Baseline Survey of Freshwater Mussels (Kakahi) in Cashmere Stream

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EXECUTIVE SUMMARY

Cashmere Stream is a peri-urban waterway located in southwest Christchurch that has been recognised for its relatively high ecological values, but there is concern that it is being degraded through agricultural land use and growing urbanisation within its catchment.

Previous surveys of Cashmere Stream have recorded the presence of the New Zealand freshwater mussel known as kakahi (*Echyridella menziesii*), but little is known about the exact distribution, size, and health of the population. The Department of Conservation recently upgraded the status of kakahi to “gradual decline”, adding impetus to the primary aim of this study, which was to thoroughly survey Cashmere Stream for its mussel population in order to establish baseline data for future monitoring.

The survey for kakahi in Cashmere Stream encompassed 58 sites which were selected using a systematic sampling design to ensure a random distribution longitudinally with good spatial coverage. At each site, ten 0.25 m^2 quadrats were selected from within a 10 m reach again using systematic sampling design. Each quadrat was surveyed for key habitat parameters and searched for kakahi using tactile detection. At sites where no live kakahi were an additional timed search was conducted to establish their presence or absence. Additionally, benthic samples were collected from three of the quadrats in an attempt to collect juvenile kakahi that may have been missed during the survey. These samples have been frozen and it is intended that they will be processed in future should funds become available.

Kakahi were found at 26 (45%) of the 58 sites surveyed,. A total of 254 kakahi were recovered from the stream during the survey, although 36 (14%) of these were dead. The spatial distribution of kakahi within sites was patchy, and kakahi were only found in 13% of the quadrats sampled. The mean density of kakahi was 0.2 per m^2 and the highest density recorded was 3.9 kakahi per m^2. The estimated population of kakahi in Cashmere Stream was placed around 3500 individuals. The estimated mean age was 27 years, with the youngest being 9 years and the oldest 44 years.

The habitat that kakahi favoured in Cashmere Stream was site specific, but generally they favoured shaded areas of deep water. Cover in the form of bank undercuts and detritus piles could be important, and younger kakahi may favour coarser substrate than that of older individuals.

While the population of kakahi is relatively large in Cashmere Stream, there are concerns over its long term viability as there are few less than 20 years old. Efforts need to be made to enhance the habitat by creating a more naturalized stream channel with meander bends, undercuts and riparian shading. The effective monitoring and mitigation of sediment pollution is essential in helping to protect the substrate favoured by young mussels, in addition to protecting the water quality. Follow-up surveys should focus on assessing kakahi condition to help establish whether mussels are stressed, and to find out more regarding the recruitment of juveniles.

1 INTRODUCTION

1.1 Study Background

The Christchurch Drainage Board reported the presence of kakahi (freshwater mussels) in Cashmere Stream at one site 1978-79 (Robb, 1980), but a follow-up survey in 1989-91 failed to detect any (Robb, 1994). However, in 2005, surveyors undertaking the Christchurch River Environment Assessment Survey (CREAS; McMurtrie & Suren, 2008) observed the presence of kakahi in this waterway (Ware & Jones, 2005) and an ecological survey of the stream's lower reaches in 2006 revealed a sizeable population between Worsley Road and Penruddock Rise (Burdon & McMurtrie, 2006). Other observations made during CREAS surveys indicate that kakahi could also be present at the confluence with the Heathcote River and in the lower reaches of Ballintines Drain, a tributary of Cashmere Stream (Manfred von Tippelskirch, pers comm.). The kakahi measured and recorded by Burdon & McMurtrie (2006) all exceeded 80 mm in length, suggesting that there was little or no recruitment of juvenile mussels into the population.

Cashmere Stream has been identified as having relatively high ecological values in the context of south-western Christchurch (EOS Ecology et al., 2005); however, there is concern that this system is being degraded by the growing urbanisation of the catchment in combination with current agricultural land-uses (McMurtrie & Taylor, 2006). It is therefore timely that this study seeks to establish baseline data for the population of kakahi before the catchment is further modified. The population in Cashmere Stream is likely to be exceptional in the Christchurch area, but despite this there is a paucity of data on its health, size and distribution. Furthermore, in 2005 the Department of Conservation upgraded the conservation status of kakahi to "gradual decline", reflecting concerns nationally that populations of this native freshwater mollusc are threatened.

The primary focus of this study was to conduct a comprehensive survey of the kakahi population in Cashmere Stream to establish baseline data for future monitoring. This study was intended to identify the range, size and age class distribution of the population to help ascertain whether or not the population is in decline. It was anticipated that the measurement of habitat variables would help identify any contributing factors to recruitment loss and mortality of kakahi. This report will concentrate on addressing the following questions:

- Where are kakahi located in Cashmere Stream?
- What is the size class and age distribution?
- What physical factors are related to their presence or absence?

The secondary focus of this report is to provide a detailed and informative account of the biological, cultural and ecological significance of kakahi drawing upon international, national, and local references.

1.2 Freshwater Mussels

Kakahi are important filter-feeders that remove algae, bacteria, and other fine particles from the water column in their river and lake habitats (Figure 1); Winterbourn, 2004). They are the biggest freshwater bivalve found in New Zealand with mature adults growing up to a length of 10 cm. However, there have been only a handful of studies conducted on kakahi in this country reflecting the paucity of knowledge on our native freshwater molluscs. Researchers have conducted studies on the population structure of kakahi, but predominantly in lentic systems like Lake Waipora in Otago (Grimmond, 1969), Lake Taupo (James, 1985), and lake and river sites in the Waikato River catchment (Roper & Hickey, 1994). This section of the report will draw on international literature and New Zealand research in addition to the local information available to provide an introduction to the biological, cultural and ecological significance of kakahi.

Figure 1 Kakahi are important filter-feeders in river lake habitats. Photo: Shelley McMurtrie © EOS Ecology.

1.2.1 Taxonomy and Biogeography

Kakahi belong to the family Hyriidae in the Unionoida, the ancient order of freshwater mussels. The family Hyriidae forms part of an austral group of molluscs that most likely had its origins in Gondwanaland (Graf & Foighil, 2000), and species of the hyriid mussel *Hyridella* are found throughout Australasia (Walker, 1981). Until recently, the two genera present in New Zealand were believed to be *Hyridella* and *Cucumerunio*, with each having two species. However, recent research has moved New Zealand's *Hyridella* into the new genera

Echyridella (Fenwick & Marshall, 2006), reflecting in part the long isolation this country has experienced since it parted from Gondwanaland in the late Cretaceous period. The latest account of New Zealand's freshwater mussel fauna lists the two genera *Echyridella* and *Cucumerunio*, with the latter having one species and the former possessing three species (Graf & Cummings, 2007). The new species *Echyridella lucasi* and *E. onekaka* have distinctive geographical distributions in the South Island, whereas *Cucumerunio websteri* is only found in the North Island. *E. menziesii*, the most common and widespread species, is found on both the main islands of New Zealand, and it is thought that this is the species present in Cashmere Stream. However, correct taxonomic identification of hyriid mussels is difficult as they are interspecifically conservative and intraspecifically variable (Fenwick & Marshall, 2006).

1.2.2 Cultural values

Kakahi are valued as a traditional source of food and tools by tangata whenua. Historically, Te Arawa Māori in the Rotorua district were known to collect kakahi with kapu (dredge rakes) throughout the year (Reed, 1963 in Winterbourn, 2000), although they were considered to be at their best during winter (Hiroa, 1921). Whilst some considered them to be bland and insipid, kakahi were often greatly desired by the sick and were used to feed motherless infants (Hiroa, 1921). The shells of kakahi were also used as tools; with Colenso (1880) describing bunches of shells being attached to flax ropes strung over a kumara plantation located near the Rotorua lakes. These lines were tied firmly together into one handle so that the old men responsible for plantation could create sufficient noise throughout the night to scare away the rats (*Rattus* spp.) that threatened the growing kumara tubers. Kakahi shells were also used to as a blade to scrape flax in preparation for weaving (Hiroa, 1923).

In Canterbury, archaeological work has uncovered large middens replete with shells of kakahi on the Kaitorete Spit (Witter, 2007), suggesting that these molluscs were an important food source for early Māori. The Kaitorete Spit appears to have been used as a base for moa-hunting expeditions, suggesting that there was a period of time when the Waimakariri River discharged into Lake Ellesmere. Witter (2007) bases this assertion on the absence of a significant archaeological site at the current mouth of the Waimakariri River, in contrast to the famous moa-hunter site at the Rakaia River mouth. These sites are consistently located near river mouths, probably because they allowed canoe access and were places of varied habitat. The past alignment of the Waimakariri River into Lake Ellesmere is corroborated by Armon (1974) and Soons et al. (1997). The evidence provided by these two papers suggests that the lake was larger and more lacustrine than currently, which may have helped it support a large population of kakahi.

Other evidence of the importance that kakahi had in this area comes from the name of the pā site Waikakahi which can be translated to "the place where kakahi was found" (Evison, 1997). The Waikakahi site is situated under the foothills to the west of Poranui (Birdlings Flat) at the Horomaka (Banks Peninsula) end of the Kaitorete Spit. This site is of significance historically as being the origin of the 1827 Kai Huanga dispute where an internal feud led to warfare within the Ngāi Tahu iwi (Evison, 1997).

In the Ngāi Tahu Claims Settlement Act (1998) kakahi is listed a non-commercially harvested species. Special reference is made to the collection and abundance of kakahi from the Hakataramea River, Mahi Tikumu (Lake Aviemore), the Ahuriri arm of Te Ao Marama (Lake Benmore), and the Waituna wetland in Southland.

1.2.3 Life history

Freshwater mussels from the order Unionoida have a unique life history trait that distinguishes them from marine mussel species. Molluscs from the marine environment typically develop with the characteristic molluscan larval stages (e.g. the trochophora and veliger larva). These marine mussel larvae are able to drift as plankton, allowing them to be dispersed passively by sea currents. In contrast, freshwater mussels brood a larval stage that relies on parasitizing host fish species for dispersal.

The reproduction of freshwater mussels from conception to adult occurs in a number of stages. The first stage is where male mussels release sperm into the water column, which then flow with the water current until a female siphons the water, collecting the sperm and fertilizing her eggs (Watters, 1995a). However, Byrne (1998) revealed that females of an Australian species *Hyridella depressa* were microhermaphrodites. This meant that sexuality was labile (i.e. liable to change) with the potential for self-fertilization by individuals that largely function as females.

Fertilisation usually takes place in the female's gills, which may also be transformed into breeding chambers in some mussel species. After fertilisation of the eggs, it may take 1 to 10 months for the glochidium, a parasitic larval form to fully develop within the female (Watters, 1995a). When the glochidia are fully developed, they can be released into the water where they drift until they find a suitable fish host. The Unionidae are divided into two distinct behavioral groups (bradytictic or tachytictic) depending on when the female disperses the glochidia (Watters, 1995a). Bradytictic (long term breeders) hold their larvae throughout the winter until the following spring or summer (Watters, 1995a). The tachytictic (short term breeders) release their larvae later the same year, usually by July or August in the northern hemisphere (Watters, 1995a). However, water temperature and algal productivity can affect the duration of reproductive output, with reproductive failure more likely at oligotrophic sites (Byrne, 1998).

