of the graph equates to the number of ova per gram of catfish (or 12 250 ova/kg) (r^2= 939). This was believed to under-represent total fecundity as the least squares regression calculated fecundity for immature fish (<190 mm F.L.). True fecundity was believed to represented by the mean ova/kg obtained from all mature ovaries counted (16 620 ova/kg).

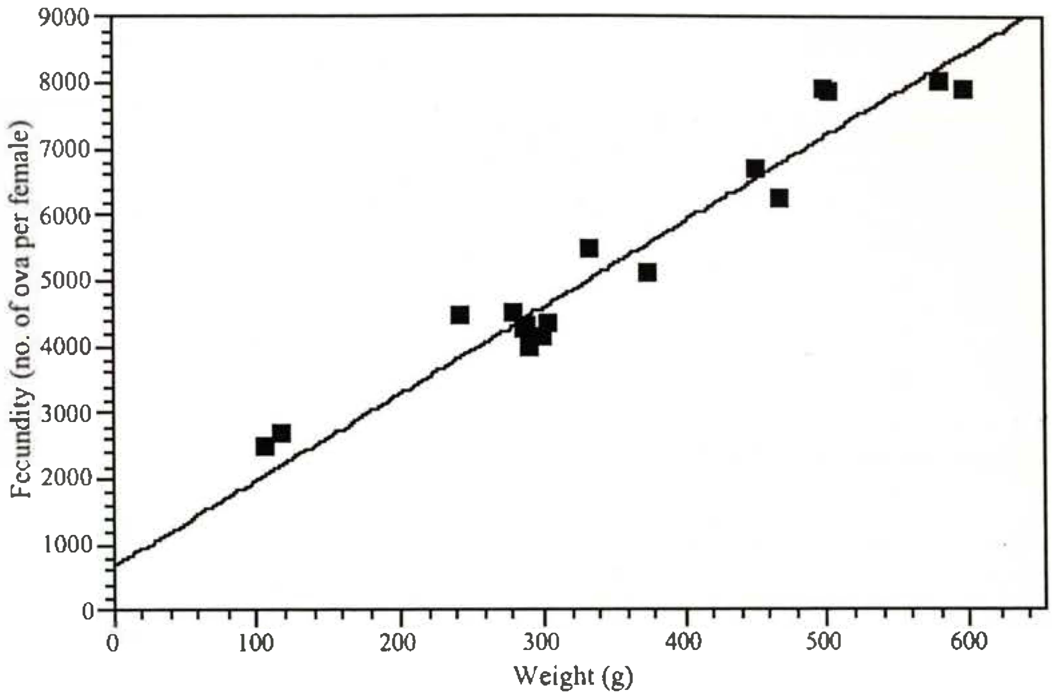

Figure 3.11: Comparison of the total number of ova versus total weight in fish captured in Lake Taupo between November and December 1995.

3.5 Diet Analysis

Diet analysis involved the removal of 283 stomachs from catfish caught between February and August 1995. A total of 117 (41%) were empty. Catfish at both habitat types examined appeared to be opportunistic omnivores, with the dominant food items reflecting relative prey abundance (Table 3.5). Indicative of the catfish's omnivorous feeding strategy was a stomach taken from a catfish in Waihi Bay which contained a partially digested chicken wing, potatoes, peas, and carrots.

Table 3.5: Number of food categories per stomach of each fish species caught in Lake Taupo between February and August 1995. Food categories are defined as taxonomically distinct prey items consisting of Gastropoda, Odonata, Trichoptera, zooplankton, chironomids, koura, fish, plant material, and detritus.

Number of food categories per stomach	Percentage (%) of stomachs	
	Weedy Habitats	Rocky Habitats
1	50	63
2	28	27
3	17	8
4	3	3
5	1	0
6	1	0

3.5.1 Weedy Habitats

Differences in the percentage of prey items consumed became apparent when frequency of occurrence was broken down into catfish size classes. (Table 3.6). Trichoptera was the most abundant food item found in catfish less than 150 mm F.L., followed by chironomids, gastropods, and zooplankton in relatively equal amounts (Figure 3.12). No discernible amounts of plant material or detritus were found. Koura and Odonata were not represented in the stomachs of catfish smaller than 150 mm F.L.

Gastropods, Trichoptera, and zooplankton were the most abundant food items found in catfish between 150 - 249 mm F.L., with each taxa represented in approximately equal amounts. Plant material and detritus were found in quite large amounts in over 10% of the stomachs sampled within this size class.

Table 3.6: Frequencies of stomachs analysed containing one or more individuals from each taxonomic group, from catfish caught at Lake Taupo between February and August 1995. Figures expressed as a percentage of all stomachs containing one or more food items. (-) denotes no items from this taxonomic group were found in stomachs pertaining to this particular habitat and size class.

Prey item	Catfish length class (mm)					
	Weedy Habitats			Rocky Habitats		
	50 - 149	150 - 249	250 - 349	50 - 149	150 - 249	250 - 349
Gastropoda	45	44	58	21	30	13
Odonata	-	13	31	-	15	4
Trichoptera	50	38	17	57	27	-
Zooplankton	25	44	-	-	-	-
Chironomidae	40	25	19	36	18	4
Koura	-	13	36	7	45	68
Fish	5	6	22	-	3	9
Plant Material	2	19	25	29	12	6
Detritus	-	13	28	7	3	2
Total Stomachs (% empty)	38 (47)	32 (50)	62 (42)	31 (55)	53 (38)	67 (30)

Zooplankton consumed consisted of the cyclopoid copepod *Macrocyclops albidus* and the cladoceran *Simocephalus.* The high percentage of zooplankton found in catfish less than 250 mm F.L. may not be entirely indicative of catfish diet as this prey item only occurred in stomachs of catfish caught at Waihi Bay over two days during April.

Gastropods were the most abundant taxa found in the stomachs of catfish greater than 250 mm F.L. A size related diet change was apparent with large percentages of koura and Odonata also consumed. Plant material and detritus were found in large amounts in over 20% of the stomachs containing food of large catfish sampled. Fish, chironomids, and Trichoptera were represented in approximately equal amounts, with figures of 22%, 19%, and 17%, recorded respectively.

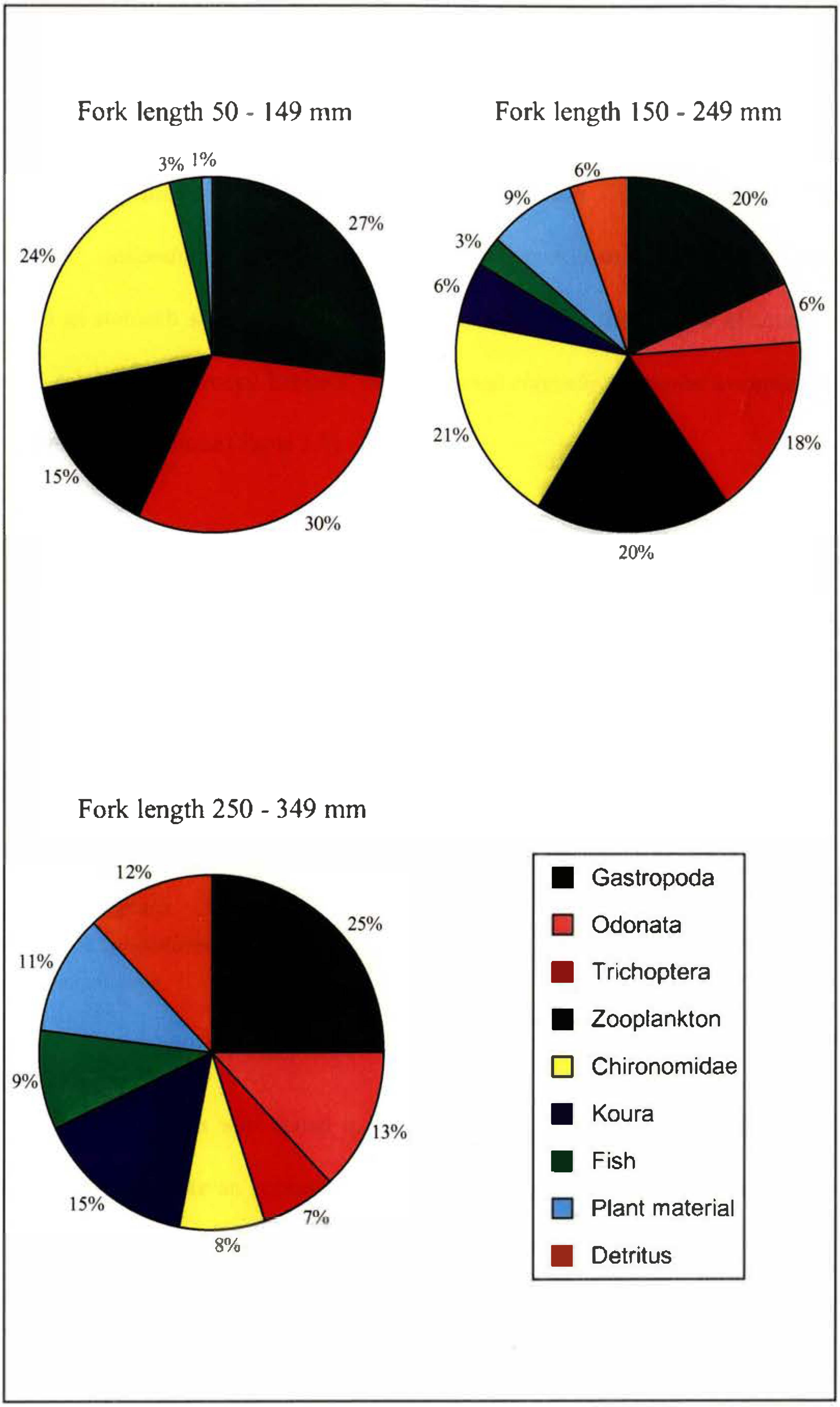

Figure 3.12: Percentage composition of food items in the diet of catfish of different size classes, caught at the weedy sites between February and August 1995.

