remnant channels, which form adjacent to active channels. These springs are formed by the constricted river cutting down into the alluvium, and intersecting the water table, rather than spreading laterally. Bank vegetation is the principal control on lateral channel movement (M. Hicks, NIWA, pers. comm.) and, hence, deep scouring by constricted flows. In the lower Selwyn River/Waikirikiri, springs that occur in the scoured beds of remnant channels likely provide refugia for fish and invertebrates during summer low-flow periods in the river, although this hypothesis has yet to be tested. Gray (2005) noted spring up-welling complexes formed in the lee of flood retention works in the upper Waimakariri River at Klondyke Corner. Kilroy et al (2004) collected 42 algal taxa in one of these sites, by far the highest diversity of any of the 24 sites sampled. Whilst it is interesting that human activities can be constructive as well as destructive in terms of habitat, we must recognise our lack of knowledge of the long-term effects of activities such as gravel extraction, flood bank construction and riparian planting of exotic trees on the distribution and permanence of springs. In general, construction of flood control barriers results in the reduction of invertebrate and habitat diversity seen in many channelised European rivers (Claret et al. 1999; Pringle 2001; Hohensinner et al. 2004).

The braided rivers of the South Island were formed in the last 20 000 years as a result of glacial action, rainfall and snow melt (Gage 1977). Continuous erosion of friable bedrock, coupled with high and unpredictable rainfall, maintains these rivers in a constant state of morphological dynamism. The alluvium that has accumulated within glacial valleys is highly permeable, and carries an alluvial aquifer within a sinuous lattice of preferential flow paths (Huggenberger et al. 1994; Woessner 2000; Poole et al. 2002). This aquifer provides stable inputs of water for springs, despite the irregularity of precipitation in each catchment.

Over time, reductions in porosity and hydraulic conductivity may occur because of the intrusion of fine sediments into interstitial spaces, or through bed-armouring processes. The clogging of the top layer of the channel sediments with fine sediment is termed 'colmation' (Brunke 1999). Under natural flow regimes, fine sediment is removed by high-flow events involving bed load movements, thereby resetting the colmation process (Brunke & Gonser 1997). Impoundment of the River Spol in Switzerland resulted in decreased discharge and a flow regime unable to effect bed mobilisation, leading to clogging of the bed interstices (Murle et al. 2003). A similar experiment conducted in the River Rhone flood plain revealed the importance of high-flow events for maintaining connectivity between surface waters and groundwaters (Claret et al. 1999). The pristine headwaters and natural flow regimes of many rivers are critical to groundwater–surface-water connectivity, as they maintain the aquifer recharge required to supply flow to many springs found along flood-plain reaches (Poff et al. 1997).

Impoundment is a feature of many large rivers. Since 1950, 10 000 km^3 of water (more than five times the volume of water in all the world's rivers) have been impounded in reservoirs globally (Rosenberg et al. 2000). Despite the damming of many of New Zealand's largest rivers, such as the Clutha, Waitaki, Waikato, Rangitaiki and Waiau, little research has been undertaken on the geomorphological and ecological consequences for groundwater–surface-water exchange, or their spring complexes. However, there is a wealth of international and New Zealand literature summarising the general downstream effects of flow regulation brought about by impoundment (e.g. see Henriques 1987; Rosenberg et al. 2000). Overall, dams and river diversions have proven to be severely detrimental to aquatic habitat, contributing to the destruction of fisheries, extinction of species and the loss of ecosystem services vital to the human economy (Pringle et al. 2000; Rosenberg et al. 2000). In particular, the negative impact of flow regulation upon the morphological and successional diversity of flood plains has been highlighted (Ward & Stanford 1995; Gilvear 2004; Hohensinner et al. 2004; Choi et al. 2005). A reduction in channel-forming flows and sediment load reduces the rate of channel migration, which is important for maintaining high levels of habitat diversity. High biodiversity in flood-plain ecosystems is a function of the diversity of water bodies with differing degrees of connectivity with the main channel, and the range of successional stages present due to historic channel migrations (e.g. Reinfelds & Nanson 1993). The effect of flow regulation is similar to that of channelisation, in that it truncates the fluvial system and disconnects the river from its flood plain (Hohensinner et al. 2004).