Some freshwater mussels are known to have only a few suitable host species, while others are generalists and utilize several species (Badra & Goforth, 2003). The timing of the glochidia dispersal is a critical factor in their survival because the larvae cannot survive for an extended period of time outside the female's body before finding a suitable host (Watters, 1995a). Some species of freshwater mussels have adapted to this problem by evolving an enlarged mantle (Kraemer, 1970). This enlarged mantle resembles a food source (i.e. a worm, insect larvae, or even a small fish); and acts to attract a predatory host fish towards the female mussel. As the fish approaches the ‘bait’, the female will expel the contents of her brood pouch at it, giving the glochidia an opportunity to attach to this potential host. Other species bind a number of glochidia into long mucus matrices (called conglutinates) which also resemble a food source for the fish host and are eaten. As the conglutinates are eaten, the glochidia attach themselves to the host's gills (Watters, 1995a). The morphology of glochidia can vary between different mussel groups. For example, in the Northern Hemisphere while pond mussels' (*Anodonta*) glochidia are armed with hooks that give a better hold in the host's gills, river mussels' (*Unio*) glochidia have no hooks (Hunter, 1964).

The purpose of the fish host apparently arose as a means of dispersal for the Unionoida (Kat, 1983; Watters, 1992). The presence of suitable fish hosts has implications for gene flow, (the exchange of genetic material) among mussel populations by allowing genetic diversity to be maintained (Badra & Goforth, 2003).

The larvae parasitize the fish host by attaching themselves to the fish’s gills or fins where they are grown over by the fish's epithelial tissue. This causes the cells on the host tissue to lyse and form a cyst (Watters, 1995a).

The fluid from the lysed cells provides an essential part of the nutrients needed for the glochidia to survive (Watters, 1995a). The timing and duration of the cyst stage can vary depending on the mussel species. The cyst stage of river mussels (*Unio*) which spawn in early summer lasts 10 to 70 days compared to pond mussels (*Anodonta*) which spawn in late summer and the glochidia stay inside the host's body until spring (Hunter, 1964). The parasitic glochidia transform into juvenile versions of the adult and drop off the host after a 6-160 day period depending on the mussel species (Kat, 1983). Depending on whether the juvenile finds a suitable location, it will eventually attach itself to or burrow into the substrate and begin to filter feed.

In New Zealand, kakahi are typical of most freshwater mussels by having a glochidium larva that parasitizes fish in the early stages of their life cycle before moving to soft, sandy sediments in lake and river beds. Percival (1931) reported that the glochidia larvae were ready for their fish hosts from late November to the end of January. They were found to be present on koaro (*Galaxias brevipinnis*) and bullies (*Gobiomorphus* sp.) from Lake Sarah, Canterbury and on bullies collected from Lake Mason, Canterbury. Although the infection rate was higher on the bullies than koaro, attributed to the benthic-dwelling behaviour of the former, the most advanced stages of glochidial metamorphosis was found on the latter, suggesting that koaro may be a preferred host species. Hine (1978) reported the widespread presence of glochidia larvae on the gills of eels (*Anguilla* spp.) collected from October to November in a range of habitats across New Zealand. The most notable record was the presence of glochidia on short-finned eels (*A. australis*) collected from Te Waihora/Lake Ellesmere. Despite these records, there is still much to be learnt regarding the life-history, biology and ecological requirements of kakahi.

1.2.4 Ecosystem function

Freshwater mussels are filter-feeders that remove algae, bacteria, and other fine particles from the water column, and this ability has been shown to change the particle content of river water (Pusch et al. 2001). In North America, the introduced zebra mussel (*Dreissena polymorpha*) has been showen to have a dramatic effect on water quality and clarity through the action of their biofiltering (Strayer et al., 1999).

Freshwater mussels are an important component in the flow of energy in stream ecosystems. They often comprise the highest percentage of biomass relative to other benthic stream organisms (Strayer et al., 1994), and are therefore a key link in the food chain from aquatic microorganisms to crayfish, muskrats, and other large predators (Badra & Goforth, 2001). Both live individuals and empty shells provide habitat for aquatic insects (Spooner & Vaughn, 2006), with the latter also providing habitat for crayfish (Badra & Goforth, 2001). Recent studies have shown that organic matter concentrations and invertebrate densities were higher in beds of live mussels (Spooner & Vaughn, 2006). It is contended that in addition to providing a biogenic structure as habitat, mussels facilitate benthic invertebrates by altering the availability of resources (algal and organic matter) through nutrient excretion and biodeposition (Spooner & Vaughn, 2006). Additionally, bioturbation of sediments through bivalve movements increase sediment water and oxygen content and help release nutrients from the sediment into the water column (Vaughn & Hakenkamp, 2001). Mussels have been shown to be an important conduit in transferring nutrients from the water column to their benthic habitat, helping to dampen the pelagic responses to nutrient enrichment (Blumenshine et al., 1997).

1.2.5 Biomonitoring

Freshwater mussels can play a significant role as ‘umbrella taxa’ for the conservation of freshwater ecosystems because they are comparatively sensitive to habitat degradation and pollution, are useful indicators of water quality (Strayer & Smith, 2003), and are dependent on fish hosts to complete their life cycle (Badra & Goforth, 2003). Mussels have been shown to be an effective indicator of overall biodiversity within streams, and this effect has been attributed to their ‘keystone’ role providing filtration, excretion, biodeposition and physical presence (Aldridge et al., 2007).

Many species of freshwater mussels are well recognized for their use as water quality indicators in environmental monitoring and impact assessment (Roper & Hickey, 1994). Species overseas are generally long-lived, some with life spans up to 50 years and more (Badra & Goforth, 2001), and estimates of kakahi longevity obtained by counting shell annual rings indicate that some individuals can live for at least 33 years (Winterbourn, 2004). Additionally, because freshwater mussels are generally sessile, spending most of their lives within a particular stream reach, and have a propensity to accumulate contaminants through their filter feeding behaviour, they are useful monitors of water pollution (e.g. Green et al., 1989; Metcalfe & Charlton, 1990; Elder & Collins, 1991; Naimo, 1995).

Empty mussel shells can reveal historic presence because they remain intact for many years post mortem (Badra & Goforth, 2003). Chemical analysis of shell material can also reveal environmental information from years past (Mutvei & Westermark, 2001) and a review by Imlay (1982) documents the use of such analyses for detecting metals deposited in mussel shells as well as using shell disturbance markings to gain a historical record of pollution. The Australian species *Hyridella australis* has been used for the biomonitoring of the pesticide endrin (Ryan et al., 1972), and in New Zealand, Hickey et al. (1995, 1997) have recognized the potential of kakahi for environmental monitoring with tissue analysis revealing accumulations of heavy metals and organic compounds.

1.2.6 Global decline

The decline of freshwater bivalves is a global phenomenon (Bogan, 1993) and the known or likely causes include influences on sediment type, food supply, water quality (pollution and eutrophication), water velocity, bed slope, and the reduction of fish hosts for the parasitic life stage (McDowall, 2002). Increasing land use intensity within watersheds, point source pollution, direct habitat alteration (e.g., drain clean-outs and dredging), and non-native species introductions have impacted native mussel and fish communities (Bogan, 1993; Fuller, 1974; Strayer et al., 1999).

This decline, particularly in North America, has been attributed in part to land-use modifications that cause changes in sediment regimes (Box & Mossa, 1999). Silt and clay particles can clog the gills of mussels (Ellis, 1936), interfere with filter feeding (Kat, 1983; Aldridge et al., 1987), or affect mussels indirectly by reducing the light available for photosynthesis and the production of unionid food items (Davies-Colley et al., 1992; Kanehl & Lyons, 1992). Although definitive studies are lacking (Waters, 1995b), it has been suggested that accumulations of silt, behind river dams in particular, smother juvenile mussels (Ellis, 1936). Although adult mussels could survive such conditions, sedimentation may also produce an oxygen demand that is potentially detrimental to mussel species, and particularly juveniles that require well-oxygenated water (Ellis, 1936).

However, small amounts of suspended silt have been found to enhance the survivorship in cultured mussels for undetermined reasons (Watters 1995a). Similarly, Roper & Hickey (1994) found that suspended silt had no significant effect on the respiration rate or condition of kakahi, but if food concentration was low and silt was high, respiration increased.

The life cycle of freshwater mussels cannot be completed without the presence of appropriate fish host species in sufficient densities (Badra & Goforth, 2003). This means that threats to native fish communities can undermine the stability of unionid populations. In New Zealand, McIntosh (2002) showed that large trout were voracious predators of the small-bodied galaxiids such as koaro, and that it was likely that they had eliminated these native fish from countless streams. McDowall (2002) has linked the impact of trout on native fish such as koaro to the decline of kakahi populations, based on the assumption that koaro are a particularly important host species for kakahi. However, other species of native fish listed as hosts for the glochidium larva, including bullies and eels (Walker et al., 2001) are still relatively widespread throughout New Zealand. The question of host specificity for kakahi is an important subject that remains poorly understood, although recent research, currently in press, may help to address this knowledge gap (Dr Chris Hickey, NIWA, pers. comm.).

In a Canadian study, although glochidia were found on every fish species present within the temperate forest lakes sampled, there was a sharp gradient in the intensity of the fish-mussel linkage among different fish species. Unsurprisingly, the species that co-occurred most often with mussels had the highest density of glochidia (Martel & Lauzon-Guay, 2005).

Another threat to freshwater mussels and their native host fish species are barriers to migration, such as dams and degraded habitats (Watters 1995b). These can hinder the successful reproduction and dispersal of freshwater mussels by inhibiting the re-colonization of suitable habitat, threaten genetic diversity through lack of gene flow, and prevent the recovery of mussel populations (Badra & Goforth, 2001). This is particularly pertinent in New Zealand, where the vast majority of native fish fauna are diadromous, requiring unfettered access to the sea (McIntosh & McDowall, 2004) and thus are particularly susceptible to migratory barriers. It is likely that the decline of native fish species has had a negative impact on the recruitment and long-term viability of kakahi populations in New Zealand.

2 STUDY SITE

2.1 Cashmere Stream

Christchurch has one of the most extensive networks of spring-fed rivers in New Zealand, comprising of over 360 km of open waterways and in excess of 500 km of piped waterways. The Avon and Heathcote rivers are two major open waterways in this network that flow through Christchurch City, eventually being connected via their confluence with the Avon-Heathcote estuary.

The most significant tributary of the Heathcote River is Cashmere Stream. Rising from springs located in southwest Christchurch, Cashmere Stream is only 4.9 km long (Woodley, 2004), but is connected to numerous drains and tributaries along its length. The 51 km of waterways in the entire catchment occupy an area of 2790 ha (Woodley, 2004). A substantial proportion of the catchment is rural dominated by grazing land and it also encompasses part of the Port Hills (Robb, 1980).

The history of Cashmere Stream reflects the extensive landscape transformation that Christchurch underwent from when the first European settlers arrived in the mid 1800s. Vegetation and waterways information compiled from early survey maps (the 'Black Maps') published in 1856 show a large part of the Cashmere Stream catchment as swamp dominated by flax, raupo and toetoe with a scattering of Kahikatea stumps. Since the first Europeans arrived in the area it has been drained for agriculture, and in the late 1850s Sir John Cracroft Wilson, an early settler, embarked upon an extensive transformation of the surrounding landscape by "at considerable cost and effort draining the swamp in Cashmere Valley and digging out Cashmere Stream" (Woodley, 2004). This reflects the large sections of the stream that are man-made with the extensive channelisation designed to assist in the drainage of the surrounding area. Whilst the comparatively wide channels of uniform depth, sided with over-steepened banks have enhanced the drainage values of the stream (Woodley, 2004), this has come at an ecological cost, resulting in a largely homogenous habitat with few natural features. Keeping in part with its function for land drainage, the streams along with its major drain tributaries are 'cleaned' three times a year with rounds that start in February, June and October (Woodley, 2004). The exact dates that these duties are performed is subject to change reflecting season variability and is done by hand, except where excessive weed growth requires mechanical removal.