Numerically the most abundant food items were aquatic gastropods, consisting of the species *Physatra variabilis*, *Potamopyrgus antipodarum*, *Lymnaea stagnalis*, *Gyraulus corinna*, and *Sphaerium novazelandiae* (Winterbourne and Gregson, 1989). The molluscs *P. antipodarum* and *P. variabilis* were approximately three times more abundant in stomach samples from weedy habitats and four times more abundant in stomach samples from rocky habitats, than *Lymnaea stagnalis*, *Gyraulus corinna*, and *Sphaerium novazelandiae* (Table 3.7).

Table 3.7: Percentage of individual mollusc species, classed as gastropods, found in weedy and rocky habitats during diet analysis.

Species	Total no. of individuals		Percentage of individuals (%)	
	Rocky	Weedy	Rocky	Weedy
Gastropods				
Physatra variabilis	199	494	37	28
Potamopyrgus antipodarum	262	635	48	35
Lymnaea stagnalis	57	180	10	10
Sphaerium novazelandiae	25	223	5	12
Gyraulus corinna	1	258	2	14
Total	544	1790		

Terrestrial invertebrates were found in the stomachs of two individuals but were not considered to constitute an important component of catfish diet in weedy habitats due to the low numbers recorded. Fish eggs (diameter < 1.5 mm) were found in the stomachs of two catfish from Waihi bay. According to trout egg size given in Cryer (1991) these eggs were considered too small to bee from rainbow or brown trout and were considered be from either common bully or goldfish.

3.5.2 Rocky Habitats

Diet of catfish from rocky habitats was found to be distinctly different to that observed in catfish from weedy habitats. The relative abundance of prey items in rocky habitats was reflected in the stomach contents of fish examined. There appeared to be a stronger reliance on koura and Trichoptera in rocky habitats than was observed in weedy habitats (Table 3.7).

Numerically, the most abundant taxa consumed in catfish less than 150 mm F.L. were the macrophyte dwelling Trichoptera, *Paraoxethira hendersoni* (Figure 3.13). Chironomids and gastropods were also major dietary items, present in 36% and 21% of stomachs from catfish of this size, respectively. Plant material were found in four times as many stomachs as detritus. No Odonata or fish were recorded in the stomachs of catfish less than 150 mm F.L., a similar to that found in fish of the same size from weedy habitats.

Koura were the most abundant species consumed in catfish between 150 and 249 mm F.L. Gastropods and Trichoptera were consumed by a similar percentage of catfish (30% and 27% recorded respectively). Chironomids and Odonata were represented in approximately 15% of stomachs sampled from catfish of this size.

Koura dominated the diet of large catfish from rocky habitats with 64% of stomachs containing at least one individual. The next most abundant food items were gastropods

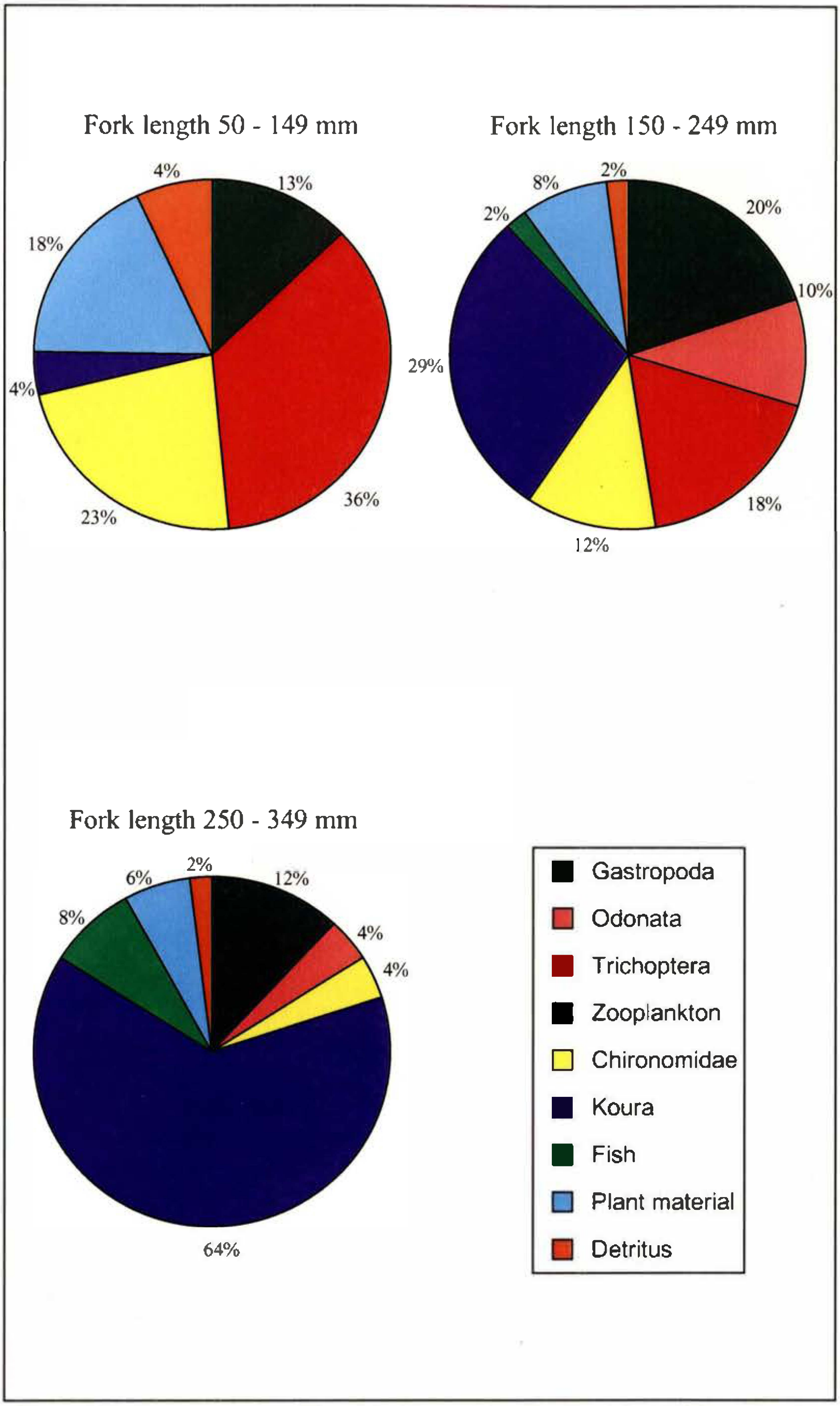

Figure 3.13: Percentage composition of food items in the diet of catfish of different size classes, caught at the rocky sites between February and August 1995.

and fish, with each item present in 12 and 8% of stomachs sampled respectively. Low percentages of plant material and detritus were recorded in the stomachs of large catfish, a similar situation to that found in all stomachs from catfish in rocky habitats.

Chapter Four

Discussion

4.1: Fish Abundance

In the examination of catfish abundance in Lake Taupo, I have made the basic assumption of fish population studies that fish abundance was proportional to catch per unit effort. This assumption is common in fish populations studies (Gulland, 1964). Abundance of catfish within the primary sampling sites was generally high, with some fyke nets catching extremely high numbers of catfish over a single night. CPUE data indicated that catfish were most abundant in rocky and weedy habitats and least abundant in sandy habitats.

Net selectivity is a factor which must be considered when evaluating fish abundance. All passive fishing techniques are selective, to some degree, for certain fish species, sizes and individual fish behaviour (Hayes, 1989). In this study, fyke netting was considered to be the most efficient fishing technique once the benthic and gregarious behaviour of the catfish was taken into account. However, fyke netting was selective to catfish greater than 100 mm in length. This resulted in age 1+ fish being under represented in the total catch, and age 0+ fish being totally absent.

A range of catfish abundance among sites was expected, due to the different physical and ecological characteristics experienced between these sites. Comparing weedy sites, mean CPUE was highest at Waihi Bay followed, in descending order, by Motuoapa Bay and Pukawa. Catfish abundance at the Pukawa weedy site was comparable to that found at the sandy sites.

Waihi Bay experienced higher mean temperatures than the other weedy sites, perhaps due to geothermal activity and reduced mixing, and supported a greater biomass of aquatic macrophytes. The productivity of Waihi Bay was influenced by the addition of relatively nutrient rich waters, with a high biomass of plankton and allochthonous material, from Lake Rotoairo due to the Tokaanu hydro-electric power scheme. For the greater part of the year the water entering Waihi Bay from Lake Rotoairo is several degrees lower and, due to a higher density, does not mix with Lake Taupo water, lying below the epilimnion in the aphotic zone. However, for three months during summer the water temperature from Lake Rotoairo is, on average, 5°C warmer than Waihi Bay, consequently, due to a lower density, the nutrient rich water lies above the epilimnion in the photic zone and is able to support a large macrophyte biomass (Gibbs, M.M. pers. comm.).

Whilst Motuoapa Bay supported dense aquatic macrophytes during summer, low winter water temperatures, relatively low nutrient status, and periodic high wave action resulted in the macrophyte communities declining markedly over winter. Motuoapa Bay receives a large anaerobic groundwater inflow which results in a high iron flux (Gibbs, M.M. pers.

comm.), and consequently, dissolved reactive phosphorus is lower than that found in Waihi Bay.