Since the 1930s, the morphology of the lower Waitaki River in the southern South Island has been significantly altered, predominantly by impoundment for hydro-electrical power generation. The reduction in flow variability and sediment input due to impoundment has caused an increase in channel stability. In the Duntroon area, encroachment of the river by exotic vegetation has reduced the width of the un-vegetated flood channel by 250 m (Meridian Energy 2003). Over the same time period the river has changed from a braided system to one characterised by more stable anastomosing channels (Meridian Energy 2003). The changes in channel morphology have resulted in a reduction in flood-plain area and associated habitat heterogeneity, with potential for loss of species adapted to life within the shifting habitat mosaic of braided rivers (Gray 2005). Although groundwater-fed channels were recorded in the lower Waitaki in 2003 (Meridian Energy 2003), the long-term effects of channel morphology changes on them are unknown.

Natural flow regimes maintain a mosaic of variable groundwater–surface-water exchange and contribute to the formation of braided river springs. Without high levels of disturbance in the main channel, vertical and lateral hydrological connectivity are reduced, and result in the loss of springs, which can be considered ‘hotspots’ of biodiversity within the braided river corridor (Gray et al. 2006). Anthropogenic activities such as diversion, channelisation and impoundment can have severe impacts upon the balance of dynamic riverine systems. Consideration of the biodiversity values of a river system must take into account habitat diversity and functional integrity of the whole system. The 3-dimensional aspect of flood plains, longitudinal linkages and connectivity between adjacent elements in the landscape mosaic should be central features of our management of braided rivers (Pringle 1997; Ward et al. 1999; Pringle 2001; Malard et al. 2002; Wiens 2002).

6. Management and conservation of springs

Direct (e.g. water abstraction) and indirect (e.g. domestic animal grazing) utilisation of springs by society produces a wide variety of benefits to humans, but these uses may also be associated with significant costs to the environment, including biodiversity loss and deterioration of water quality, which threaten the ecological integrity of spring ecosystems. Effective management of springs will be achieved by recognising the full range of environmental and societal values associated with these habitats, understanding threats to the sustainability of these values and formulating strategies that provide a balance between potentially conflicting uses.

Throughout the world there is a growing recognition of the value of springs, and several initiatives have been implemented to ensure their protection and sustainable management. In the eastern USA, the Florida Springs Task Force has outlined steps for protecting and restoring Florida's springs and underground aquifers (Hartnett 2000), while in the west a conference focusing on spring-fed wetlands in Las Vegas, Nevada, has helped to unite visions on spring habitat management (Sada & Sharpe 2004). Moreover, the Bureau of Land and Management, USA, has also produced a guide to effectively manage and protect western freshwater springs (Sada et al. 2001). In Germany, the Society of Spring Ecology and Conservation (SSEC) has played an important role in producing valuable information related to spring habitats with the creation of the journal Crunoecia. SSEC also organised the first European symposium on spring ecology and conservation. In Australia, the Great Artesian Basin (GAB) is the focus of a group of researchers that meets annually to discuss questions related to the management and protection of springs. Furthermore, the South Australian Department for the Environment has published a plan for the management of Australian mound springs (Fatchen 2000). More broadly, the Australian federal government has developed national strategies for the management of groundwater-dependent ecosystems (GDEs; Sinclair Knight Mertz 2001). The goal is to provide water for the environment to sustain and where necessary restore ecological processes and biodiversity of GDEs, such as springs.

