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72196 Introduction to New Zealand Ecology

Assignment 2

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1 Coastal Dunes

1.1 Introduction

To many people coastal sand dunes are probably the most nondescript ecosystems of New Zealand. Close to the beach, active dune systems appear to be plain mounds of sand which are grown over by grass; further inland stable dunes may seem to be no more than mere wilderness. Dunelands, however, belong to New Zealand's most endangered habitats (M. J. Hilton, 2006)—partly because their ecological value has long not been recognized. This essay aims to provide an overview of the coastal sand dunes of New Zealand, and discuss the threats that human activity poses to these unique habitats.

1.2 Description

Where on-shore winds sweep over sandy beaches, sand is carried landward and accumulates as mounds when wind speeds are reduced (Packham & Willis, 1997, p. 158). In the presence of sand-binding plants, these sand drifts can grow in size and may stretch over many kilometres along New Zealand's beaches (Wardle, 1991). Dune systems can be divided into three parts: the sandy foredune (closest to the sea), sand plains and dune hollows (inland behind the foredune), and rear dunes which—dependent on age—may support podocarp forests (DiBona, Williams, Buxton, & Forgie, 2011). Waves and strong winds can erode the foredune, allowing beach sand to blow farther inland (Wardle, 1991, p. 350). These so-called blowouts are a first stage in the formation of parabolic dunes, a curved mound of sand with two vegetated arms reaching towards the sea (Codrington, 2005, p. 201).

1.3 Distribution

The first recorded survey of sand dunes in New Zealand's was conducted by Cockayne (1911) and estimated the total dune area of New Zealand to be around 127,000 ha, with more than 90% located on the North Island. M. J. Hilton (2006) states that through the 20^{th} century the total area of active duneland has been reduced to only about 30% of its extent in the early 1900s, citing dune stabilization and following afforestation as the major cause for the decline. The largest areas of active coastal duneland are now found along the coast in Manawatu, Auckland and Northland (M. Hilton, Macauley, & Henderson, 2000).

Stable sand dunes are older dunes that have migrated inland for thousands of years (DiBona et al., 2011). According to DiBona et al. (2011) only few unmodified stable dune ecosystems remain as many were affected by agricultural land use. Stable dune systems can be found in Manawatu and in Southland, which are dominated by vegetation in a late stage of succession (DiBona et al., 2011).

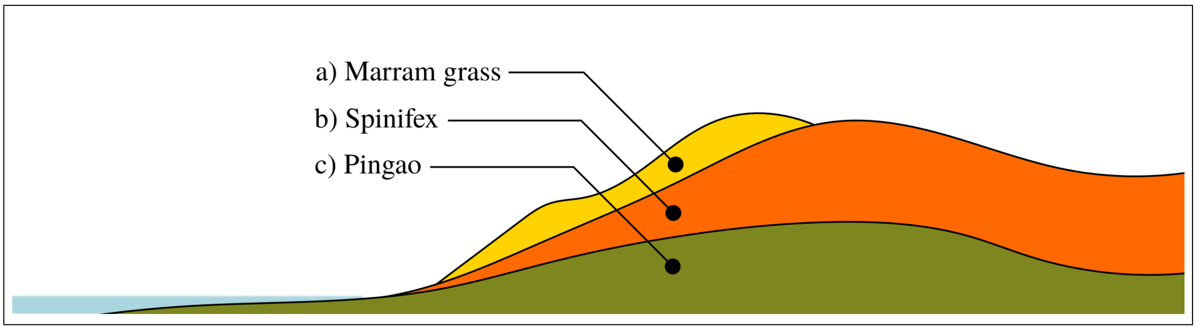

Figure 1: Generalised profiles of foredunes resulting from the growth forms of the three primary colonisers *(a)* marram grass *(b)* spinifex, and *(c)* pingao. Based on Esler (1970), Figure 2.

1.4 Environmental effects and vegetation zones

Early colonisers of the seaward slope of the foredune stabilise the shifting sands with their long root networks and slow down on-shore winds, thus favouring the deposition of more dry sand (Auckland Regional Council, 2007). Not far from the shore, sand dunes are exposed to strong, saline coastal winds and are occasionally eroded by high waves. Plants colonising the foredune hence must *(a)* be able to tolerate salt spray (Codrington, 2005, p. 201); *(b)* be adapted to withstand sand blast by strong winds (Esler, 1970); *(c)* withstand covering with sand and the uncovering of roots by winds (Esler, 1970) *(d)* resist soil erosion by spring tides; *(e)* be able to thrive in nutrient-poor, dry and saline soils (Clayton, 1972; van der Valk, 1974). These conditions limit the number of plant species that can establish themselves on the foredune. Only three plant species are prominent on New Zealand's foredunes: the native grass spinifex (*Spinifex sericeus*), the native, threatened sedge pingao (*Desmoschoenus spiralis*) and the introduced marram grass (*Ammophila arenaria*). Experiments by Maze and Whalley (1992) have demonstrated the extent of spinifex's adaptation to these harsh conditions, as it derives nutrients from salt spray and grows even more vigorously when partially buried in foredune sands. The growth forms of these different colonisers influence the way sand is deposited on the dune slope by affecting wind patterns and thereby determine the topography of a dune (Wardle, 1991, p. 352). See Figure 1.