Catfish abundance at the Pukawa weedy site was consistently low. This site did not share the same characteristics as the other weedy sites. The site was in an exposed position and thus was subject to high energy wave action. Consequently, the macrophyte communities at this site were limited.

From my study, it appears that macrophyte communities are an important factor in the regulation of catfish abundance as they provide shelter during daylight hours and habitat for catfish prey. CPUE data suggests that whilst weedy habitats generally supported the highest abundance of catfish, not all weedy sites were suitable to supporting large numbers.

There were also differences in abundance between the two rocky sites. The high abundance at Motuoapa Headland was thought to be influenced by the large biomass of submerged macrophytes that existed at depths of 2 - 5 m. There appeared to be little or no established macrophyte communities at the Pukawa rocky site.

Motuoapa Headland had a markedly higher abundance of catfish over the winter months than the Motuoapa Bay weedy site. Fluctuations in mean CPUE, between Motuoapa Headland and Motuoapa Bay were thought to indicate a possible concentration of catfish at rocky habitats during winter and weedy habitats during summer. However, the high variation in catches within each habitat type made this conclusion tenuous.

Catch rates of catfish at northern sites were low compared to southern sites. This may indicate that catfish are still spreading to the northern regions of the lake, and that their numbers have yet to reach the level of Motuoapa and Waihi Bay. There are no known physical reasons that would prevent catfish in weedy areas within the northern regions of the lake from reaching the densities of their southern counterparts. Kinloch and Acacia bay do support considerable stands of aquatic macrophytes during the summer as do numerous other bays on the northern shores of Lake Taupo. The significance of the data obtained from the northern sites must be treated with caution as sampling was carried out during winter when macrophyte biomass and catfish activity were at their lowest.

The shoreline of Lake Taupo is characterised by cliffs (ca. 25% of the shoreline) and sandy beaches with shallow benches below the wave zone ending in steep slopes down to a relatively flat lake bed (Lister, 1978). This shape is reflected in one-third of the lake being less than 100 m deep, whereas the remaining two-thirds are between 100 m and 250 m deep (Timperley, 1983a). Areas that support dense aquatic macrophyte communities are generally restricted to the southern areas of the lake and sheltered bays in the north (Howard-Williams and Vincent, 1983). The availability of vacant habitats supporting dense macrophyte communities was believed to be a major factor restricting the ultimate number of catfish in Lake Taupo.

Previous catches of catfish in Lake Taupo showed that abundance at Motuoapa Bay has remained relatively constant (Table 4.1) (Fechney, 1986). For the purpose of this comparison, CPUE was calculated from an estimated effort of 15 nets (Stephens, R.T.T pers. comm.). To avoid possible effects of seasonal variation in abundance, results from the 1986 study in Lake Taupo were compared to catches from Motuoapa Bay during February. Very few studies on catfish state the total fishing effort, in number of nets set, making abundance comparisons through CPUE data difficult.

Table 4.1: Comparison between catch per unit effort of catfish caught in Motuoapa Bay during 1986 and 1995, and in Hamilton Lake 1992 and 1995.

Location	Author	CPUE (fish net^{-1} $night^{-1}$)
Lake Taupo,		
All sites combined	present study	23
Motuoapa	present study	12.5
	Fechney (1986)	15.5
Hamilton Lake	Bell (unpublished data, 1992)	9.3
	Kane (1995)	0.82

The comparison of catch rates between 1986 and the present study suggest that catfish have reached, maximum densities in Motuoapa Bay. The 1986 study was conducted with fyke nets with a 10 mm stretched mesh, whilst the present study used 25 mm stretched mesh. This resulted in a greater number of catfish less than 90 mm in length being caught in the 1986 study. Removal of fish less than 90 mm F.L. from the 1986 study data resulted in the CPUE for 1986 reducing to 14.4 fish net^{-1} $night^{-1}$.

Catch rates obtained from Hamilton Lake during 1992 and 1995 are extremely different. A total of 111 catfish were caught in Hamilton Lake in 1992 from a fishing effort of 12 nets resulting in a CPUE of 9.3 fish net^{-1} $night^{-1}$ compared to a CPUE of 0.82 in 1995 (Kane, 1995). The variation in catch rates could be attributed to both spatial and temporal differences in the sampling methods between the two studies. Both studies appeared to show that abundance is lower than that found at all sites combined in Lake Taupo. Abundance in Hamilton Lake during 1992 and 1995 appeared to be similar to catch rates from the weedy site at Motuoapa Bay, Lake Taupo and of sandy sites, Lake Taupo, respectively. (Appendix I).

The combined seasonal mean yield of catfish from all sites sampled in Lake Taupo was compared to the mean yield of freshwater eels obtained from catch rate data from commercial eel fishery operations throughout New Zealand (Annala, 1994). The mean yield from catfish in Lake Taupo (2.7 kg net^{-1} $night^{-1}$) was less than half that found in commercial freshwater eel catches (6.5 kg net^{-1} $night^{-1}$). Eel biomass in unexploited streams of the Waikato River basin has changed little in 40 years, with the yield of longfinned eels from lowland pastoral streams found to range between 308 and 519 kg ha^{-1}(Chisnall and Hicks, 1994).

Assuming similar activity and feeding behaviour between freshwater eels and catfish, the biomass of catfish in Lake Taupo could be extrapolated from freshwater eel data. The biomass of catfish in Lake Taupo ranged between 120 and 200 kg ha^{-1} and was calculated by dividing the mean yield of catfish from Lake Taupo with the commercial mean yield of freshwater eels and then multiplying with the biomass range of freshwater eels from the Waikato River basin. The use of freshwater eel data in calculating the biomass of catfish in Lake Taupo was considered to be merely a crude indication of catfish biomass as the extrapolation from freshwater eel data was extremely tenuous due to the many assumptions that must be made between the two populations.

4.2 Population Attributes

4.2.1 Length Frequency Distributions

The length composition of catfish caught at rocky and weedy habitats appeared to be similar. Conclusions from direct habitat comparisons are difficult due to the domination of particular sites in terms of total fishing effort and total numbers of catfish caught, however, it appeared catfish prefer rocky and weedy habitats over sandy habitats. This was believed to be a consequence of higher prey abundance and greater shelter at rocky and weedy habitats.

A combination of CPUE and length frequency analysis of both rocky and weedy sites appeared to support the hypothesis that catfish live in weedy sites during summer and rocky sites during winter. This could be related to prey abundance, spawning territory, and available shelter. The weedy sites supported a high biomass of prey that lived on, or closely to, aquatic macrophytes. Weedy sites also provided a suitable nest building substrate and adequate shelter during nesting. The dieback of aquatic macrophytes during the cooler months was likely to be a factor in the migration of catfish to rocky habitats, where large rocky substrates provide protection during the day and a source of prey during the night.

A site comparison of length frequency revealed the influence Waihi Bay and Motuoapa Headland had on length frequency distribution in weedy and rocky habitats respectively. The two weedy sites were found to have similar length frequency distributions, although total catches between Waihi and Motuoapa Bay were extremely different. Motuoapa Headland had a similar length frequency distribution to that found at the weedy sites. This is thought to be due to the influence of the extensive macrophyte community surrounding the Headland site. It would appear that catfish from Motuoapa Headland seek shelter in the rocky substrate whilst feeding on fauna associated with aquatic macrophytes.

A comparison of length frequency data between other studies outside Lake Taupo (Waikato (Patchell, 1977), and Hamilton Lake (Bell, unpublished data)) demonstrated considerable variation in catfish length frequency composition (Figure 4.1). For the purpose of this comparison only fish captured in Lake Taupo during the summer of 1995 were included in order to coincide with the sampling times of the other studies.

Lengths of catfish captured from the Waikato region were normally distributed and consisted predominantly of large individuals with a single mode occurring at 250 mm in length (Patchell, 1977) (Figure 4.1A). Numbers of catfish smaller than 200 mm were low, suggesting that fish of this size were either not present in the Waikato or were able to avoid capture. The sampling method and mesh size were the same as that used in the present study, where high numbers of catfish between 100 mm and 200 mm were captured. Patchell (1977) concluded that the population of catfish in the Waikato region was dominated by large catfish.

Lengths of catfish from Hamilton Lake in 1992 were similarly distributed as fish from the Waikato region (Figure 4.1B). The population consisted of large individuals greater than 200 mm F.L. A similar conclusion could be drawn from the Hamilton Lake data in that the population is dominated by large individuals with low numbers of juvenile catfish present. Large catfish might restrict, through predation and competition, the numbers of juvenile catfish recruited into the population (Keen, 1981).

Length frequency analysis of catfish captured in Lake Taupo during February 1986 (Figure 4.1C) showed a normal distribution with a range from 50 mm to 250 mm (Fechney, 1986). Of the catfish captured, 72% were between 100 mm and 180 mm. Very few catfish greater than 200 mm were captured, a fact which could be attributed to catfish being released into the southern region of Lake Taupo sometime between the late 70's, early 80's.