6.1 SPRINGS AS GROUNDWATER-DEPENDENT ECOSYSTEMS

We believe that a GDE management framework (Hatton & Evans 1998) may be applicable and beneficial to springs management in New Zealand, although it will form only part of a complete management framework. Recognition of springs as GDEs is essential to their management and protection, because groundwater abstraction and consumptive use, as well as land-use practices impacting on aquifer quality, are key threats to the integrity of spring habitats.

Hatton & Evans (1998) recognised five classes of ecosystem dependency on groundwater attributes (e.g. flux, level, pressure, quality): entirely dependent, highly dependent, proportionally dependent, opportunistically dependent and not dependent. Many springs can be classified as falling into the 'entirely dependent' category, because even slight changes in groundwater attributes can lead to their demise. However, some spring types (e.g. linear alluvial springs) may be also classified under the 'highly dependent' category, as these ecosystems may be adapted to naturally varying groundwater levels.

There are four key steps to developing GDE management strategies:

1. Identify potential GDEs
2. Determine the degree of ecosystem dependency on groundwater
3. Assess the water regime in which dependency operates
4. Determine the environmental water requirement

With regard to the management of springs, Steps 1 and 2 are implicit, whereas Steps 3 and 4 require assessments of the full range of existing groundwater water uses and the effects different uses have on ecosystem integrity. As is the case with freshwater ecosystems throughout the world, determining a spring's environmental water requirements is a challenging task. In springs, complete loss of flow would be devastating, but the ecosystem may be able to function at reduced levels of groundwater flux, pressure or quality.

6.2 KEY ELEMENTS OF A SPRING MANAGEMENT FRAMEWORK

As with any management strategy, the clear definition of management goals for springs is a precursor to effective conservation, protection and restoration. Set out below, we provide a synopsis of steps followed in spring management worldwide, and recommend key elements that we believe should form the basis of a spring management strategy in New Zealand.

6.2.1 Spring mapping

Mapping of springs is essential to estimate spring densities and describe broad-scale environmental characteristics. In New Zealand, the first attempt to create a national spring database has yielded 527 springs over a 2-month period (see section 2.2.1). Spring locations were obtained through polling of management agency staff and the freshwater science community. This database is complemented by an additional 1400–1500 springs in the pre-existing ECAN database. Further work is required to expand the spring database, and to link it to available physico-chemical and biological data. It should be noted that current freshwater classification schemes in New Zealand (e.g. REC) do not explicitly include spring habitats. Further development of a spring database may allow this to be rectified in the future.

Several spring mapping surveys have also been carried out on a regional level in Germany (Groever et al. 1996; Hotzy 1996; Krueger 1996). In the district of Gueterlosh (220 km^2), 203 springs were located in a 12-month period (Groever et al. 1996), whereas 700 springs were recorded over 3 years in Brandenburg (29 000 km^2), although this has been suggested to be only

10% of the estimated total number (Krueger 1996). Extrapolation of spring densities and types from one region to another is likely to generate significant errors, as spring numbers and typology are highly influenced by regional hydrogeology (van Everdingen 1991; van der Kamp 1995). Moreover, locating spring sites and collecting information (i.e. past disturbances, land uses) involves extensive public consultation with locals and private landowners, and thus must be tackled at a regional level. GIS techniques have proved quite efficient for the retrieval of information on springs such as land uses, vegetation, underlying geology and climate data, but ground-truthing of such information is vital.