Urban growth in the Cashmere Stream catchment has a long history of adverse effects on the local environment. The expansion of housing across the Port Hills led to the severe erosion witnessed on Worsleys Spur after the winter storms of 1975 (Wilson, 1989). More recently, there have been a number of incidents involving point-source discharges of silt-laden water polluting Cashmere Stream, including the high profile Aidanfields event. This refers to the discharge of highly turbid water into Dunbars Drain (a tributary of Cashmere Stream) on the 6th August 2004 from a failed stopbank in an uncompleted detention basin of the Aidanfield subdivision near Halswell (McMutrie & Taylor, 2006). It is estimated that approximately 5000 litres of silt-laden water carrying at least 4000 kilograms of suspended sediment entered Cashmere Stream resulting in a 47% increase in concentrations of suspended solids below the confluence with Dunbars Drain (Environment Canterbury, 2006).

Dunbars Drain continues to receive stormwater from the Aidanfield development, although at this stage the detention basin and much of the Aidanfield catchment has matured (McMurtrie & Taylor, 2006). A sediment sources survey in 2008-09 indicates that the major tributary contributors of sediment to Cashmere Stream were Hoon Hay Valley Drain, Milns Drain, Dunbars Drain, Hendersons Road Drain, a major stormwater pipe originating from Westmorland (Penruddock Pipe), and Worsleys Drain (James & McMurtrie, in press).. Much of the sediment pollution in the catchment originates from rural land use and excavations for residential developments.

Despite the extensive landscape changes and ongoing sediment issues, Cashmere Stream has high ecological values. It is one of the only waterways in Christchurch city where koura (freshwater crayfish) are still present and has the only documented kakahi population of any of the city's periurban streams (EOS Ecology et al., 2005) although there is anecdotal knowledge of their presence in other Christchurh rivers. Ten species of caddisfly are known to be present and in a study of 14 sites in the Heathcote catchment a site in Cashmere Stream supported the highest abundance of EPT taxa (EOS Ecology et al., 2005). It also has high aesthetic and amenity values for the local community and is the focus of a stream care group (Environment Canterbury, 2006).

3 METHODS

3.1 Sampling Design

The sites for the survey were selected using a systematic sampling design. Strayer & Smith (2003) recommend systematic selection of habitat units because it is easy to implement under field conditions, provides good spatial coverage of the area of interest, and is efficient for rare and clustered populations (Christman, 2000). Because systematic sampling is analogous to cluster sampling (Thompson, 1992) it is considered to be a good technique to use where the sample population is spatially patchy. Systematic sampling has been found to be a better design than simple random sampling for describing the spatial distribution of mussels because systematic sampling spreads out the sampling effort and provides good spatial coverage of the study area (Strayer & Smith, 2003).

Since systematic sampling can be applied at multiple spatial scales (Strayer & Smith, 2003), this technique was employed for site selection as well as the selection of quadrats to sample within a site. Sites were selected using systematic sampling with multiple random starts (Strayer & Smith, 2003). A random start is a randomly generated distance from one end of the area to be surveyed. Nine random starts (i.e. nine chains of three sites) were used to locate the position of the 27 sites sampled in the initial survey. 30 more sites were selected for the second and third phases of the survey using ten random starts (i.e. ten chains of three sites). The distance between the sites in a chain was determined using the formula provided by Strayer & Smith (2003). The 58th site (Site 33) was an additional site added during the second survey to provide more information on the section of stream where the distribution of mussels ended.

The general location for each site was located in the field using a Garmin® GPSmap 60CSx with pre-loaded waypoints. The exact location of each site was determined during fieldwork and a GPS waypoint recorded. Site photos were also taken as a visual record of each site.

For the first and second phases of the survey, each site was divided into a grid of 10 m long and 10 m wide (an approximation given the natural fluctuation of the channel width) with the unit of division being 0.5 m. This unit of division was used because Strayer & Smith (2003) recommend a quadrat size of 0.25 m^2 to maximize the accuracy of the data recorded (0.5 m being the length and width of that area). The exact width of the channel was measured at three points (0, 5, and 10 m) along the reach prior to the selection of quadrat locations. Ten quadrats were selected using systematic sampling with four random starts (three chains of three sites and one chain with one site) by generating random coordinates for the lengths across and along the stream grid. The equation from Strayer & Smith (2003) was used to determine the distance between quadrats on each chain.

There were two sites that were exceptions to the standard design of 10 quadrats sampled per site location. Fifteen quadrats were sampled at Site 1 (five chains of three quadrats), but as this proved to be more time consumptive than budgeted for, the level of replication was scaled back to ten quadrats. At Site 18 twelve quadrats were sampled (four chains of three quadrats) when it was discovered that mussels were present in appreciable densities along the fourth chain. Since one quadrat had already been sampled in this chain it was logical to continue on and do the other two to gather additional habitat information on the presence of kakahi at this site.

After the locations of the quadrats were selected, two measuring tapes were used to measure out the exact positon of each quadrat, and it was marked with a fluoro-marked stake (Figure 2). Each quadrat was then surveyed for habitat variables and the presence of freshwater mussels (Figure 3).

Figure 2 A survey site marked out with the location of ten quadrats selected using a systematic sampling design with multiple random starts.

Figure 3 Searching for kakahi within a quadrat.

3.2 Study Sites and Dates

A total of 58 sites were surveyed for kakahi along 4.02 km of Cashmere Stream, stretching from its confluence with the Heathcote River to just below the culvert running beneath Sutherlands Road (Figure 4).

Figure 4 Location of the 58 sites surveyed for kakahi between 7 June 2007 and 14 May 2008.

The survey for kakahi in Cashmere Stream was broken up into three distinct phases (Table 1). An initial survey of 27 sites located in the lower reaches was conducted over six days between 7–20 June 2007. When additional funds were made available, a second survey of 23 sites upstream of the first survey was sampled over five days between 28 November and 19 December 2007. The final eight sites extending upstream to the culvert underneath Sutherlands Road were sampled 14 May 2008 using a modified study design.

Table 1 Dates that 58 sites were surveyed for kakahi in Cashmere Stream.

Phase	Date	Sites	Sampling used
1	7th June 2007	1-2, 4	Systematic sampling with ten 0.25 m^2 quadrats
	8th June 2007	3, 5-7	
	12th June 2007	8-12	
	13th June 2007	13-16	
	14th June 2007	17-22	
	20th June 2007	23-27	
2	28th November 2007	28-30	
	29th November 2007	31-32, 35-36	
	11th December 2007	34, 37-40	
	17th December 2007	41-45	
	19th December 2007	33, 46-50	
3	14th May 2008	51-58	Timed search

3.3 Habitat Measurements

The habitat data recorded was based on the instream habitat assessment methods originally developed in Christchurch (Suren et al., 1998) and known as the USHA methodology. Instream habitat variables were quantified at each quadrat, and this included water depth, macrophyte cover and depth, soft sediment depth, and substrate composition. Water velocity was also quantified. This methodology was developed to analyse the effect of relevant habitat parameters on the presence or absence of freshwater mussels, but also to enable a comparable repeat survey of habitat and mussel densities in future years to help elucidate whether environmental changes are affecting the freshwater mussel population in Cashmere Stream.

Substrate composition was quantified by visually estimating the percentage cover of substrate types within eight classes using a modified Wentworth Scale: concrete/bedrock; silt; sand (< 2 mm); gravels (2 - 16 mm); pebbles (16 - 64 mm); small cobbles (64 - 128 mm); large cobbles (128 - 256 mm), boulder (> 256 mm). The presence and type of organic material was quantified at these same points to one of twenty defined classes (see Appendix I for a description of these).

Water and sediment depth were quantified at the same 10 quadrats. Three depths were recorded; free-water depth (the depth of water free of vegetation or other material), macrophyte depth (the depth of the water within which aquatic or terrestrial plants were growing), and soft sediment depth (the depth to which soft sediment such as silt and sand overlay a harder substrate). Total water depth was derived by summing free-water and macrophyte depths.

Mean water velocity (i.e. 0.4 x depth) was gauged at the same 10 quadrats, using an OTT meter (40 second recording interval). The OTT meter was positioned in the middle of the quadrat to give an approximate measure of water velocity at that point.

Riparian conditions (vegetation type) were assessed along the stream bank on either side of sample area for a distance of five metres and a brief description was recorded. A more quantitative method was used to record visible sky and canopy cover used ranked categories from 1 to 5. These categories were 1 (< 5%), 2 (5-25%), 3 (25-50%), 4 (50-75%), and 5 (>75%).

3.4 Detection of Freshwater Mussels

Adult mussels at each quadrat were sought out using tactile detection (i.e. manually searching through sediment using ones hands). Where present, they were retrieved and measured for shell length, width, depth and wear using Vernier callipers, and an estimate of age was made by enumerating growth rings on the shell before the mussel was returned to the stream.

At three randomly selected quadrats per site the substrate with the 0.25 m^2 quadrate was disturbed to a depth of 10 cm and the perturbed material collected using a conventional kicknet (ca 250 μm mesh size). In areas where macrophytes filled the water column, samples were collected from amongst the macrophytes and from the substrate. Where there was insufficient water velocity, collection was facilitated at all sites by using a sweeping motion to create flow into the net. These samples were placed in bags and labelled before being frozen. It was anticipated that these samples would be sieved down to 0.5 mm and processed underneath a stereo microscope. Juvenile *Echyridella* were to be recorded along with all other bivalves, and all specimens were to be retrieved and preserved for each sample. However, budgetary constraints meant that these were not able to be processed under the current project, and remain frozen in storage in the hopes that funding becomes available in the future.

3.5 Data Analysis

The data describing the substrate composition was simplified by creating a substrate index, such that:

Substrate index = [(0.7 x % boulders) + (0.6 x % large cobbles) + (0.5 x % small cobbles) + (0.4 x % pebbles) + (0.3 x % gravels) + (0.2 x % sand) + (0.1 x % silt) + (0.1 x % concrete/bedrock)] / 10

Where: derived values for the substrate index range from 1 (i.e. a substrate of 100 % silt) to 7 (i.e., a substrate of 100% boulder); the larger the index, the coarser the overall substrate. In general, coarser substrate (up to cobbles) represents better instream habitat than finer substrate. The same low coefficients for silt and concrete/bedrock reflect their uniform nature and lack of spatial heterogeneity, and in the case of silt, instability during high flow.

The estimated population of mussels at each site was calculated from the survey data following the methods of Strayer & Smith (2003). Standard 90% confidence intervals were calculated along with the log-based 90% confidence interval adapted by Strayer & Smith (2003) from Seber (1982). Age of mussels and AFDM were estimated using the equations developed by Olgilvie (1993).

Multidimensional scaling (MDS) is a set of related statistical techniques often used in information visualization for exploring similarities or dissimilarities in data. Non-metric multidimensional scaling (NMDS) is one of these ordination techniques that can be used to examine how ecological communities characterised by different habitat variables differ between locations. It can graphically describe these variables by representing each sample as a point (an ordination score) on an x-y plot. The location of each point/sample reflects the combination of the various habitat variables measured, as well as its similarity to the habitat in other samples/points. Thus points situated close together indicate samples with similar habitat, whereas points with little similarity are situated further away. The location of each point can be described as axis scores (e.g. Axis 1 and 2). Normally there is a greater degree of separation in community composition on the x-axis (Axis 1) than the y-axis (Axis 2). The habitat variables can also be correlated with the different axes, providing an indication as to what habitat conditions influence the location of points in the ordination plot.

Habitat variables recorded in quadrats were grouped by the presence or absence of kakahi data were analysed for significant difference using parametric (Students t-test) and non-parametric (Mann-Whitney test) analyses for paired data sets.

The counts of mussels in quadrats were analysed using parametric (Pearson’s product moment correlation, linear regression) and non-parametric (Spearman Rank Order correlation) analyses. Before undergoing regression, all data distributions were checked for normality (which is an assumption of the analysis undertaken) and if required log-transformed to normalise data and reduce heteroscedasticity.