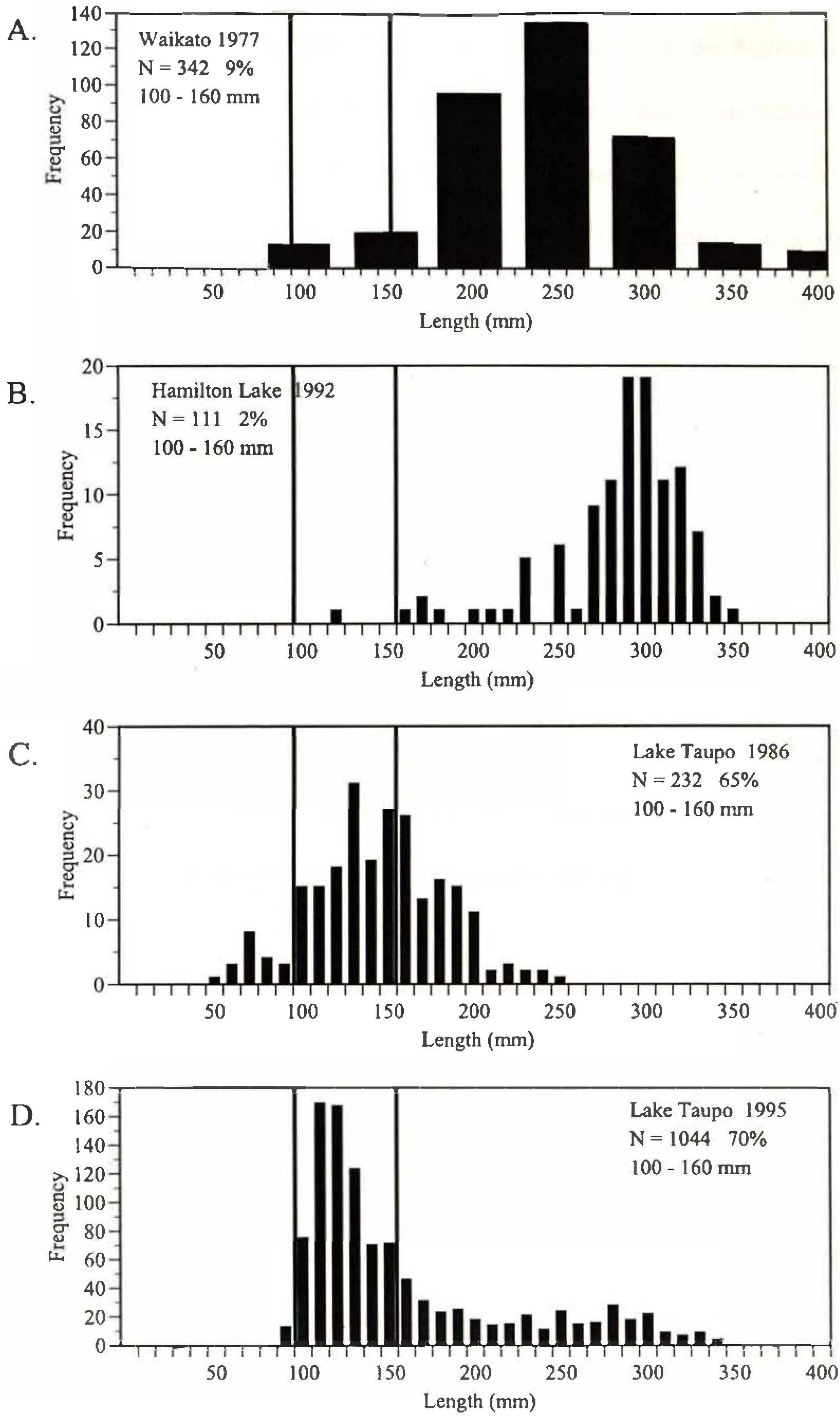

Figure 4.1: Length frequency of catfish in Motuoapa Bay, Lake Taupo (D. February 1995 and C. 1986) and in the Waikato region (A. 1977, B. Hamilton Lake, 1992) Area between thin lines represents age 2+ catfish (100 -160 mm F.L.)

Length frequency analysis of catfish caught at Motuoapa and Waihi Bay during summer, 1995, showed a positively skewed frequency distribution with the highest numbers of catfish between 100 and 160 mm F.L. There were however, considerable numbers of catfish greater than 200 mm captured. It is apparent that in the nine years since the previous study was conducted in Motuoapa Bay the catfish population has reached a point were all age groups are adequately represented in length frequency analysis. Catfish in Motuoapa and Waihi Bay have not yet reached the length composition apparent in the Waikato region where the population is dominated by large individuals.

Before conclusions can be drawn from the length frequency distributions of different populations of catfish, the relationship between the biomass of a population and its food consumption, growth, and production must be considered. In an ecosystem in which the limiting resource is food or territory, an increase in the number and biomass of a dominant species will lead to a reduction in the amount of food each individual can obtain, and this in turn will lead to a reduction in individual growth rate and recruitment of juvenile fish (Warren, 1971).

Body size is one of the primary factors determining the outcome of intra or interspecific competition between animals for limited food resources (Wilson, 1975). In populations of catfish where social organisation is not of major importance, larger body size generally facilitates the more efficient exploitation of a limited food resource and is thus an important factor in the growth rates of individual fish within groups (Keen 1981). In a population as established as catfish in the Waikato region, the high numbers of large individuals are likely to restrict the amount of available food and nesting territories available to smaller fish. Consistently low capture rates of juvenile catfish in the Waikato region may be consistent with Johnson's (1994) theory that in unexploited populations, length frequency distributions of dominant fish populations indicate an almost total absence of young fish which results from the stability brought about by the dominance of larger fish, maintained by the gradual and ordered replacement of individuals (Johnson, 1994). Catfish are captured as a by-catch of the eel fishery in the Waikato region and therefore the population studied was not strictly unexploited. However, the number of catfish removed from the Waikato population was not considered to be large enough to influence length frequency (Patchell, 1977).

Johnson's (1994) theory continues that in exploited populations where large individuals are removed from the population, the length frequency was dominated by juvenile fish. Once fishing ceased the large mode was found to reform to pre-fishing levels. There does not appear to be a similar progression from a small size mode to a large size mode in the length frequencies of catfish captured between the 1986 and present studies.

The large numbers of catfish less than 160 mm F.L. Motuoapa and Waihi Bay length frequency indicated the population of catfish in Lake Taupo is still increasing. It is hypothesised that the numbers of large catfish present in Motuoapa and Waihi Bay have reached carrying capacity, in terms of available nesting territories, and thus their offspring are being forced to migrate out of these habitats in search of new territories. This would account for the presence of catfish, in relatively low abundance, in the northern regions of Lake Taupo.

4.3 Age and Growth

4.3.1 Age Assessment

The centra of the fifth vertebrae showed a series of dark bands which are believed to represent annual markings formed during a period of slow growth. These markings were similar in appearance to those found by Patchell (1977) in catfish from the Waikato region, and by other authors studying Ictalurids (Hensel, 1966; Appelget and Smith, 1951; Keast, 1985). The age of catfish captured in Lake Taupo ranged from 1 to 8 years of age, with the majority of the fish in their third season of growth.

Seasonal differences in mean water temperatures (between summer and winter) were thought to be sufficient to indirectly slow growth to the point where annular markings are laid down (Keast, 1985). Patchell (1977) found that the presence of growth rings were associated with a greater rate of calcium deposition in that zone than in the rest of the vertebra. This lead him to conclude that a period of slow growth of the vertebral margin allowed time for a greater deposition of calcium in the bone matrix, and hence formation of an annual ring.

Validation of the ageing method suggested that growth rings within the fifth vertebra were laid down at the same time each year. The results in section 3.3.2 are similar to those found by Patchell (1977). It was illustrated that the time of ring formation was during winter, because in spring there was the smallest amount of growth past a ring. Although the exact time for appearance varied, it was assumed that by the end of a season's growth the new ring would have appeared. If not, the calculated age would be far too high and would stand out in an age/length analysis (Patchell, 1977).

4.3.2 Growth in Length

Initially, somatic growth is comparable to the Waikato population (Lake Taupo 82 mm at age 1+; Waikato 80 mm at age 2+) (Table 4.2), however, length varied considerably between the two populations amongst fish in their third season of growth. Catfish in the Waikato continued to attain a greater size than the Lake Taupo population throughout their lifespan, reaching a maximum length in their fifth year of growth. The Taupo population lived for a longer period of time than catfish in the Waikato, with ages of 7+ common, however, mean maximum length does not appear to have been achieved until the 6+ age class. The maximum length of catfish in the Taupo sample (359 mm) is considerably less than that found in the Waikato (455 mm) (Patchell, 1977), and the maximum length quoted by Mansueti & Hardy (1967) of 508 mm.

Table 4.2: Comparison of mean length at age of catfish captured in Lake Taupo with other studies in New Zealand and overseas. (-) denotes number not available.

Location	N	Mean fish length (mm)at each year									Author
		1	2	3	4	5	6	7	8	9	
NEW ZEALAND											
Lake Taupo	101	82	150	196	264	277	295	289			Present study
Hamilton Lake	161		160	220	250						Wise (1990)
Waikato	-	80	186	273	337						Patchell (1977)
CANADA											
Upper Ottawa River	163	63	136	187	242	276	297	321	343	345	Rubec & Qadri (1982)
Opinicon L.	70	90	126	169	202	237					Keast (1985)
CZECHOSLOVAKIA											
Pond Zehun	63	93	145	187	239	271					Frank (1955)[a]
Elbe River	107	98	132	163	180	198					Hensel (1966)

[a]Cited from Carlander (1969)

Raney and Webster (1939) found a mean total length increment of 77 mm for fish in Lake Cayuga, New York, USA. A study on the catfish population in Lake Opinicon, Canada, showed first year population reached a mean total increment of 90 mm (Keast, 1985). A mean fork length of 80 mm was recorded for age 1+ by Patchell (1977) during population studies in the Waikato region. The length of the spawning season and time of spawning must be considered before the mean fork length at age 1+ can be considered similar between New Zealand and overseas studies.