6.2.2 Spring habitat assessment

A full-scale scientific investigation of all springs within a region is unlikely to be justifiable. However, the evaluation of spring ecosystem conditions is necessary to record basic information, which will be used to establish management and restoration priorities. This information should include discharge characteristics, habitat structure, flora, fauna and water chemistry. Different methods can be used for spring habitat assessment. In Australia, the GDE approach (see section 6.1 above) has been useful for spring management (e.g. Fatchen 2000), and this approach may also be useful in New Zealand. In Germany, environmental quality indices are in widespread use (Hinterlang & Lischewski 1993), with specific evaluation methods for spring flora and riparian vegetation (Hinterlang et al. 1993), fauna (Fischer 1996; Zollhöfer & Gonser 1998) and water chemistry (Andree et al. 1996) currently in use. Assessment of proper functioning condition of spring habitats can also be used for rheocrene (Prichard et al. 1998) or limnocrene and helocrene (Prichard et al. 1999) spring types as suggested by Sada et al. (2001). Recording of exotic and rare species, disturbance conditions and conflicting issues with management objectives is highly desirable (Sada & Pohlmann 2003). The assessment process should also clearly identify existing and potential threats to the range of values provided by springs.

6.2.3 Management priorities and direction

Once spring biotic and abiotic characteristics have been evaluated, and the management needs identified, then management priorities and direction can be developed. Examining habitat condition and determining whether a spring needs protection or restoration will determine management responses. Priority should be assigned to protecting unaltered spring habitats and restoring habitats with a high potential for recovery (Sada et al. 2001). Selected habitats may also need protection to prevent further degradation until restoration activities start to take effect.

There are many factors that can be considered in setting up management priorities, and resource agencies must decide which ones are most appropriate for their region and conservation programmes (Sada & Pohlmann 2003). Springs within a region can be ranked according to their resource values and restoration needs using matrix analysis (Sada et al. 2001). This would indicate the relative importance of each spring and how each one can be considered during management and restoration programmes (Sada et al. 2001; Sada & Pohlmann 2003). Consequently, resources can be allocated according to the management priorities that have been set.

6.2.4 Spring monitoring

The efficiency of management strategies and progress towards stated goals can be assessed through monitoring programmes. These programmes should be designed to quantitatively describe biotic communities, riparian habitats and spring flow characteristics, accounting for their spatial and temporal variability. Moreover, monitoring surveys should become less intensive as more information is gathered on biotic and abiotic natural variability (Sada & Pohlmann 2003). Changes outside natural ranges can be determined as excessive, while those within the natural range are likely to be acceptable. Site selection for monitoring is crucial and appropriate reference sites for intermittent and/or altered springs will be required to allow separation of changes associated with anthropogenic and natural changes (Sada & Pohlmann 2003). Because spring habitats can be sensitive to disturbance, particularly where local endemics may occur, the frequency and destructiveness of sampling techniques used in the monitoring programme should be carefully considered (Resh 1983). Monitoring programmes should be part of any management plan in order to review and update management strategies to achieve desired goals. Monitoring methods would also need to be consistent with initial assessment methods so as to have comparable baseline and post-management datasets.

6.3 PROTECTION, ENHANCEMENT AND RESTORATION OF SPRING HABITATS

The environmental context (e.g. hydrogeological properties, land use) of a given spring should be carefully considered when determining management actions to protect, enhance or restore ecological integrity. For example, fencing and exclusion of cattle from spring habitats have different effects on springs in arid and temperate regions. In temperate regions, cattle exclusion, which is one of the first measures implemented by spring restoration programmes in Germany (e.g. 'Aktionsprogramm Quellen', J. Römheld, Bayerisches Landesamt für Wasserwirtschaft, München, 2005, pers. comm.), helps to re-establish woodland vegetation, which contributes to enhanced habitat quality. In contrast, exclusion of livestock reduced plant diversity and free water areas in springs of the GAB because of large increases in vegetation biomass of the most competitively superior species (Fatchen 2000). The appropriate management regime should take into account the natural condition of a spring with respect to exclusion of grazing animals. A grazing/non-grazing rotation programme or the maximisation of desirable outcomes can be the solution to manage spring habitats successfully in arid regions (Fatchen 2000).

In pre-human times (1000 years BP), most of New Zealand was heavily forested and ungulate grazers were absent. Therefore, the natural condition of most springs in New Zealand would have included extensive riparian vegetation and a very different grazing regime from that found now, so protection and restoration of these habitats should take this into account.