The mussel count data from the quadrats where kakahi were found was additionally analysed using hierarchical partitioning, which is a multiple regression methodology. Hierarchical partitioning of R^2 values was used to determine the proportion of variance explained independently and jointly by selected environmental variables (Chevan & Sutherland, 1991; Mac Nally, 2000). This method enables the identification of variables whose independent correlation with the dependent variable is strong, in contrast to the variables with little independent effect, but which may have a high correlation with the dependent variable resulting from a joint correlation with other independent variables (Hatt et al., 2004). The variables that explained a greater proportion of variance than could be explained by chance were identified by the comparison of the observed value of the independent contribution to explained variance (I) to a population of Is from 500 randomizations of the data matrix. The statistical significance of these variables is based on the upper 95% confidence limit (Z-score > 1.65; Mac Nally, 2000). Hierarchical partitioning was conducted using the hier.part (version 1.0-2) package (Walsh & Mac Nally, 2007), which was run as a part of the R (version 2.5.1) statistical package (R Development Core Team, 2007).

4 RESULTS

4.1 Distribution

Kakahi were found at 26 (45%) of the 58 sites sampled. Their distribution was contiguous for the first 20 sites surveyed, before becoming increasingly fragmented and Site 34 was the last location that a live mussel was recorded from (Figure 5 and Figure 6). This meant that mussels were absent from the last 26 sites sampled, although a piece of shell was recovered from the stream at Site 36. There was no evidence of kakahi from this point moving upstream. A total of 254 mussels were recovered during the survey, although 36 (14%) were dead.

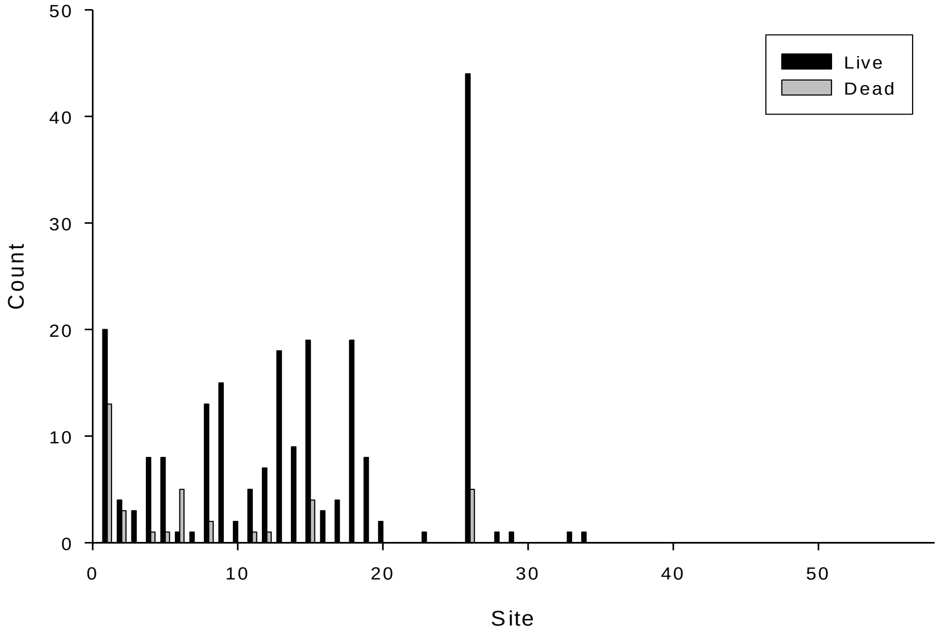


Figure 5 Number of mussels recovered from sites surveyed in Cashmere Stream during 2007/2008.

Figure 6 Sites where mussels were present and absent in Cashmere Stream from the 2007/2008 survey.

Kakahi were found in 13% of the quadrats sampled (Figure 7A). Although the average density from all 50 sites was 0.2 mussels per m^2 (Table 2), the spatial distribution within sites was patchy, and mussels showed some evidence of clustering together. Over a third of the quadrats that kakahi were found in contained three or more mussels (Figure 7B).

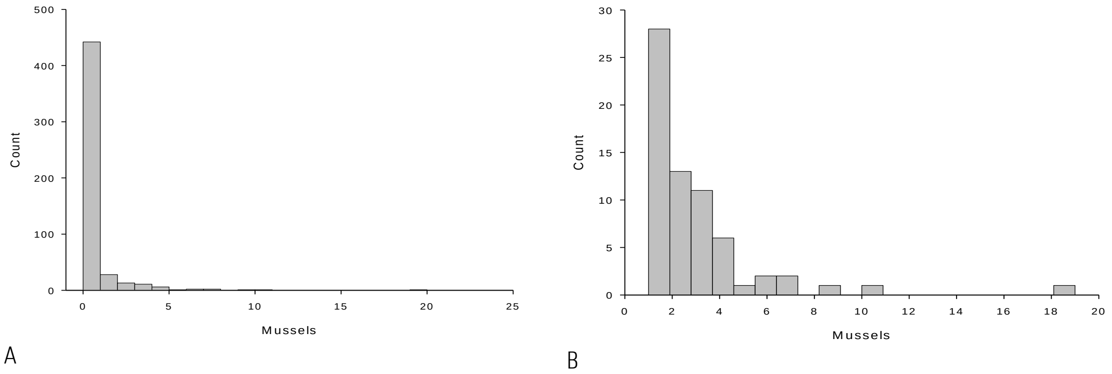


Figure 7 Count data of kakahi for A) all quadrats (*n* = 507) and B) quadrats where mussels were present (*n* = 66) from sites surveyed in Cashmere Stream during 2007/2008.

Figure 8 shows that mussel density was variable across sites with Site 26 having the greatest mean density of kakahi (3.8 mussels per m^2). This site also had the highest concentration of mussels found within a single quadrat (19), equivalent to a density of 76 mussels per m^2. The majority of sites where mussels were recorded in quadrats had relatively low densities (Figure 8).

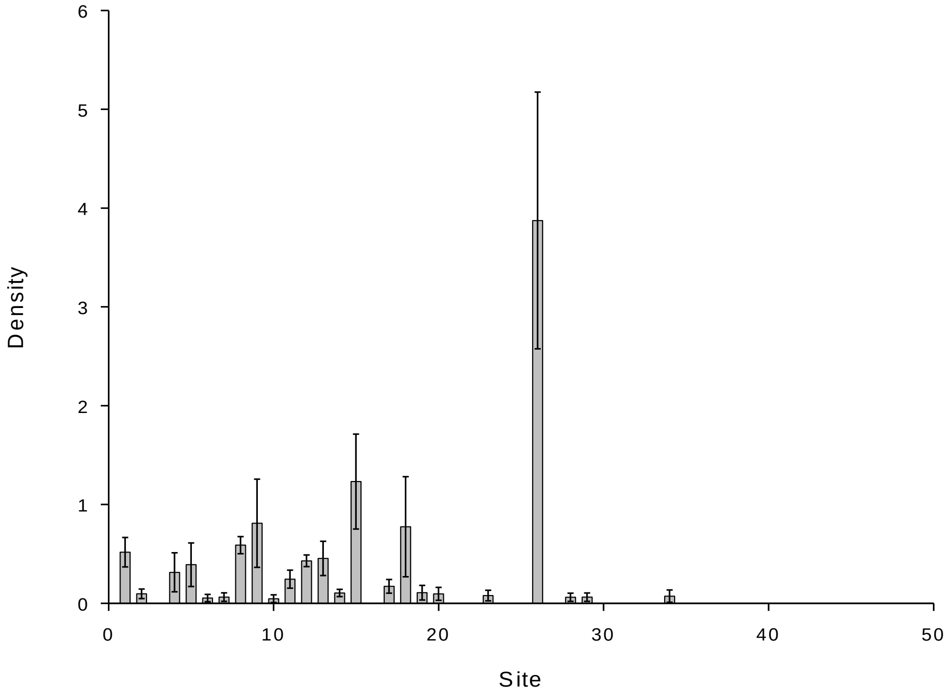


Figure 8 Mean density of mussels (no. per m^2) recorded in quadrats (0.25 m^2) sampled from sites surveyed in Cashmere Stream during 2007. Error bars represent the standard 90% confidence interval.

Over all 50 sites, there was no relationship of density over distance moving upstream from the confluence with the Heathcote River. However, residual analysis indicated that Site 26 was an outlier and its removal from the regression model rendered a significant negative relationship of mussel density over increasing distance moving upstream ($F_{1,47} = 15.8$, $P < 0.001$, $R^2 = 0.252$).

The mean number of mussels found at each site and the overall density increased after removing the sites where mussels were unlikely to be present or if present only in very low densities (Table 2). The mean values for the main range of kakahi in Cashmere Stream (Sites 1 to 26) indicated that they could be present at a density of 0.4 mussels per m^2 within this section of the stream.

Table 2 Summary statistics of mussel numbers and density (mussel per m^2) recorded from sites surveyed on Cashmere Stream during 2007. Site 26 was the last site where greater than one individual was recorded and Site 34 was the last site where mussels were recorded.

Sites	Mussels by site	Mean	Max	Min	Standard 90% Confidence Interval		Logarithmic 90 Confidence Interval	
					Low	High	Low	High
1–50	Count	4	44	0	2	5	-	-
	Population	9	119	0	5	14	3	40
	Density (mussels per m^2)	0.2	3.9	0	0.1	0.3	0.1	0.9
1–34	Count	5	44	0	3	7	-	-
	Population	14	119	0	8	19	4	59
	Density (mussels per m^2)	0.3	3.9	0	0.2	0.5	0.1	1.3
1–26	Count	7	44	0	5	9	-	-
	Population	17	119	0	12	23	5	74
	Density (mussels per m^2)	0.4	3.9	0	0.2	0.6	0.1	1.6

4.2 Population Size

The estimates of population size indicate that the number of kakahi in Cashmere Stream may total nearly 3500, however, there is a considerable range surrounding this figure due to the the different approaches for calculating the 90% confidence intervals (Table 3). The standard 90% confidence interval indicated that the population could be a low as 900 individuals, but as this value was calculated using all 50 sites it may be overly conservative. The survey showed that the distribution of mussels is unlikely to be contiguous over the entire stream length, so discarding the upstream sites where mussels were not found or had very limited densities improved the range around the mean described by the standard 90% confidence interval. Limiting the number of sites to 34 and 26 respectively meant that the standard 90% confidence interval was greatly reduced. However, the use of the log-based 90% confidence interval adapted from Seber (1982) and recommended by Strayer and Smith (2003) indicated that a low estimate of the population could be around 1000, whereas a high estimate could extend to nearly 15000 mussels (Table 3).

Table 3 Population estimates for kakahi in Cashmere Stream based off mussel densities recorded from sites surveyed in 2007. Site 26 was the last site where greater than one individual was recorded and Site 34 was the last site where mussels were recorded. * The standard 90% confidence interval incorporates the measure of error for stream area in addition to that measured for the average density of mussels. The logarithmic 90% confidence interval does not include the error for stream area.

Sites	Population Estimate	Standard 90% Confidence Interval*		Logarithmic 90% Confidence Interval	
		Low	High	Low	High
1–50	3105	900	5309	918	13098
1–34	3439	2231	4647	1017	14510
1–26	3649	2833	4465	1099	14815

4.3 Population Structure

The mean length of kakahi collected from Cashmere Stream was 86 mm and the median was slightly higher at 89 mm (Table 4). Although a maximum length of 101 mm was recorded, the minimum length recorded was 46 mm, suggesting that juvenile mussels were either not detected by the tactile sampling method employed or were not present. The estimated mean age was 27 years, and the youngest and oldest mussels recorded were 9 and 44 years respectively. The mean biomass of each mussel was estimated as being 2.91 g (AFDW).