Lake Taupo catfish, in their second and third year of growth, had a growth rate lower than the Waikato population (Figure 4.2). With the exception of the Waikato region and Elbe

River, incremental increases in growth generally decreased after the first growing season. Catfish from Lake Taupo had a higher growth rate than catfish from Czechoslovakia (Figure 4.2). There appeared to be an increase in the growth rate of catfish from Lake Taupo, Pond Zehun, and the Upper Ottawa River during their fourth season of growth.

The characteristics of growth for selected studies was examined further using the von Bertalanffy growth equation. Values for L_∞, K, and t_0 were calculated and length age data graphed accordingly (Figure 4.3). The growth rate of Lake Taupo catfish apparent in Figure 4.2 is reflected in Figure 4.3, where an initial rapid increase in length is followed by a levelling off of length in fish 5 years and older.

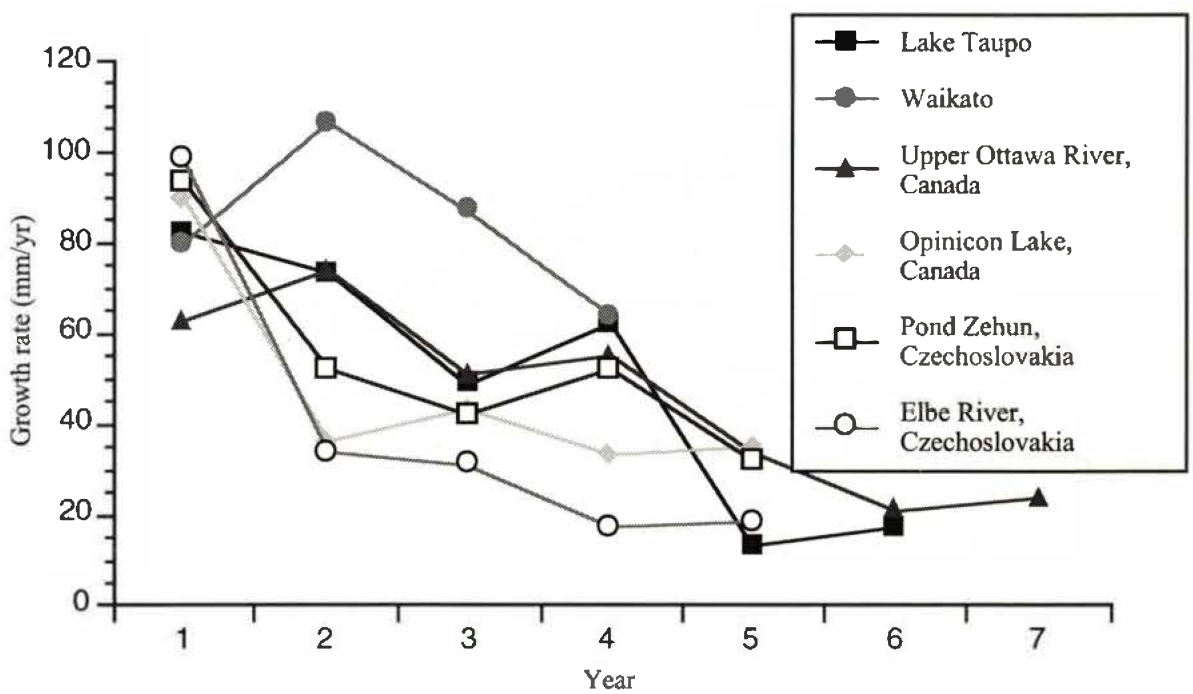

Figure 4.2: Mean growth rate comparison between catfish caught in the present study and results obtained from New Zealand and overseas studies.

Catfish from the Upper Ottawa River, Canada exhibited a slower growth rate but a higher maximum length than Lake Taupo catfish. Slow growth rate and low maximum size was apparent in catfish captured during the Pond Zehun, Czechoslovakia study in 1955.

It thus appears that the growth rate in this study was similar to that of Waikato and Canadian fish in the first two years and, whilst lower than the Waikato, was faster in overseas studies in the following years. The growth rate of catfish from Czechoslovakia was much slower. This suggests that the conditions found in Lake Taupo and many of the Waikato lakes were favourable for rapid catfish growth.

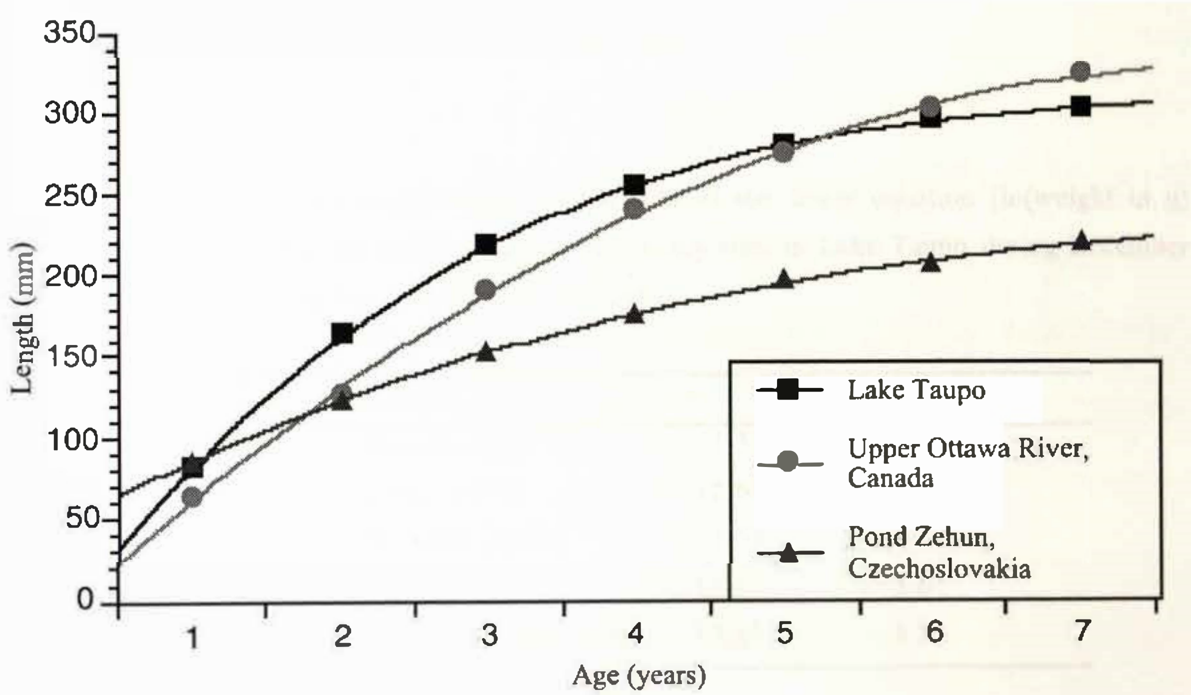

Figure 4.3: Von Bertalanffy growth comparisons of catfish caught in Lake Taupo between September and December 1995 and from two overseas studies.

4.3.3 Growth in Weight

The weight-length relationship for catfish was found to have a slope of b= 3.06, a typical relationship found in catfish and many other fish (Patchell, 1977). The similarity of slope for catfish was consistent with results from previous studies (Table 4.3). There were found to be significant differences ($p<0.001$) between slopes and intercepts of the separate length-weight regressions for catfish at different habitats during each season. Catfish from weedy sites were found to regain a greater condition faster and before catfish from rocky sites. Differences in prey type, prey abundance, and physical conditions exclusive to each habitat type, could account for these differences. It is also possible that migrations of highly fecund females from rocky to weedy habitats prior to spawning could account for the greater length-weight regression slope in weedy sites.

Table 4.3: Comparison of length-weight coefficients of the linear equation [ln(weight in g) =a+b(ln(length in mm))] for catfish caught in the weedy sites in Lake Taupo during December 1995 with other studies in New Zealand and overseas.

Site	Author	a	b
Lake Taupo	Present study	-11.52	3.05
Hamilton Lake	Kane (1995)	-12.68	3.26
Waikato	Patchell (1977)	-11.53	3.06
USA	Priegel (1966)	-11.65	3.07
Canada	Rubec and Qadri (1982)	-12.67	3.26

4.3.4 Temperature Effects on Growth

Temperature has been classified as a controlling factor governing metabolism and hence, the growth of fish (Fry, 1971; Brett, 1979). The optimal temperature for growth in catfish has been established by numerous authors (Crawshaw and Hammel, 1974; Keast, 1985; McDowall, 1990; Scott and Crossman, 1973). Keast (1985) conducted a temperature dependent growth study with age 0+ and age 2+ catfish. The study found that instantaneous growth was absent or low at 5, 10, and 15°C; however, it peaked at 20 to 30°C for the age 2+ catfish and at 30°C for the age 0+ catfish. Crawshaw and Hammel (1974) found that 26°C was the preferred temperature of catfish in a temperature gradient of 9 -30°C.

Catfish sampled in the present study achieved higher growth than catfish from warmer climates, even though maximum water temperature did not reach the point established by Keast (1985) and Cranshaw and Hammel (1974) for optimal growth. This suggested that water temperature and food abundance were not factors limiting growth in catfish from Lake Taupo.

4.4 Reproductive Biology

4.4.1 Size and Age at Maturity

No external differences between the sexes were apparent, but the sexes could be differentiated by gonads present in fish longer than 90 mm. The female first begins to develop secondary oocytes at a length of 130 mm and age 1+ (Blumer, 1986). Menzel (1945) reported the length at maturity for catfish in Virginia, USA, as being 152 - 180 mm, which is similar to that found in the Lake Taupo population as well as in the Waikato study (Patchell, 1977). However, in American studies, sexual maturity was attained by age 3 and a length of 203 mm (Scott and Crossman, 1973).