Delineation of the spring recharge basin is desirable in order to protect spring water quality (Jensen et al. 1997), despite it being difficult to achieve—it requires a detailed knowledge of underlying geology and groundwater flows. However, it will help to identify possible areas that may act as sources of groundwater pollution, and to develop best management practices through local land-use planning. Areas adjacent to spring sources, or in their recharge basins, have been purchased as part of restoration programmes in Florida (Hartnett 2000) and Germany (Buechler & Hinterlang 1993; Hurck 1996).

Springs and a portion of their associated springbrooks should be protected from activities that decrease biological diversity and cause functional changes. Groundwater abstraction close to the spring and development around the spring should be carefully controlled. Diversions, impoundment or other types of habitat modifications, when necessary, should not be done within the first 50 m of the spring and should stop drawing water when it is not needed (Sada et al. 2001; Sada & Pohlmann 2003). Where fish access to springs is a desired management goal, appropriate measures should be taken to ensure uninterrupted access (e.g. fish-friendly culvert design). Appropriate native riparian vegetation (i.e. woodland vegetation or grasses) should be planted or allowed to grow to restore sediment and nutrient run-off filtering and to stabilise spring banks (Collier et al. 1995). Proper management practices, such as construction of sign-posted walkways, toilet facilities and rubbish containers will also protect springs on public lands from damage associated with recreational use (Fatchen 2000; Hartnett 2000).

Populations of non-native plants and animals need to be controlled, and it is important that control efforts are specific to these species. Application of more generic treatments such as rotenone, or broad-spectrum herbicides, can have deleterious effects on spring biodiversity and ecosystem functioning (Sada et al. 2001; Erman 2002). Methods that minimise impacts such as manual removal, targeting only a small portion of habitat during a single treatment, or confining natives where they are protected from treatment effects, are preferred (Sada et al. 2001). Elimination of noxious weeds can be effectively achieved by a combination of mechanical methods and proper riparian management (i.e. providing shade) (Young et al. 1999), without the extirpation of other native flora.

Finally, education programmes can assist in improving community understanding of the relationship between land uses and the quality and quantity of spring water. Thus, a coordinated educational programme, employing a range of educational materials (e.g. brochures, pamphlets, booklets, slide exhibitions, videotapes, school field trips or regional and international conferences) will help to communicate this understanding and facilitate spring ecosystem protection (Laukoetter et al. 1992; Hartnett 2000).

Habitat restoration is an important aspect of managing spring resources, although it may take lower priority than protection of unmodified springs, where these unmodified habitats are under threat and contain significant biodiversity values. Restoration may include removal of barriers between groundwater, spring and springbrook, including man-made structures such as pipes, troughs, spring boxes or dams for impoundments, all of which impede the natural movement of water. Restoration may also include active transfer of fauna or flora from one spring to another, although it does create risks for genetic diversity (Erman 2002), particularly for groups with high levels of local endemicity (e.g. hydrobiid snails). Such threats to genetic diversity can be minimised by developing a detailed knowledge of the spring fauna and flora of the region (Sada et al. 2001). However, it would seem safer to favour natural recolonisation processes than to play an active role (Waechter & Ruether 1994; Glattfeld et al. 1996), except where natural recolonisation may be precluded by limited dispersal ability.

6.4 PROTECTION OF NEW ZEALAND'S COLDWATER SPRINGS

Many of New Zealand's largest springs are afforded some level of protection because they are part of the conservation estate (e.g. Waikoropupu Springs; Ohinepango Springs), or through their use for public water supply (e.g. Hamurana Springs). However, large springs are rare features in the landscape, and most springs are small and inconspicuous.

Based on springs' distributional density, their poor representation in the conservation estate and their high potential for anthropogenic disturbance through water abstraction and land-use intensification, we suggest that small, lowland springs are most at risk of degradation and further loss of biodiversity. Many of these small lowland springs are already impacted, and active rehabilitation and restoration will be required. However, many of these springs will also be located on private land, so their protection will be very dependent on the motivation of the landowner. Education of landowners on the values and services provided by intact, functioning springs will play an important role in protection or restoration of these systems.