Table 4 Summary statistics for mussel length (mm), age (years) and biomass (g) from mussels (*n* = 218) collected during sampling in 2007. Age and biomass were calculated from the anterior-posterior lengths following Ogilvie (1993).

Statistic	Length	Age	Biomass
Mean	86	27	2.91
Median	89	28	3.07
Min	46	9	0.45
Max	101	44	3.80
Stdev	9	7	0.54
90% CI	1	1	0.06
Low	85	26	2.85
High	87	28	2.97

Mussel size was strongly skewed to the right with a predominance of large individuals (Figure 9A). The low number of smaller (40-70 mm) individuals recorded indicated that there may be a paucity of mussels in these size classes. Estimation of age classes from shell length revealed that there was a strong bias to older individuals, and little evidence for the recruitment of younger age classes in recent years (Figure 9B). Only 38 (17%) mussels found were less than 20 years old and there appears to be three distinctive age cohorts, suggesting there may be periodicity in the recruitment of mussels into the population.

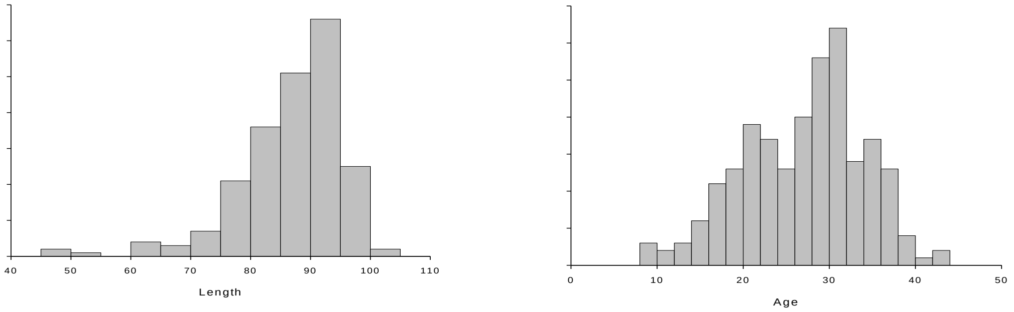


Figure 9 Count data of a) mussel length (mm) and b) age (years) for mussels ($n = 218$) collected from sites surveyed in Cashmere Stream during 2007. Age was calculated from the anterior-posterior lengths using the polynomial equation outlined in Ogilvie (1993).

The mean and median ages by site indicated mussels were youngest at the most downstream and upstream sites and oldest in the middle sites (Figure 10A & B). This relationship was further supported non-linear regression (Figure 11). Although Site 18 had the oldest mean age, a paired t-test with the mussels recorded from Site 26 indicated no significant difference in the age of these two sites (t_{61} = -1.476, P = 0.145). A series of age class histograms from selected sites indicates the increasing age of mussels moving upstream from the confluence with the Heathcote River (Figure 12).

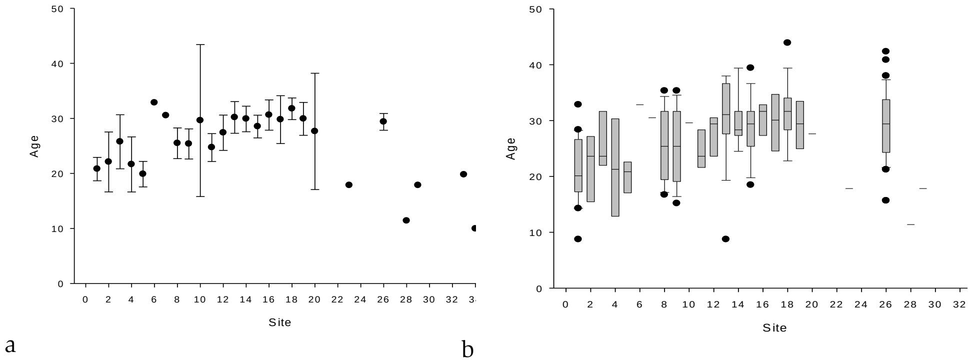


Figure 10 a) mean mussel age (years ± 90% confidence interval) and b) vertical box plot showing median ages (years) with 10th, 25th, 75th, 90th percentiles and outliers (solid dots) collected from sites surveyed during 2007.

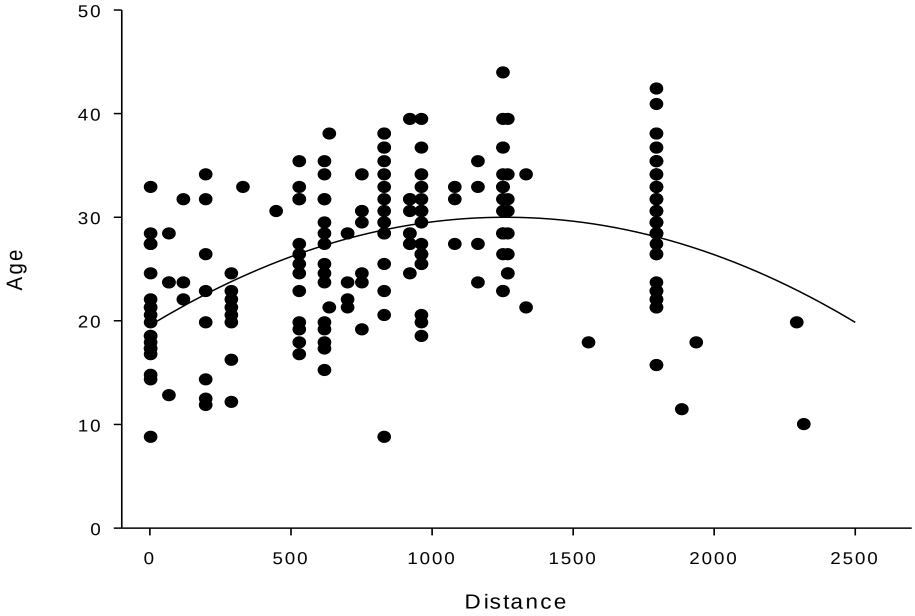


Figure 11 Non-linear regression of mussel age (years) over distance (metres) moving upstream from the confluence with the Heathcote River. Ages were calculated following Ogilvie (1993) using anterior-posterior lengths recorded from mussels collected during surveying in 2007. The regression was significant ($F = 29.2$, $P < 0.001$, $R^2 = 0.214$) and the equation is: Age = 19.542 + (0.0166 × Distance) – (6.59×10^{-6} × Distance^2).

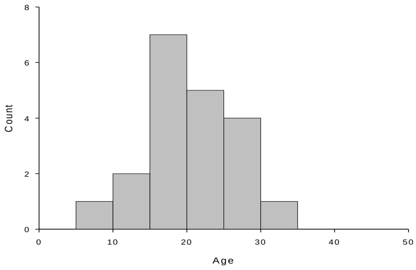
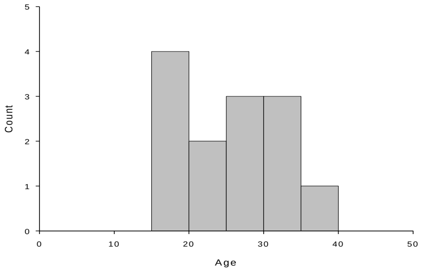
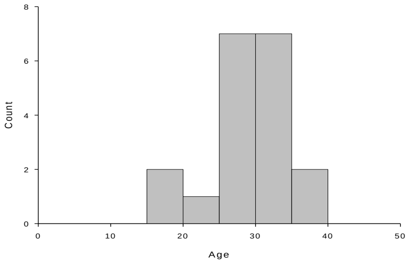
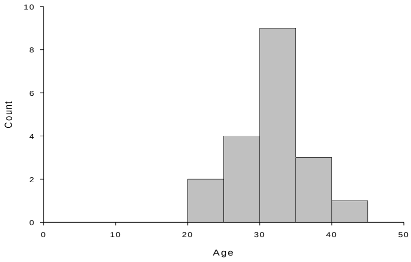
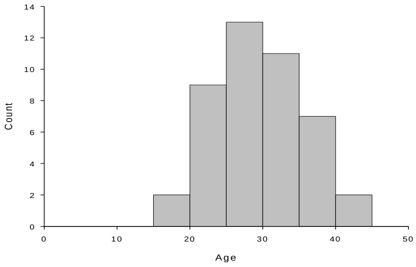
Site 1	
Site 8	
Site 15	
Site 18	
Site 26	

Figure 12 Age class data of mussels collected from selected sites surveyed in Cashmere Stream during 2007.

4.4 Habitat Preferences

There were a number of habitat characteristics that kakahi appear to favour (Table 5). Although there was no significant difference in water velocity between quadrats where mussels were present and absent, mussels appeared to have a preference for low to moderate velocities (0.05–0.36 m/s) and avoided the higher velocities typically found in riffle habitats (Figure 16). Mussels tended to be found in deeper water (Mann-Whitney Rank Sum test, $T = 21448$, $P < 0.001$) while macrophyte and sediment depth were not significantly between mussel presence and absence sites ($T = 14912$, $P = 0.095$). Stream width ($T = 23312$, $P < 0.001$) and distance from bank ($T = 23963$, $P < 0.001$) were significantly higher where mussels were present, but this is likely to reflect the restriction of mussels to the lower half of Cashmere Stream where the channel widths are generally wider. The quadrats where mussels were present had significantly greater substrate index scores ($T = 19628$, $P < 0.05$). A closer inspection of the substrate categories from which the index score is derived showed the proportion of gravels was significantly higher in quadrats where mussels were present ($T = 19073$, $P < 0.05$), whereas the proportion of fine silts was higher where mussels were absent ($T = 14586$, $P < 0.05$). The proportion of detritus cover was significantly higher where mussels were present ($T = 21306$, $P < 0.001$). There were no differences in canopy cover, visible sky or percentage macrophyte cover.

Table 5 Summary statistics of selected habitat variables recorded from 0.25 m^2 quadrats sampled at sites surveyed in Cashmere Stream during 2007. Variables where there were significant differences between present and absent sites are shaded.

Quadrats	Statistic	Velocity (m/s)	Water [1] (m)	Macrophyte [1] (m)	Sediment [1] (m)	Width (m)	Bank [2] (m)	SI [3]	Canopy [4]	Sky [4]	Detritus [5] (%)	Macrophyte [5] (%)
All quadrats (*n* = 507)	Mean	0.22	0.37	0.02	0.10	4.3	1.3	1.6	2.8	3.2	13	34
	Min	0.00	0.00	0.00	0.00	2.4	0.0	1.0	1.0	1.0	0	0
	Max	1.07	0.75	0.34	0.57	8.8	4.0	5.5	5.0	5.0	100	100
	Stdev	0.12	0.12	0.04	0.10	1.4	0.7	1.0	1.4	1.2	18	36
	90% CI	0.01	0.01	0.00	0.01	0.1	0.1	0.1	0.1	0.1	1	3
	Low	0.21	0.36	0.02	0.09	4.2	1.2	1.6	2.7	3.1	12	31
	High	0.23	0.38	0.02	0.10	4.4	1.3	1.7	2.9	3.3	14	37
Mussels absent (*n* = 441)	Mean	0.22	0.38	0.02	0.10	4.2	1.2	1.6	2.8	3.2	12	35
	Max	1.07	0.75	0.34	0.57	8.8	4.0	5.5	5.0	5.0	100	100
	Min	0.00	0.13	0.00	0.00	2.4	0.0	1.0	1.0	1.0	0	0
	Stdev	0.13	0.12	0.04	0.10	1.3	0.7	1.0	1.4	1.2	17	36
	90% CI	0.01	0.01	0.00	0.01	0.1	0.1	0.1	0.1	0.1	1	3
	Low	0.21	0.37	0.02	0.09	4.1	1.1	1.5	2.6	3.1	11	32
	High	0.23	0.39	0.02	0.11	4.3	1.2	1.7	2.9	3.3	13	38
Mussels present (*n* = 66)	Mean	0.22	0.44*	0.02	0.07	5.2*	1.8*	1.7*	2.8	3.2	20*	29
	Max	0.36	0.65	0.12	0.53	8.5	3.5	4.9	5.0	5.0	100	100
	Min	0.05	0.13	0.00	0.00	3.1	0.0	1.0	1.0	1.0	0	0
	Stdev	0.06	0.10	0.03	0.10	1.4	0.8	0.9	1.3	1.2	21	36
	90% CI	0.01	0.01	0.01	0.02	0.3	0.2	0.2	0.3	0.2	4	7
	Low	0.20	0.43	0.01	0.05	4.9	1.6	1.5	2.5	3.0	16	21
	High	0.23	0.45	0.02	0.09	5.5	2.0	1.9	3.0	3.5	25	36