4.4.2 Seasonal Reproductive Cycle

Ictalurids are known to invest considerable time and energy in nest building, guarding, and manipulation of eggs, larvae, and juveniles (Blumer, 1986; Stranahan, 1910). Previous authors have recorded spawning dates in catfish that range from early spring to early summer, depending upon water temperature (Raney and Webster, 1939; Blumer, 1985; Rubec and Qadri, 1982). Although nesting was not directly observed, I conclude from observation of ovarian development that catfish in Lake Taupo spawn between September and December, at a similar time to catfish from the northern hemisphere.

If spawning in Lake Taupo was temperature related, as was the case in the Waikato (Patchell, 1977) and in the northern hemisphere (Scott and Crossman , 1973), then the temperature threshold is considerably lower in Lake Taupo. Normally, catfish require a minimum water temperature of 21°C before commencing spawning (Scott and Crossman, 1973). Spawning in Lake Taupo occurred when the mean water temperature was 12°C suggesting that catfish have adapted to the cooler temperatures common in Lake Taupo.

The wide range of values and high standard deviations of GSI figures during spring and summer could be considered characteristic of a population with a long spawning season. Studies have shown that in fish with a short spawning season mean GSI falls abruptly after the commencement of spawning (Yamamoto & Yoshioka, 1961). The high standard deviation in data from this study suggested the catfish population consisted of early and late spawners.

Time of spawning appears to be size related because the majority of females captured in November over 220 mm were in a mature state. The first incidences of mature females less than 200 mm long, did not occur until the third week of December. Blumer (1985) found a relationship between male size and spawning time, where large males spawned earlier in the season than smaller males.

4.4.3 Fecundity

4.4.3 Fecundity

Total oocyte production is comparable to catfish from the Waikato region where fecundity ranged from 3522 to 7433, dependent upon fish length (Patchell, 1977). Due to the continuous development of oocytes throughout the year Patchell (1977) summed the number of yolked oocytes in the ultimate modal groups of mature fish which increased the range of fecundity from a maximum of 7433 to 17 000. A similar summation of ultimate modal groups in catfish from Lake Taupo was expected to increase fecundity to the levels found in the Waikato.

In a study on the reproductive natural history of bullhead catfish, Blumer (1985) found that fecundity ranged from 1500 - 2700 eggs, considerably less than those encountered in the Lake Taupo and Waikato studies. Studies in the United States of America have shown fecundity ranging from 2000 - 13800 (Mansueti & Hardy, 1967) and 6000 - 13 000 (Eddy & Surber, 1943).

These figures indicated that the fecundity of catfish in New Zealand is considerably higher than those encountered in its native range, which could be attributed to lower levels of intraspecific competition between similar sized catfish, or the abundance and type of prey available. The data obtained from other studies must be treated with caution as these figures do not account for catfish size. An accurate comparison of fecundity would be to compare ova/kg between studies, however, the inclusion of data necessary to make this conversion was not available in the above studies.

4.5 Dietary Analysis

Catfish have small eyes and poor sight (McDowall, 1990). It was suggested that the presumed inability of catfish to discriminate between prey types predisposes them to be generalist and opportunistic feeders (Keast, 1985). The chemosensory feeding catfish, whilst showing generalist feeding strategies, was not limited to that role in Lake Taupo. Keast (1985) considered the chemosensory method is particularly suited for finding concentrations of smaller prey or large individual organisms.

The diet of small catfish (<150 mm F.L.) included chironomids, cladocerans, Amphipoda, Trichoptera, and algae (Gunn et al, 1977; Keast, 1985; Moore, 1972; Raney and Webster, 1939; Rubec and Qadri, 1982). Above this size the diet primarily consisted of chironomids, and gastropods. As fish become larger, Decapoda and fish become more important (Atkinson, 1931; Cable, 1928; Scott and Crossman, 1973).

In this study, catfish from weedy habitats fed predominantly upon gastropods (mostly *Physatra* and *Potamopyrgus* sp. (refer Table 3.6)), Trichoptera, cladocerans, and chironomids (refer Table 3.7). A size related diet change was observed where catfish larger than 150 mm F.L. were found to prey, to a greater extent, on koura, fish, and Odonata.

Large catfish (>150 mm F.L.) from rocky habitats had distinctly different diets to fish from weedy habitats, feeding predominantly on koura and, to a lesser extent, gastropods. Small catfish, less than 150 mm F.L., consumed a similar array of prey items to that observed at weedy habitats. However, results from fish caught in rocky habitats were not considered to be truly indicative of catfish diet due to the large biomass of macrophytes, and associated macrophyte dwelling prey items, present at the Motuoapa Headland site. The diet of catfish from the Pukawa rocky site was considered to be a more reliable indication of catfish diet at rocky sites and consisted primarily of Odonata, chironomids, and koura.

Direct observations of piscivory at both rocky and weedy habitats were made during the course of the study whilst SCUBA diving. Catfish were seen to lie prone on the lake floor before darting upwards towards the approaching prey. At Whareroa, a sandy bay outside the study area, catfish were observed to predate shoaling smelt in low water depth (Clements, S. pers. comm.).

The inflection in mean catfish length observed between ages 2+ and 4+ (refer figure 3.4) was thought to be diet related. This study showed that the population of catfish in Lake Taupo consists of fast and slow growing individuals which was evident in the ages of large catfish (>230 mm F.L.), ranging between 3 and 7 years of age. Catfish are believed to undergo a

Trichoptera, gastropods, and cladocerans, to consuming larger prey including Odonata, koura, and fish.

Flexibility is an important adaptive feature of the foraging behaviour of fishes, because most natural environments vary both spatially and temporally (Dill, 1983). Fish respond to low levels of food availability by altering their behaviour in ways which ensure higher feeding rates, larger feeding territories, and broader diets (Dill, 1983). Keast (1985) states that " consuming the most abundant rather than the energetically most rewarding prey could influence the growth rate of catfish". The calorific values of Decapoda and fish (1077 and 1493 cal g^{-1}, respectively) from Lake Opinicon, Canada were at least two times greater than those found in chironomids (Keast, 1985). The writer concludes that the energy gained by switching from the most abundant prey to larger prey was sufficient to increase the mean length of catfish in Lake Taupo.

Lake Taupo trout are heavily dependent upon smelt, especially as juveniles (Cryer, 1991). Rowe (1984) examined the diet of trout from several North Island lakes of varying size and clarity, and found that trout in oligotrophic lakes tended to consume a greater proportion of smelt than did those in more turbid lakes, where bullies and koura usually became the major prey (Cryer, 1991). Brown trout have been found to prey on a greater proportion of bullies and koura than rainbow trout due to its littoral feeding strategy.

Rainbow trout in Lake Taupo undergo a similar diet change to that observed in catfish (Dedual, pers. comm.). Large trout, though still reliant upon smelt, took an increasing proportion of less mobile prey such as koura and bullies (Cryer, 1991). Cryer (1991) believed the reasons for this selectivity were likely to be energetic, but further study would be needed to elucidate this.

The large number of empty stomachs was a product of the fishing method employed and the nocturnal behaviour of catfish. Fyke netting keeps the catfish alive from the time of capture until they are placed on ice upon removal from the water. Fish captured early in the evening would have little food in their stomachs, assuming that they had had time to digest the previous evenings meal yet no time to feed that night. Fish caught after a couple of hours had passed from when the net was set, would have had up to 10 hours to digest any food items preyed upon prior to capture. Thus, only fish caught late in the night would potentially have full stomachs when examined.

In a 1990 study on the catfish population in Hamilton Lake, Hamilton, Wise (1990) found, during a 24 hr distribution study, that most catfish were caught in the fyke net between the hours of 11 p.m. and 1 am. If this was the case in Lake Taupo, it could be assumed that the majority of the fish had been held in the net for up to 8 hours before being placed on ice.

Catfish densities within individual nets, on many occasions, reached very high numbers, for example, over 600 fish were caught in one net in one night during December in Waihi Bay.

It was not uncommon to have over one hundred fish caught overnight in individual nets set in Motuoapa and Waihi Bay. These high densities were thought to create stressful situations for those fish confined within the net. Studies have shown that regurgitation of food whilst under stress was quite common amongst catfish (Patchell, 1977). Whilst this appeared to be the case within this study, the degree of regurgitation was not considered to be significant because in nets where regurgitation had occurred there still remained a high percentage of individuals with full or near full stomachs. It is believed to be unlikely that the proportion regurgitated would change seasonally or that prey species would be differentially regurgitated (Stephens, 1984).

4.5.1 Predator/Prey Confinement

The significance of the dietary study would be significantly diminished if it could be shown that the predation of koura and fish were a result of both predator and prey being confined within the same area. As previously mentioned in section 3.1.2, there existed a high by-catch of principal prey items, especially koura. The fact that koura survived at high densities throughout its confinement with catfish suggested that the degree of predation by catfish during confinement was insignificant. This view was supported by the presence of partially digested koura and common bully within the stomachs of catfish. The degree of digestion suggested that the prey had been captured earlier in the evening and not during the previous night. The incidence of regurgitation, however small, also suggested the environment created within the fyke nets was not conducive to feeding.