We have identified three major spring types based on their underlying geology which may provide a useful basis for determining management approaches to the conservation and protection of spring biodiversity. These are:

- *Karst springs*—These exhibit a relatively high degree of permanence, although their discharge may be variable. Throughout New Zealand, but especially in Northwest Nelson, karst springs are a centre of hydrobiid snail and amphipod diversity. The high levels of local endemism observed in karst springs suggest that they may require management at relatively small spatial scales. For example, protection of individual springs will be required where maintainance of local endemics is a management priority.
- *Volcanic springs*—These are a major feature of the North Island, particularly around the Central Plateau and Mt Taranaki. Volcanic springs tend to have relatively high permanence and flow stability, but their history of large-scale disturbance tends to reduce their biodiversity values, and spring assemblages tend to be dominated by vagile insect taxa. Management of such springs should focus on protection of representative spring habitats within particular biogeographic regions.
- *Alluvial springs*—These tend to be concentrated in intensively farmed, lowland areas, especially in Canterbury and Southland. These springs are at risk from groundwater abstraction, river management and habitat

destruction. Management of alluvial springs should be intimately linked with groundwater management, so that spring flows and groundwater quality are maintained at the aquifer scale. Protection and rehabilitation of springs may also be required at the local scale, so that representative habitats are maintained within the landscape.

The key to the protection of small springs is to raise awareness of the values associated with spring habitats, so that landowners see them as valued landscape features. Raising awareness should be a deliberate, but gradual process. Organisations such as the QE II National Trust will have an important role to play. The Trust facilitates the protection of habitats of significant natural values on private lands. At present the Trust's database of covenants includes c. 350 wetlands, many of which will include springs (R. Allibone, QE II National Trust, 2005, pers. comm.).

Regional council activities will also be crucial to raising public awareness of the values associated with springs. Examples include work on the ecology of spring-fed systems in the Wairau River valley (e.g. Young et al. 2002), the extensive spring database produced by ECAN, and recent work detailing sustainable management of water resources of the Ruataniwha Plains (HBRC 2004).

7. Conclusions and future directions

Springs occur at the interface of groundwater, surface water and terrestrial ecosystems. As ecotone habitats, they are characterised by sharp gradients in physico-chemical characteristics (e.g. dissolved gases, temperature), but their defining characteristics (thermal and hydrological stability) are controlled by the hydrogeological context of their parent aquifer. Spring size, permanence, water quality and substrate type are all controlled by aquifer hydrogeology.

Springs throughout New Zealand contain a diverse fauna and flora. There is a significant spring specialist fauna, which includes a significant diversity of spring snails (Hydrobiidae), isopods of the family Phreatoicidae, amphipods of the family Paraleptamphopiidae, and a number of insect taxa (e.g. the mayfly *Zephlebia nebulosa*, the cased-caddis *Pseudoeconesus* spp.). The hydrobiid snail fauna of springs is of particular importance, as New Zealand is a significant hotspot of hydrobiid diversity. The high levels of local endemism observed in spring snails and amphipods indicate that springs are important centres of genetic diversity and radiation for poorly-dispersing taxa. At the regional level, Northwest Nelson and Southland appear to be hotspots for spring biodiversity. In braided river catchments, springs provide stable habitats in otherwise harsh aquatic environments. As a result, springs and the brooks they feed are important centres of biodiversity for both algae and invertebrates in these landscapes. Overall, the biodiversity values associated with New Zealand coldwater springs dictate that protection is required, particularly to halt the decline in indigenous biodiversity, and protect a full range of aquatic habitats.