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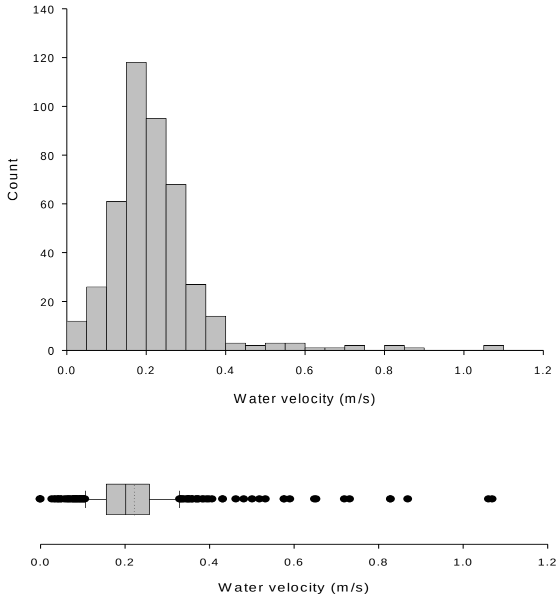
[1] Water, macrophyte and sediment refer to depth measurements of these three variables.

[2] Bank refers to the distance from the closest stream margin.

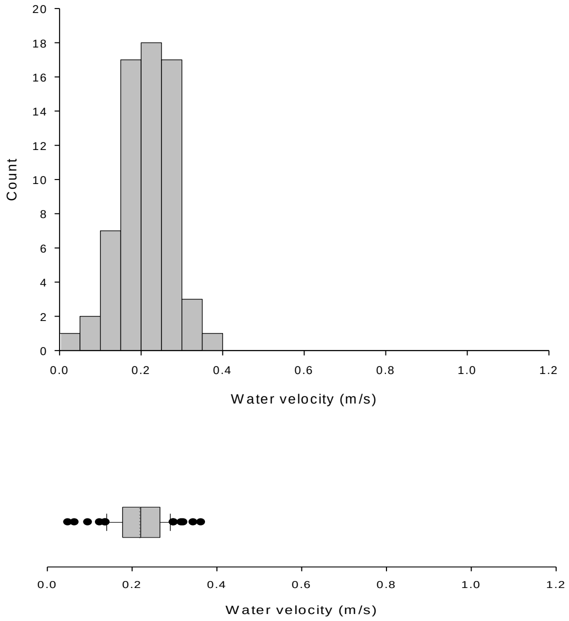
[3] The substrate index (SI) was calculated following the equation described in the methods section.

[4] Canopy cover and visible sky were estimated using a predetermined scale.

[5] The percentage area covered by detritus combined three categories (leaf detritus, small woody debris and large woody debris) and was estimated visually along with percentage macrophyte cover.



Mussels absent



Mussels present

Figure 13 Water velocity values recorded from 0.25 m^2 quadrats surveyed in 2007. The histograms show velocity classes from quadrats where mussels were absent and present. Below each histogram is a horizontal box plot describing median, mean (dotted line), 10th, 25th, 75th, 90th percentiles and outliers (solid dots).

The NMDS plot of all quadrats according to the measured habitat variables and count of mussels (

Figure 14) showed that quadrats located to the left of Axis 1 were associated with faster water velocities, coarser substrate, greater distances from the bank and greater canopy cover. The quadrats located to the right of Axis 1 were associated with slower flow, greater macrophyte and sediment depths, greater visible sky overhead, and they were located further upstream. The quadrats located to the bottom of Axis 2 were associated with faster flow, coarser substrate, greater canopy cover and were further from the stream banks. The quadrats located to the top of Axis 2 were associated with greater water, macrophyte and sediment depths had greater visible sky overhead, and were located further upstream.

There was no clear distinction between quadrats where kakahi were present and absent. However, there is a notable cluster of quadrats where they were largely absent to the right along Axis 1 and around the centre of Axis 2. These sites tended to be further upstream where it has been already noted that kakahi were not found.

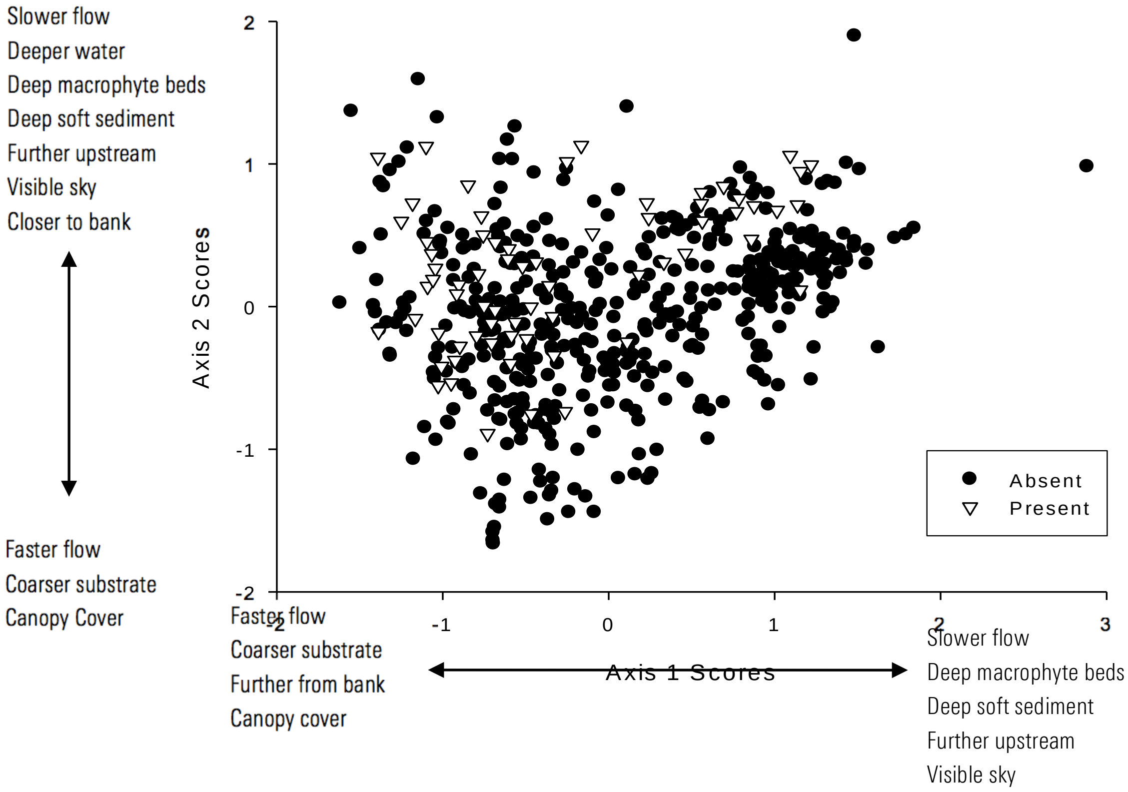


Figure 14 Non-metric Multidimensional Scaling (NMDS) ordination showing the similarity in habitat variables and mussel densities from quadrats (0.25 m^2) surveyed in 2007. Mussel presence or absence in quadrats is indicated. Habitat variables associated with each of the axes are indicated. Final stress for two-dimensional solution = 19.56.

Hierarchical partitioning analysis was performed on 11 habitat variables recorded from the quadrats at sites where mussels were found (Figure 15). This analysis indicated four variables (water depth, distance upstream, distance from the bank and percentage cover of detritus) with a significant effect on the number of mussels counted from quadrats (Table 6). Of these four variables, distance from the bank and percentage detritus cover was negatively associated with mussels counted. The significance of percentage detritus cover was marginal and the importance of this variable was regarded as being equivocal.

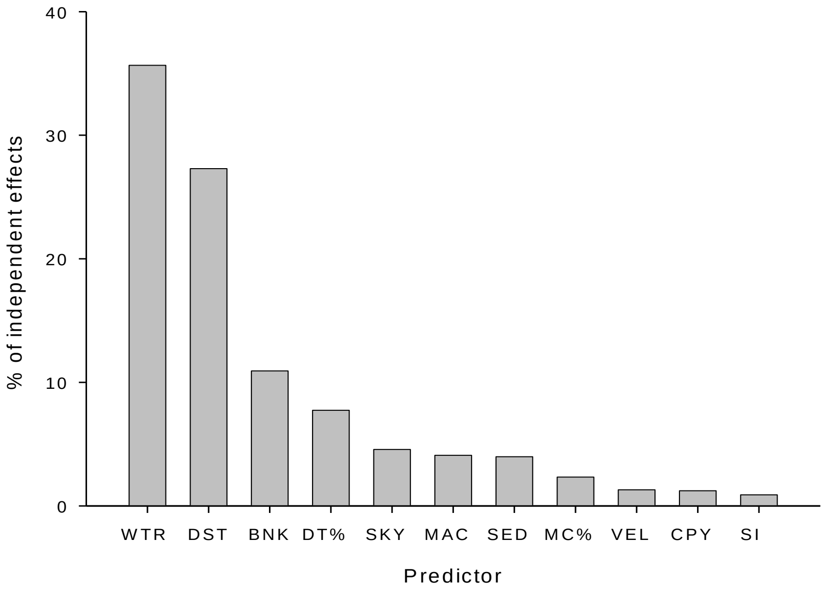


Figure 15 Percentage distribution of independent effects (I%) of predictor variables, calculated from hierarchical partitioning on mussels counted in 0.25 m^2 quadrats. Wtr: Water depth (m); Dst: Distance upstream from confluence (m); Bnk: Distance from bank (m); Dt%: Percentage cover of detritus; Sky: Visible sky; Mac: Depth of macrophyte beds (m); Sed: Depth of soft sediment (m); Mc%: Percentage cover of macrophytes; Vel: Water velocity (m/s); Cpy: Canopy cover; SI: Substrate Index.

Table 6 Results from hierarchical partitioning (HP) on mussels counted from the 66 quadrats where they were present in the 2007 Cashmere Stream survey.

Variable	I	J	Total	I%	Z.score	Coefficient
Water depth (WTR)	0.0158	0.0296	0.0454	35.66	13.34*	0.401
Distance upstream (DST)	0.0121	0.0252	0.0373	27.29	9.43*	0.201
Distance from bank (BNK)	0.0048	0.0131	0.0179	10.92	3.43*	-0.221
% detritus cover (DT%)	0.0034	0.0089	0.0123	7.73	1.7*	-0.063
Visible sky (SKY)	0.0020	0.0007	0.0027	4.56	0.92	0.307
Macrophyte depth (MAC)	0.0018	-0.0014	0.0004	4.09	0.56	0.004
Soft sediment depth (SED)	0.0018	0.0030	0.0048	3.98	0.35	-0.065
% macrophyte cover (MC%)	0.0010	0.0005	0.0016	2.33	0.01	0.004
Water velocity (VEL)	0.0006	-0.0005	0.0001	1.30	-0.23	-0.003
Canopy cover (CPY)	0.0005	-0.0005	0.0001	1.23	-0.41	-0.129
Substrate index (SI)	0.0004	-0.0003	0.0001	0.89	-0.47	-0.063

Shown are the independent (I), joint (J) and total effects of predictors on the response variable. I% represents the contribution of the I-values to the total explained variance in the response variables. The Z-scores shown were calculated as [observed mean (1000 randomizations)]/SD (1000 randomizations) and their statistical significance indicated. The Pearson or Spearman correlation coefficient for each predictor variable was outside the HP analysis, but was included to indicate the nature of the predictor variables relationship against the response variable.