4.5.2 Consumption of Detritus and Plant Material

Previous studies have shown that plant material and detritus, consisting of macrophytes algae, and unidentified debris, constituted a large proportion of the total stomach contents of catfish (Raney & Webster, 1939; Gunn et al, 1977; Klaberg & Benson, 1975; Wise, 1990; Patchell, 1977). Without exception, these studies were conducted in eutrophic waters with a thick layer of detritus covering the bottom sediment, which was quite the opposite to the conditions found in the oligotrophic waters of Lake Taupo. The percentage of detritus found in the stomachs of catfish in Lake Taupo (Table 3.7) was considerably smaller than that encountered in the above studies, but it was considered important by the author to establish whether or not it was a significant food item.

Of the major food items consumed by catfish in Lake Taupo, chironomids and oligochaete worms are detritus dwelling species, whilst *Paraoxethira* and molluscs feed on, and associate with, submerged macrophytes (Coffey, 1975). Whilst it has been shown there was some nutritional value to be gained from consuming detritus (Gunn et al, 1977), it was believed that the detritus consumed by catfish in Lake Taupo was primarily a product of its foraging strategy as aquaria studies have shown that catfish feed by engulfing the food item and any debris surrounding it (Patchell, 1977) with the catfish either expelling the debris or ingesting it.

Plant material made up a large portion of food items within the stomach contents of catfish in sites where extensive submerged macrophyte communities were present. The association of plant material and macrophyte dwelling species is not as strong as that found amongst detritus dwelling species, suggesting catfish were able to discriminate between animal and plant and thus selectively target the animal. Cable (1928) studying the food of bullheads in South Dakota, USA, found that where both animal and plant foods were available, the fish took the animal and rejected the plant material. Other authors studying the diet of bullheads made no mention of significant amounts of plant material being consumed (Raney & Webster, 1939; Klaberg & Benson, 1975).

Chapter Five
Conclusion

5.1 Relative Abundance

A total of 6226 catfish were caught from 273 fyke nets set at three distinct habitat types in the southern region of Lake Taupo between February and December 1995. Very few age 1+ catfish were caught as fyke netting was selective to catfish greater than 100 mm in length. Densities of catfish were greater in weedy habitats than rocky habitats. Catch rates of catfish at sandy sites were consistently low.

Different ecological and physical site characteristics were believed to account for the variation in catfish abundance. Macrophyte communities provided catfish with protection during daylight hours and spawning, and a large food source from associated macrophyte dwelling prey species. However, whilst weedy habitats generally supported the highest abundance of catfish, not all weedy sites were found to be suitable for supporting large numbers of catfish due to unfavourable physical site characteristics such as high wave energy.

I believe that catfish have reached the carrying capacity of the Motuoapa Bay ecosystem as comparison of present data with previous catches in this area showed that abundance has remained relatively constant (Fechney, 1986). The restricted availability of vacant nesting territories within Motuoapa Bay is likely to prompt maiden catfish to migrate outside the bay in search of new territories.

Catfish are believed to have spread from the original point of liberation and become established throughout the littoral zone of Lake Taupo. It is my conclusion that while the abundance of catfish at Kinloch and Acacia Bay was lower than found at similar habitat types in the southern areas of the lake, there are no known physical or ecological reasons that would prevent catfish in weedy areas within the northern regions of Lake Taupo from reaching the densities of their southern counterparts. The availability of vacant habitats supporting dense macrophyte communities is believed to be a major factor restricting the maximum number of catfish in Lake Taupo.

It is possible to speculate on the abundance of catfish in Lake Taupo at water depths greater than 10 m. I believe the abundance of catfish will decrease with increasing depth because light level and temperature reductions cause the species diversity and biomass of the macrophyte communities to decrease. As the highest densities of catfish are associated with dense macrophyte communities it is considered probable that catfish abundance at depths where macrophytes ceased to grow would be similar, or lower, to that found at the sandy sites.

5.2 Population Attributes

The mean length composition of catfish caught at rocky and weedy habitats appeared to be similar, however, seasonal differences in length frequency and length-weight relationships between habitats were apparent. Larger sized catfish were proportionally more abundant in weedy sites. The variation in weight between sampling sites was attributed to differences in food availability and the migration of highly fecund females from rocky to weedy habitats prior to spawning, in search of nesting territories.

A comparison of length frequency data between Patchell (1977), Fechney (1986) and the present study indicated an absence of age 2+ fish (100 - 160 mm F.L.) in the Waikato population. This may support Johnson's (1994) theory that in unexploited fish populations there is an almost total absence of juvenile fish. This is due to the stability brought about by the dominance of larger fish, maintained by the gradual replacement of individuals. Catfish in Lake Taupo have not been present in the lake long enough for the numbers of large catfish to be great enough to restrict the recruitment of juvenile fish into the fishery. It is the authors conclusion that, although individual habitats may be close to, or at, carrying capacity, the catfish population in Lake Taupo is still expanding.

Ages of catfish were determined from the fifth vertebra. The ages of catfish in Lake Taupo ranged from 1 to 8 years of age, with the majority of the fish in their third season of growth.

Seasonal differences in mean water temperatures were thought to be sufficient to indirectly slow growth to the point where annular markings are laid down.

The conditions found in Lake Taupo and many Waikato lakes are favourable for rapid catfish growth. The maximum length of catfish in Lake Taupo (359 mm F.L.) is less than found in the Waikato (455 mm F.L.). Somatic growth of catfish in this study was similar to that of Waikato and overseas fish in the first two years and, whilst subsequently lower than the Waikato, was faster than other studies in the following years.

5.3 Reproductive Biology

Catfish in Lake Taupo spawn between September and December, at a similar time to catfish from the northern hemisphere. The temperature threshold necessary for spawning to occur in overseas populations is considerably higher than observed in Lake Taupo. Time of spawning appeared to be size related with larger fish spawning earlier than smaller fish.

Fecundity was in the order 16 000 - 17 000 ova/kg. Comparison with other studies was limited to ova/fish, an inaccurate assessment as these figures do not account for fish size. I tentatively conclude that the fecundity of fish in the present study is comparable with the Waikato and higher than encountered in overseas populations

5.4 Dietary Analysis

The diet of catfish was size and habitat related. Catfish from weedy habitats fed predominantly upon gastropods, Trichoptera, cladocerans, and chironomids. Larger catfish were found to prey, to a greater extent, on koura, fish, and Odonata. Generally, catfish from rocky habitats have a similar diet to fish from weedy habitats, however, large catfish fed predominantly on koura and, to a lesser extent, gastropods.

Catfish are generally considered to be obligate omnivores, often consuming the most abundant prey encountered (Scott and Crossman, 1973). The diet of catfish in the present study showed a high degree of selectivity, especially in larger fish. The size related diet change, from predating principally small abundant items, to consuming larger, energetically more rewarding prey, is considered indicative of an adaptive feeding strategy. I consider the energy gained from switching to koura and fish is sufficient to increase the mean length of fish greater than age 3+ and, ultimately, the maximum length of catfish in Lake Taupo.

5.5 Potential Ecological Impacts

The practice of introducing wild animals into new countries and new localities is long established and world-wide (McDowall, 1968). New Zealand has a long legacy of ill-conceived and detrimental species introductions. The introduction of exotic freshwater conceived and detrimental species introductions. The introduction of exotic freshwater salmonids into local waterways has historically generated little public opposition and was generally met with enthusiasm from sport fishers.

Lake ecosystems are considered inherently unstable and are similar to islands in that they are isolated, small, and relatively young (Magnuson, 1976). Elton (1958) noted that introductions, whether deliberate, accidental, or the result of natural dispersal, often lead to ecological explosions, due to the breakdown of the ecological balance of biotic communities. It is evident that the introduction of animals and plants to new ecosystems causes modifications of both the physical and biotic environments as equilibrium is re-established (Gulland, 1968). Bump (1951) pointed out that "it should be realised that no species can succeed in a new habitat without causing some changes in plant and animal associations already established there."

Hobbs (1955) listed one of the essential environmental conditions for newly introduced species as "either a biotic vacancy or a place weakly held by a displaceable species." An empty niche is difficult to predict because and exotic species may adopt a different realized niche as a response to new ecological conditions (Li and Moyle, 1981). Catfish have been suggested to be occupying a previously vacant niche within the lake, as prior to their introduction, no large, nocturnal, benthic omnivore, existed. However, there exists considerable overlap in the diets and habitat requirements of young catfish and common bullies, to the extent that a true vacant niche did not exist. Bullies could be considered to be a displaceable species and thus the introduction of catfish could of been to the bullies detriment.

McDowall (1968) believes "it is simpleminded to assume that the presence of a vacant niche is all that is necessary to achieve a successful introduction". Irrespective of the degree of biotic vacancy, the introduction of catfish is likely to bring about niche reduction and/or displacement of species which occur at the same or adjacent trophic levels in the same environment (McDowall, 1968).

The high abundance of catfish within the southern regions of the lake, coupled with the dominance of young fish within the population, demonstrates the potential for catfish to rapidly increase its population in the entire lake if suitable conditions arise. However, this is unlikely as the greatest densities of catfish were found to occur primarily in weedy habitats, a habitat that constitutes a small percentage of the total lake ecosystem (Howard Williams and Vincent, 1983). The distribution of catfish was found to be widespread throughout the lake and it is believed that the abundance of catfish in the weedy bays of the northern regions of the lake are likely to reach similar levels seen in the south.

Catfish are top order carnivores, and thus predation on established biota within the lake may lead to a decrease in prey abundance. The predation of koura by large catfish will potentially decrease its densities within the littoral zone in rocky and sandy habitats. The degree of piscivory found in catfish at present densities is not believed to be sufficient enough to cause a large decline in prey species, especially bullies. However, more research on impact of catfish on bullies would be needed to confirm this.