Spring community structure is controlled, first and foremost, by spring permanence. In permanent springs, community structure varies with geology, elevation and disturbance history. Research on the Waimakariri River indicates that successional stage (which is determined by vegetation types and reflects time since disturbance) is a key factor influencing community structure in braided river catchments, although the presence/absence of macrophytes is important at local scales. At a range of spatial scales we have found that catchment land use and riparian vegetation composition are significant factors associated with spring invertebrate biodiversity patterns. Springs shaded by native vegetation have greater relative abundance of mayflies and stoneflies, and stock access appears to act as an additional, or cumulative source of disturbance. In general, lowland springs in pastoral landscapes with unlimited stock access can be expected to have reduced biodiversity values, although local factors, such as substrate composition, may mitigate impacts.

The key anthropogenic threats to the biodiversity values of New Zealand's coldwater springs are the unsustainable use of groundwaters through over-pumping, or chemical contamination, and the destruction of spring habitats through vegetation clearance and stock trampling. At the local scale, we suggest that spring protection on private land might be easily achievable, given sufficient landowner motivation, because springs are generally of small size, and their protection can provide a number of additional benefits to the landowner (e.g. water supply, nutrient trapping). At the regional scale, protection of the underlying aquifers to maintain spring flows constitutes a more difficult process, particularly in groundwater-dependent regions such as Canterbury and Hawke's Bay.

The key steps to improving our management of springs include an effective mapping of spring resources, identification of biodiversity values and other services, provision of methods for assessing spring habitat quality and biological integrity, definition of management goals for springs within different hydrogeological and land-use settings, monitoring to assess management effectiveness, public education and the provision of information on effective approaches for spring restoration or rehabilitation in degraded landscapes.

7.1 KEY KNOWLEDGE GAPS

Based on our review of available knowledge pertaining to New Zealand springs, we have identified a number of knowledge gaps that should be addressed in future studies. These are:

- *Spring classification*—There is a pressing need to recognise groundwater-dependent ecosystems (GDEs), such as springs, within national freshwaters classifications systems (e.g. River Environment Classification, REC). At present the REC system does mention spring-fed sources of flow, but these must be user defined. We recommend that efforts be made to include groundwater dependence within the GIS framework of the Source of Flow class of the REC. This should enhance our ability to map and better manage springs and spring-fed systems. The springs database developed during this programme may provide a useful starting point for inclusion of a springs GIS layer within the REC.

- *Identification tools*—Recent detailed biosystematics research has identified a huge diversity of spring fauna, particularly within the Hydrobiidae (Mollusca) and Paraleptamphopiidae (Amphipoda). Much of this detailed knowledge is relatively inaccessible to ecologists and managers, because of the highly specialised nature of species identification in these groups. Provision of identification tools even to genus level would help ecologists increase the taxonomic resolution of their spring research projects and more clearly identify biodiversity hotspots.
- *Springs as refugia*—Several authors have suggested a refugial role for springs in the landscape (e.g. Mosley 1983; van Everdingen 1991). We suggest that springs may provide significant thermal refugia for native fish and invertebrates in some regions of New Zealand. This is probably most likely to occur in alluvial springs in lowland areas of New Zealand (e.g. Canterbury Plains and Ruataniwha Plains, southern Hawke's Bay), where river temperatures can exceed critical temperatures for key stream invertebrates. Research testing this hypothesis may help increase the profile of springs, and increase public perceptions of their value.
- *Restoration ecology of springs*—To our knowledge, no work has tracked spring restoration in New Zealand. In addition to the obvious management need for information on restoration processes, research on the restoration of springs would provide a test of the importance of dispersal characteristics in determining spring recolonisation dynamics. For example, in alluvial springs, the importance of groundwater as a pathway for dispersal could be tested—i.e. does the aquifer represent a continuous, navigable habitat or are organisms restricted in their movement by phreatic dispersal barriers or contemporary anthropogenic impacts.
- *River management effects on springs*—Recent preliminary work on the occurrence of springs within braided river systems has shown that flow regulation, channelisation and flood protection works can have severe impacts on flood-plain habitat heterogeneity. We suggest that further research is required to identify linkages between biocomplexity in braided rivers and large-scale human interventions in flow and habitat characteristics.
- *Development of methods to measure spring habitat quality and biotic integrity*—Such methods will be required for biomonitoring of springs. Closely aligned to this would be work to assess the use of spring fauna as indicators of sustainable use of groundwaters, both in terms of groundwater quantity (i.e. spring permanence) and quality (i.e. spring fauna as indicators of contamination).