Linear regression indicated water depth was positively related to number of mussels, indicating that kakahi have a preference for deeper water in Cashmere Stream (Figure 16). Conversely, mussel numbers were negatively related to stream width (Figure 17). This may have been partly related to the negative relationship of water depth to stream width (Pearson's product moment correlation, $r = -0.345$, $P < 0.01$). Similarly, distance from the bank was positively correlated to stream width ($r = 0.663$, $P < 0.001$). Due to this co-linearity with distance from the bank and water depth, stream width was omitted from the hierarchical partitioning analysis. Although the regression was not significant, there was a negative relationship of mussels counted to distance from the bank (Figure 18). There was potential for a positive relationship between the proportion of gravel on the streambed and mussels counted (Spearman Rank Order correlation, $r = 0.210$, $P = 0.09$), however linear regression analysis confirmed that this relationship was not significant.

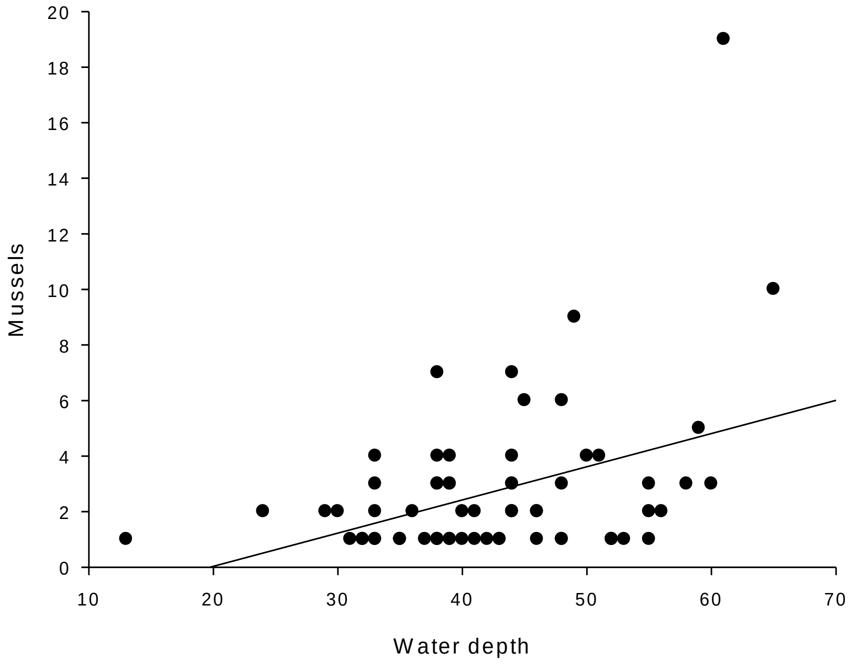


Figure 16 Linear regression of mussels counted in 0.25 m^2 quadrats against depth of water (centimetres). The regression of the log-transformed mussel data was significant ($F_{1,\ 64}$ = 10.1, $P < 0.01$, R^2 = 0.136). The log-transformed regression equation was: Log$_{10}$ (y) = -0.0123 x - 0.220.

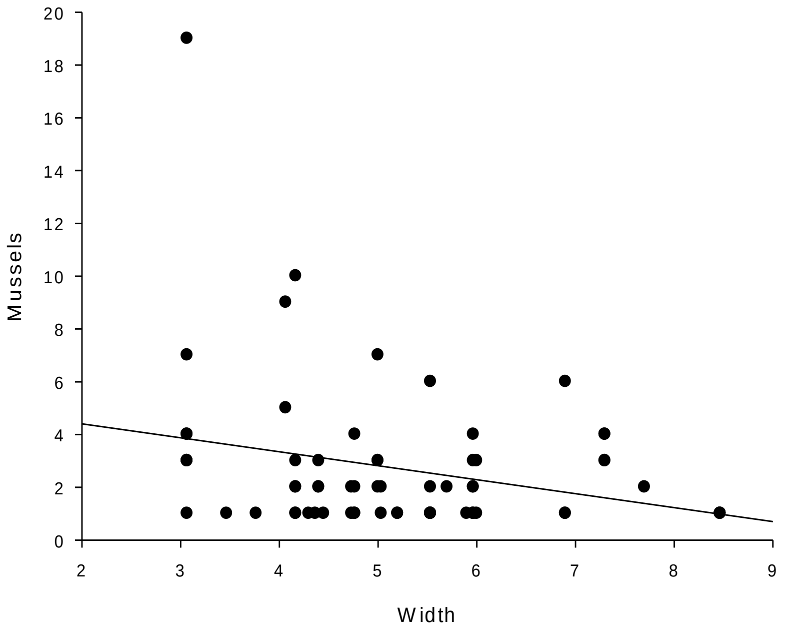


Figure 17 Linear regression of mussels counted in 0.25 m^2 quadrats against stream width (metres). The regression of log-transformed mussel and width data was significant ($F_{1,\ 64}$ = 4.8, $P < 0.05$, R^2 = 0.069). The log-transformed regression equation was: Log$_{10}$ (y) = - 0.791 [Log10 (x)] + 4.152.

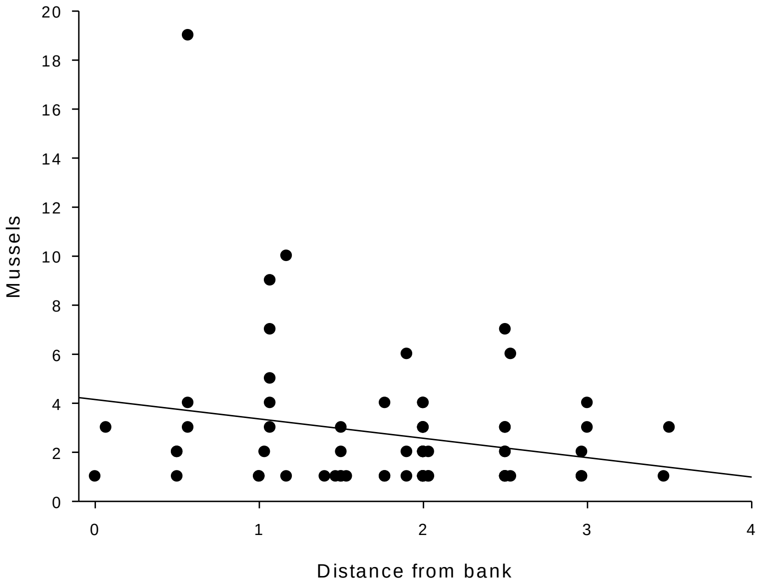


Figure 18 Linear regression of mussels counted in 0.25 m^2 quadrats over distance from closest bank (metres). The log-transformed regression was not significant, although the power of the test (0.040) was well below the desired power of 0.800. This means that it was more likely to not have detected a difference when one actually exists.

There were a number of significant relationships for habitat variables with increasing distance moving upstream. Water depth ($r = 0.319$, $P < 0.01$) and visible sky (Spearman Rank Order correlation, $r = 0.440$, $P < 0.001$) were both positively correlated with distance, whereas sediment depth ($r = -0.316$, $P < 0.01$), stream width ($r = -0.842$, $P < 0.001$) and distance from the bank ($r = -0.574$, $P < 0.001$) were all negatively correlated longitudinally.

Mussel age was negatively related to the substrate index (Figure 19). A closer inspection of the components that make up this index showed that the age of mussels similarly had a negative relationship with the proportions of pebbles ($r = -0.235$, $P = 0.057$), small cobbles ($r = -0.305$, $P < 0.05$) and large cobbles ($r = -0.285$, $P < 0.05$) indicating that younger mussels favour coarser substrate. Mussel age was negatively related to stream width and distance from the bank; however this may have reflected the underlying longitudinal trends present in Cashmere Stream rather than any direct causality.

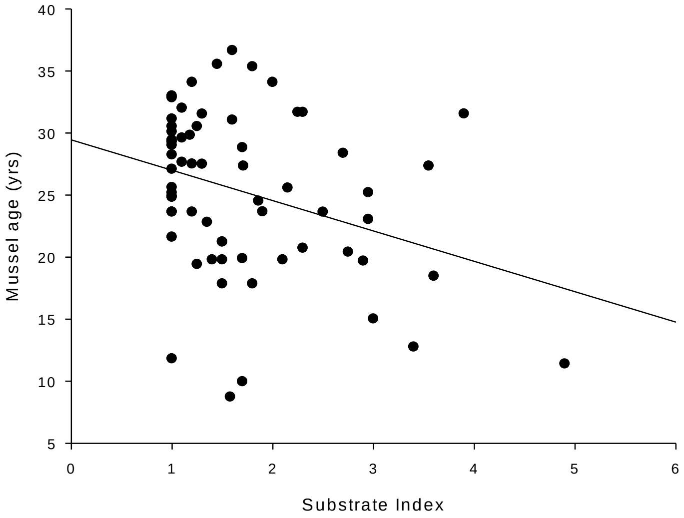


Figure 19 Linear regression of mean age (years) of mussels recorded in 0.25 m^2 quadrats against substrate index. The regression was significant ($F_{1,64} = 7.6$, $P < 0.01$, $R^2 = 0.106$). The regression equation is: y = 29.442 - 2.446 x.

5 DISCUSSION

The distribution of kakahi in Cashmere Stream was far more extensive than previously thought, and the estimated size of the population indicates that this population is highly likely to be exceptional in the greater Christchurch context. The large number of individuals around the age of 30 years old indicates that the habitat present in Cashmere Stream may have been more conducive to the recruitment of juveniles in the past. Furthermore, currently there may be a problem with recruitment due to habitat changes induced by the growing urbanisation of the catchment. The analysis of habitat variables associated with the presence of kakahi indicated that a more naturalised stream channel may be more desirable habitat.

Cashmere Stream supports a large population of freshwater mussels, and this is probably due to its stable flow, relatively un-developed catchment and good water quality from its spring sources. The substrate in the past may have been more conducive for colonisation by juvenile kakahi, with a predominance of gravels and some fine sediments. Certain water chemistry parameters may also be beneficial. The Christchurch Drainage Board (Robb, 1980) reported the $CaCO_3$ concentrations were higher in Cashmere Stream (71 g/m^3) than in the Avon River (45 g/m^3). Calcite is a key constituent of mussel shells and its abundance and biological availability may be important in determining kakahi growth. The presence of some turbidity in the water column from the fine loess soils washed down from the hills during rainfall events may have been beneficial to kakahi, as it has been suggested that some suspended silt is beneficial occasionally as turbid water may be required to aid the release of the glochidia larvae and may help with them locating an appropriate fish host (Dr. Chris Humphries, Environmental Research Institute of the Supervising Scientist, Darwin, Australia, pers. comm.).