Competition for food amongst juvenile catfish and bullies in weedy habitats is likely to result in a decrease in bully numbers considering the large numbers of age 2+ catfish in these habitats. However, as large numbers of catfish are restricted to areas in, or close to, weedy habitats, the extent to which catfish will restrict the total bully population in the lake is limited.

There exists a potential for direct competition to occur between large catfish and large rainbow trout. Large trout (>450 mm F.L.) are known to predate greater proportions of bullies and koura than juvenile trout. Koura were found in 50% of the stomachs sampled in large rainbow trout (>550 mm F.L.) (Stephens,1984). Catfish greater than 250 mm F.L. consume a high proportion of koura and thus, could be in direct competition with rainbow trout for this food source. However, this was believed to be insignificant, considering the pelagic feeding strategy of rainbow trout. At present population levels, catfish are unlikely to influence trout size or numbers, however there is potential for negative impacts to occur if catfish numbers increase significantly, particularly at greater depths.

I believe that catfish would have a greater ecological impact if they were released into a more turbid lake. There is the potential for catfish to indirectly impact the size and numbers of trout in lakes of low water clarity. Rowe (1984) found that in these conditions trout switched from smelt and fed predominantly on bullies and koura. Under these conditions catfish are believed to have a competitive advantage over the visually feeding trout in that they are able to chemically sense the presence of prey.

There exists a large potential for catfish from Lake Taupo to be processed and sold at commercial fish markets. Catfish are caught as a by-catch of the eel fishery in the Waikato River basin, and are currently marketed and sold in the Auckland Asian food markets. Estimated annual catch of catfish sold in 1992/93 was 5200 kg, increasing to 7500 kg in 1993/94. A drop in demand from the food markets decreased the amount sold to 2500 kg (McGregor, G. pers. comm.)..

5.6 Recommendations

This study was intended to give a broad understanding of the population biology and general ecology of the brown bullhead catfish in Lake Taupo. While it is the author's opinion that the presence of catfish at current population levels is unlikely to have any negative impacts on the trout fishery in the lake, further research is needed to confirm many of the conclusions made.

Regular sampling on an annual basis is necessary to determine population levels and migration trends. Further sampling is required in the northern and western regions of the lake to confirm current catfish densities.

No effort was made to catch catfish at water depths greater than 5 metres. If further research establishes the presence of catfish in high numbers at depth then the potential for negative impacts on the lake's ecosystem is far greater.

Every effort must be made to reduce the possibility of catfish being liberated into other lakes in the region. As previously discussed, the impact of catfish in smaller, more turbid lakes is considered to be far greater than that found in Lake Taupo. Whilst I acknowledge this is potentially an impossible task, the risk could be decreased by making the public aware of the possible negative impacts on the trout fishery.

Appendices

Appendix I:

Catch rates of catfish caught at each habitat type between February and December 1995. Mean catch rates are calculated with (E) and without (E-) empty nets included in the total fishing effort.

Site Type	Season	Catch	Effort		Catch Per Unit Effort ($Fish.net^{-1}.night^{-1}$)	
		(C) (No.Fish)	(E) (No. Nets)	(E-) (No. nets)	Mean C/E	Mean C/E-
Weedy	Late Summer	850	41	33	19.6	25.76
	Autumn	592	22	16	26.9	37.00
	Winter	205	30	22	5.97	9.32
	Spring	480	21	19	22.6	25.26
	Early Summer	1889	19	17	92.1	111.12
Rocky	Late Summer	150	27	22	5.48	6.82
	Autumn	156	4	4	39.0	39.00
	Winter	1100	25	21	44.0	52.38
	Spring	589	20	16	23.5	36.81
	Early Summer	116	6	2	34.3	58.00
Sandy	Late Summer	44	22	12	2.00	3.67
	Autumn	6	8	4	0.75	1.50
	Winter	0	8	0	0.00	0.00
	Spring	70	16	12	3.00	5.83
	Early Summer					

Appendix II:

Total number of catfish caught, nets set, weight(g), and hours set at both Southern and Northern sites between February and December 1995. (-) = nets not set.

Site type	Location	Number of fish					
		Late summer	Autumn	Winter	Spring	Early summer	Total
Weedy	Motuoapa	329	90	75	81	206	781
	Pukawa	22	0	0	73	-	95
	Waihi Bay	499	502	130	326	1683	3140
	Acacia bay	-	-	2	-	-	2
	Kinloch	-	-	14	-	-	14
Rocky	Motuoapa	100	156	818	510	116	1700
	Pukawa	50	-	282	53	-	385
	Motutere	-	-	11	-	-	11
Sandy	Pukawa	14	4	0	35	-	53
	Stump Bay	30	2	0	35	-	67
	Total	1044	754	1337	1113	2005	6239
		Number of nets					
		Late summer	Autumn	Winter	Spring	Early summer	Total
Weedy	Motuoapa	25	4	12	8	6	55
	Pukawa	8	4	4	8	-	24
	Waihi Bay	8	14	14	5	13	54
	Acacia bay	-	-	13	-	-	13
	Kinloch	-	-	13	-	-	13
Rocky	Motuoapa	15	4	14	12	6	51
	Pukawa	12	-	12	8	-	32
	Motutere	-	-	13	-	-	13
Sandy	Pukawa	12	4	8	8	-	32
	Stump Bay	10	4	-	8	-	22
	Total	90	34	103	57	25	309
		Mean number of hours set per night					
		Late summer	Autumn	Winter	Spring	Early summer	Total
Weedy	Motuoapa	14	18	16.5	16	15	79.5
	Pukawa	14.4	16.5	16	16	-	62.9
	Waihi Bay	16.6	18	17	16	15	82.6
	Acacia bay	-	-	17	-	15	32
	Kinloch	-	-	16.5	-	-	16.5
Rocky	Motuoapa	15.1	18	16.5	16	-	65.6
	Pukawa	15	-	16	16	-	47
	Motutere	-	-	17	-	-	17
Sandy	Pukawa	14	16.5	16	16	-	62.5
	Stump Bay	16.5	18	-	16	-	50.5
	Total	105.6	105	148.5	112	45	516.1
		Total weight (g)					
		Late summer	Autumn	Winter	Spring	Early summer	Total
Weedy		50.3	100.3	31.9	69.7	216.5	468.7
Rocky		20.0	30.6	150.4	34.2	6.1	241.4
Sandy		5.6	-	-	4.1	-	9.7
	Total	75.9	130.9	182.3	108.0	222.6	720.6

Appendix III

Coefficients of linear equations [Ln(weight in g)=a+b(Ln(length in mm))] for all catfish caught at Motuoapa, Waihi bay, and the Pukawa rocky site between February and December 1995.

Site	Month	N	Sex combined			Female			Male		
			a	b	r^2	a	b	r^2	a	b	r^2
MotW	2	329	-11.72	3.09	0.984	-13.15	3.35	0.989	-12.64	3.25	0.972
	4	90	-11.84	3.10	0.995	-12.29	3.18	0.996	-12.81	3.28	0.971
	7	75	-11.91	3.12	0.993	-11.67	3.07	0.993	-11.86	3.10	0.995
	10	81	-12.13	3.17	0.992	-12.40	3.19	0.986	-11.90	3.20	0.994
	12	206	-11.73	3.08	0.919	-10.08	2.91	0.962	-12.55	3.23	0.997
WaihiW	2	499	-11.40	3.20	0.993	-12.24	3.17	0.986	-12.48	3.21	0.945
	4	502	-11.90	3.12	0.987	-11.85	3.10	0.994	-12.09	3.15	0.994
	7	130	-12.18	3.17	0.996	-11.83	3.10	0.985	-12.09	3.15	0.994
	10	326	-11.91	3.13	0.979	-12.30	3.19	0.993	-12.28	3.17	0.992
	12	1683	-11.55	3.06	0.997	-10.63	2.89	0.939	-11.59	3.06	0.974
MothR	2	100	-11.40	3.02	0.992	-11.63	3.07	0.918	-11.68	3.07	0.995
	4	156	-11.90	3.12	0.988	-12.34	3.20	0.995	-12.05	3.15	0.993
	7	818	-11.80	3.09	0.988	-12.37	3.20	0.984	-12.63	3.24	0.984
	10	536	-12.25	3.18	0.989	-12.25	3.18	0.969	-12.35	3.43	0.993
	12	116	-11.65	3.06	0.994	-11.18	2.98	0.998	-11.53	3.04	0.987
PukR	2	50	-11.79	3.10	0.982	-12.49	3.29	0.976	-12.00	3.14	0.996
	4	DNS									
	7	282	-12.54	3.23	0.950	-13.15	3.35	0.989	-12.64	3.25	0.972
	10	53	-13.09	3.33	0.991	-13.18	3.36	0.964	-14.61	3.62	0.961
	12	DNS									

Appendix IV:

Total fecundity of female catfish captured during November and December 1995. Number of ova per individual.

Length (mm)	Weight (g)	Ovary Weight (g)	No. of Ova
314	469.7	39.2	5261
312	452.6	31.7	6678
337	580.4	64.1	8014
265	280.6	15.8	4523
330	503.4	50.6	7854
288	289.6	72.7	4296
279	292.6	16.5	3964
274	288.0	18.9	4258
360	596.5	55.9	7894
314	334.6	26.5	5462
298	304.5	23.9	4325
263	242.7	25.7	4487
289	301.6	36.9	4109
306	375.8	42.6	5109
332	500.2	65.7	7895
189	107.6	15.9	2458
195	118.3	18.2	2692

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