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Appendix 1

ALGAL AND MACROPHYTE TAXA FOUND IN A SURVEY OF FIVE COLDWATER SPRINGS

This survey was carried out by F.B. Michaelis in 1974. Presence of a species is denoted by 'x'. '*' indicates introduced vascular plants. Sites are: A = Hamurana Springs (Rotorua), B = Lake Hayes spring (Queenstown), C = Otangaroa Springs (Putaruru), D = Three Springs (Fairlie), E = Waikoropupu Springs (Takaka), and F = Western Springs (Auckland).

	A	B	C	D	E	F
Diatoms						
Achnanthes spp.					x	
Cocconeis spp.					x	x
Cymbella spp.					x	
Fragilaria spp.						x
Gomphonema spp.					x	x
Navicula spp.					x	x
Synedra spp.					x	x
Cyanobacteria						
Entophysalis rivularis					x	
Nostoc parmeloides					x	
Nostoc verrucosum					x	
Microcoleus?					x	
Oscillatoria?					x	
Filamentous green algae						
Ulothrix zonata						x
Stigeoclonium spp.						x
Chlorophyta						
Chaetophora elegans					x	
Spirogyra spp.					x	x
Chrysophyta						
Vaucheria spp.					x	x
Rhodophyta						
Batrachospermum sp.					x	
Hildenbrandia rivularis					x	
Mosses						
Acrocladium cuspidatum					x	
Bryum blandum					x	
Calliergonella cuspidata					x	
Cratoneuropsis relaxa				x	x	
Cyatophorum bulbosum					x	
Drepanocladus aduncus					x	
Drepanocladus fontinaliopsis						x
Echinodium hispidum					x	
Fissidens rigidulus		x			x	
Hypnobartlettia fontana					x	
Hypopterygium filiculaeforme					x	
Thamnium pandum	x					
Thiudiopsis furfurosa	x					

Continued on next page

Appendix 1 continued.

	A	B	C	D	E	F
Liverworts						
Chiloscyphus austrigenus					x	
Lophocolea austrigena					x	
Lophocolea minor					x	
Neesioscyphus phoenicorhizus					x	
Radula sp.					x	
Riccardia sp.	x					
Ricciocarpus natans						x
Vascular plants						
Callitriche stagnalis	x		x		x	x
**Elodea* spp.						x
**Egeria* spp.						x
**Juncus microcephalus*					x	
**Lagarosiphon major*	x		x			
Lemna minor		x	x		x	
Myriophyllum elatinoides					x	x
Myriophyllum porpinquum	x					
**Nasturtium officinale*	x	x	x	x		
Potamogeton spp.	x					x
**Salvinia* spp.						x

What are the biodiversity values of coldwater springs?

Coldwater springs are formed when the water table intersects with the earth's surface, or groundwater rises to the surface through rock faults, fractures or depressions. Springs are a significant component of the New Zealand landscape, yet they have received little attention from freshwater ecologists and conservation managers. Recently, a major research effort has been directed towards understanding the invertebrate biodiversity values of coldwater springs. This report summarises the state of our knowledge regarding the ecology of New Zealand springs, and identifies the approaches that are required to manage, protect and rehabilitate springs.

Scarsbrook, M.; Barquín, J.; Gray, D. 2007: New Zealand coldwater springs and their biodiversity. *Science for Conservation 278.* 72 p.

New Zealand Government