The distribution of kakahi in Cashmere Stream showed an interesting pattern. Kakahi were found frequently in the lower half of the stream, but were conspicuously absent from the upstream half. This pattern could be related to the historic distribution of mussels in Cashmere Stream, reflecting the natural path of the stream prior to the draining of the swamp in Cashmere Valley and the cutting of a new channel connecting the main springs feeding the Cashmere Stream with the then existing stream channel. If this assertion is correct, then the dispersal of mussels into the new channel has been slow, patchy, and relatively unsuccessful, and this may be a result of the underlying habitat conditions, which could be ill-suited to kakahi. The slow dispersal of kakahi upstream of Site 26 could be inferred from the relatively youthful age of mussels in this section. The man-made section of Cashmere Stream is channelized with steep banks reflecting a relatively homogenous habitat dominated by fine sediments. There is little shading of the stream due to the scarcity of riparian vegetation and as a consequence the growth of macrophytes in the stream channel can be extensive in this section. These weed beds are removed to improve the drainage potential of the stream. This activity continually disturbs the streambed, which may harm juvenile colonist kakahi and may also result in the unintentional removal of individuals along with the macrophytes. The habitat that kakahi favoured in the open sites downstream of Penruddock Rise was deep water located close to the bank, and this combination of parameters was typically associated with the sinuous winding of the stream channel scouring out of streambed and undercutting of the bank created by meander bends in addition to the overhang created by the roots of riparian trees. It may be that a naturalised stream with riparian trees provides the best type of habitat for kakahi and that the homogenous drainage channel upstream of the Cashmere Road bridge is ill-suited to kakahi.

A Spanish study investigating the ecology of the endangered European freshwater pearl mussel (*Margaritifera margaritifera*) found this mussel showed a preference for the strip of river bed within 1.5 m of the bank and also favoured sites with greater than 80% canopy cover, avoiding the sites with less than 50% cover (Outeiro et al., 2008). The open sites where kakahi were found in Cashmere Stream were until recently heavily shaded by a line of tall trees that have been felled as part of the landscape redevelopment associated with a new subdivision. The preference of the European freshwater pearl mussel for the section of riverbed close to the bank has been reported in other studies. In Scotland, Hastie et al. (2000) found that this species was most common between 1-3 metres of the bank (within a possible range of 0-8 m) where the mean flow velocity was between 0.25 and 0.75 m/s (the entire range was 0 to 2 m/s). In contrast to the results of the Cashmere Stream survey, Gittings et al. (1998) found that in Ireland the European freshwater pearl mussel favoured shallow water (0.2 m), albeit with a strong preference to shaded areas. This did contrast to the behaviour of the same species at latitudes further north where they favour deeper water to avoid freezing in winter, showing that the behaviour of mussels can be flexible to accommodate different site characteristics.

Outeiro et al. (2008) linked the distribution of the European freshwater pearl mussel on the riverbed to the possible requirements of its potential fish host species brown trout (*Salmo trutta*) and salmon (*S. salar*). The juvenile stages of these two fish species typically find areas of moderate flow close to the bank with tree cover to avoid predators (Armstrong et al., 2003). Any preference by freshwater mussels for occupying microhabitats favoured by its fish host species may be a strategy to increase their reproductive success. The association of kakahi with detritus in Cashmere Stream could be evidence of this behaviour, as these sites would provide cover for potential fish hosts. This also opens up an interesting question on the ability of kakahi to parasitize exotic fish species. It is known that the riffle section (Site 27) on Cashmere Stream is a salmon spawning site, and it is highly likely that the stream's population of brown trout also build redds at this location, meaning that the number of juvenile and adults salmonids in the vicinity of this site could be high at certain times of the year. The greatest density of mussels was recorded downstream of this riffle at Site 26, with one 0.25 m^2 quadrat yielding 19 mussels (analogous to a density of 76 mussels per m^2). It is tempting to consider this result as being more than just a coincidence; however the presence of mussels at high densities at this site may be related to historical and site-specific factors as opposed to any salmonid-unioid connection.

In the restored section of Cashmere Stream (Sites 21-25) downstream of the site with the highest mean density (Site 26) mussels were relatively rare with only one mussel being found at Site 23. There could be a number of explanations for the paucity of mussels in this section. Firstly, two of the sites were located in shallow, fast-flowing and hard-bottomed reaches (riffles), which did not represent optimal mussel habitat. Secondly, there were a number of deep pools, which were not wadeable meaning that they were unable to be sampled using the methodology employed in this survey. These pools could contain mussels, but to assess this would require a different sampling methodology utilising wet-suits and face-masks allowing full immersion while searching for mussels.

During the survey we measured shell dimensions and then used a length-age equation help establish the age structure of the population of kakahi in Cashmere Stream. This was an important area of inquiry, as the absence or scarcity of juveniles indicates reproductive failure and population decline (Bauer & Wachtler, 2001). The kakahi age data from Cashmere Stream indicates that there are a number of different cohorts of mature mussels, but with no apparent recruitment of juvenile mussels. These results were comparable to those found in other studies. The absence of small individuals in freshwater mussel populations is a common phenomenon and similar results in New Zealand were found by Grimmond (1969), James (1985), and Roper & Hickey (1994). Hunter (1964) noted that for *Unio* and *Anodonta* species, post-glochidial juveniles have rarely been found and that little is known about the development and ecology of these newly-metamorphosed mussels. Likewise, Outeiro et al. (2008) only recorded a handful of individuals in the 5-10 and 10-15 year classes. Green (1980) described a population of *Anodonta grandis* where individuals younger than about 5 years were absent. Resampling the same population 13 years later showed a decline in growth rate, a shift to an older age structure, and a drop in population density, possibly as a result of anthropogenic impacts (Bailey & Green, 1989). In New Zealand, James (1985) dismissed the effects of environmental degradation on the absence of juveniles in Lake Taupo, and speculated that the ‘periodicity in age structure’ resulted from breeding characteristics (i.e., sporadic recruitment) and climatic conditions. However, the absence of juveniles in these studies could also be indicative of the global trend of decline in freshwater mussel populations.

In Scotland, Hastie & Cosgrove (2002) considered that a population of the European freshwater pearl mussel was viable (with sufficient recruitment) when at least 25% of the specimens recorded were younger than 20 years old. Using this as a guide indicates that the population of kakahi in Cashmere Stream is not viable, as only 17% of the mussels recorded were less than 20 years old. Furthermore, Hastie & Cosgrove (2002) considered that recent recruitment had taken place when specimens of <30 mm were present in a population. The youngest kakahi found in Cashmere Stream was estimated as being 9 years old from a length of 46 mm, and there were only a handful of individuals of a similar age, which suggest that there has been no recruitment in Cashmere Stream for some time.

The problems with sediment pollution in Cashmere Stream may be a factor in limiting successful recruitment. The silt deposited on the streambed may smother juveniles, and limit their favoured habitat. There was a tendency for the younger mussels to favour coarser substrates, indicating that there may be life-stage shifts in habitat preferences. James (1985) found that kakahi in Lake Taupo favour sites with clean sand and sufficient bed slope so as to avoid the accumulation of fine materials, but in this study there were no small individuals recovered. Phillips (2007) reported similar findings from a survey of kakahi in the Rotorua lakes. Grimmond (1969) suggested that the settlement of young kakahi in Lake Waipora might have been limited to the areas of loose sand and gravel around river inlets. If this assertion holds true for river as well as lake populations, then such suitable habitat is likely to be threatened in Cashmere Stream by excessive sedimentation.

The mussels at the most downstream sites may be the most susceptible to the cumulative impacts of contaminants entering Cashmere Stream from urban and rural runoff. This could help explain why mussels were more youthful in this section, as they may have a lower life expectancy due to the sub-lethal effects of exposure to contaminants such as cadmium and zinc. Conversely, access for potential fish hosts and the underlying substrate may be more favourable for mussels, resulting in more recent recruitment episodes.

A direct impact on kakahi populations was observed along the reach encompassing Sites 13–15 where recent channel cleaning activities were evident. Live adult mussels were found deposited along the bank some distance from the water. They were most likely removed during channel cleaning and not returned to the water. However, there are documented cases of kakahi being removed from the water by terrestrial predators. Brown rats (*Rattus norvegicus*) are regarded as wetland or riparian specialist (Harper et al., 2005) and kakahi have been recorded as a dietary component for these rats on Mokaia Island, Lake Rotorua (Beveridge & Daniel, 1965). Used shells of kakahi have been found in the dens of rats in Northland, and Kirk (1895) reported that in tributaries of the Waikato River small heaps of empty kakahi shells were common place with markings consistent with that of rat predation. If rats were indeed interested in Cashmere Stream kakahi, they may find it difficult to get to the soft body tissue due to the large size of the kakahi. They may therefore have to utilise a method by rakali water-rats (*Hydromys chryogaster*) in Australia, whereby the mussel is left out of water to expire so that the rat can get access to the soft tissue (Tets, 1994). The New Zealand pukeko (*Porphyrio porphyrio melanotus*) has been observed eating kakahi (Philpott, 1913; McElrea, 1947) although it is unclear whether they were merely opportunistically feeding on discarded remains, or had actively sought out the mussels themselves.

It should be noted that there is the potential for aquatic predation of kakahi by freshwater crayfish (*Paranephrops zelandicus*), which are present in the upper half of Cashmere Stream, although such predation has not been reported in New Zealand. Overseas studies have shown that crayfish can significantly reduce mussel populations in streams, although such studies often involve invasive species that are larger than *P. zelandicus* (e.g., Perry et al., 1997).

6 RECOMMENDATIONS

6.1 Further Investigations

This study has illustrated a number of knowledge gaps that require further investigation. Furthermore, if Cashmere Stream kakahi are ever to be used once again as mahinga kai, then it is important to determine the viability and food safety of the population.

- Follow-up surveys focused on searching for juveniles to determine if the Cashmere Stream population is undergoing recruitment, and therefore viable in the long-term.
- Measuring the condition of Cashmere Stream kakahi to compare to other populations from more pristine environments to determine whether changes in the catchment are having a negative impact on kakahi. Tissue samples from mussels could be also tested for heavy metals and microbiological contamination to provide information on the ecological and food safety impacts of contaminants entering Cashmere Stream.
- Repeat the population survey at five yearly intervals to determine the status of Cashmere Stream kakahi distribution and abundance (stable, declining, or increasing).
- Detailed fish surveys would assist in establishing whether there are adequate fish hosts in Cashmere Stream by capturing fish from the stream and inspecting them for the presence of the parasitic glochidia larvae.

6.2 General Recommendations

There are also a number of recommended actions that would be beneficial for kakahi in Cashmere Stream:

- The restoration of instream and riparian habitats could be beneficial for kakahi in Cashmere Stream. A more naturalised stream channel with meander bends, under cuts and riparian cover would provide favourable habitat for kakahi as well as potential host fish species.
- The protection and restoration of sand and gravel substrates should be a key management focus in order to provide kakahi with suitable habitat for the recruitment of juveniles. This means the inputs of fine sediment need to be minimised (e.g., fencing to prevent stock access, effective treatment of all stormwater runoff, and enforcement of sediment control requirements in new developments). The active removal of deposited sediment from the channel in the upper catchment could also be investigated.
- Because kakahi are concentrated in the lower half of Cashmere Stream, they may be particularly susceptible to the adverse effects of stormwater entering the stream via the numerous drain tributaries. The long-term exposure to contaminants such as cadmium have been shown to have a negative effect on shell strength in bivalves and there should be an emphasis on capturing and remediating first flush stormwater from urban areas in the Cashmere Stream catchment.

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9 APPENDICES

9.1 Appendix I: Organic matter categories

Group	Category
Macrophyte	*Nitella* spp. *Potamogeton crispus* *P. ochreatus* *P. cheesemanii* *Myriophyllum* spp. *Elodea canadensis* *Ranunculus* spp. *Nasturtium* spp.
Detritus	Detritus (leaf litter) SWD (small branches) LWD (branches, logs)
Other	Filamentous algae Algal mats Bryophytes *Azolla* spp. *Lemna* spp. *Callitriche stagnalis* *Mimulus guttatus* Terrestrial vegetation