Behind the foredune the environmental conditions are less limiting to plants as these areas are sheltered from strong on-shore winds and waves. The vegetation that dominates the backdune can be divided into zones (see Figure 2) with increasing distance to the sea (Asplin & Fuller, 1985–1986): *(a)* shrubland dominated by tauhinu (*Ozothamnus leptophylla*[1]) and *Coprosma* spp.; *(b)* sand-plains and hollows; and *(c)* an old forested zone dominated by podocarps.

[1]formerly *Cassinia leptophylla* (Breitwieser & Ward, 1997)

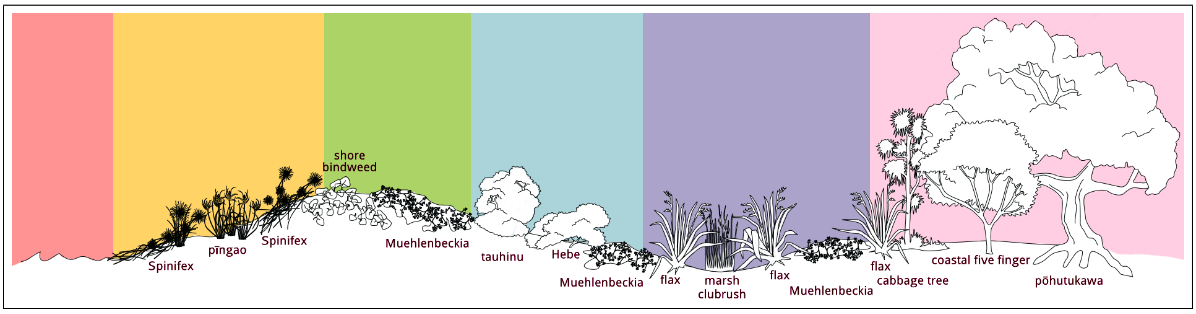

Figure 2: Vegetation zones of a typical coastal dune. Sandy beach; foredune (sea-facing slope); foredune (crest and lee slope); shrubland; plains and hollows; forested rear dune. Adapted from Auckland Regional Council, 2007.

1.5 Native fauna

Seventeen native bird species are associated with the dune systems in Wellington Conservancy. Seven of eight using dune systems as breeding sites (Milne & Sawyer, 2002, p. 47) are assigned a risk category under the New Zealand Threat Classification System (see Table 1). An example for a bird at risk nesting on sand dunes close to the beach is the Little Blue penguin (*Eudyptula minor*). The recreational use of beaches by humans exposes the penguins to predation by dogs and increases the likelihood of car-related fatalities (Braidwood, 2009).

Dunes also provide habitat for a number of lizard species. The 'common' skink *Oligosoma maccanni* for example is in some places almost exclusively found in dunelands (Freeman, 1997). Other skink species (e.g. *O. lineoocellatum* and *Cyclodina* spp.) inhabit the scrubland or grassland zones of dunes (Towns, Neilson, & Whitaker, 2002; Towns, 1999).

According to Stephenson (1999), the invertebrate flora of New Zealand's dunes is rather poorly documented and information about the number of species that solely depend on dune systems is limited. Associated with dune habitats are two notable threatened species: the flightless Cromwell chafer beetle (*Prodontria lewisi*) living in stabilised sand dunes and the red katipo spider (*Latrodectus katipo*) living in coastal sand dunes. Both species had to suffer decline due to the modification of dunes (Watt, 1979; Patrick, 2002).

1.6 Anthropogenic effects

It is difficult to say exactly what New Zealand's dunelands looked like before the arrival of humans as the earliest surveys were conducted not until the first decades of the 20th century. It is not known whether the duneland area measured then represented the 'natural state' (M. Hilton et al., 2000). Hesp (2001), for example, associates the extinction of dune inhabiting animals due to hunting by Maori with a change in vegetation cover on the Manawatu dunes, destabilising them and promoting migration inland. Generally, though, it is believed that the occupation by Maori only had localised effects (M. Hilton et al., 2000).

Research during the 20th century, has shown that human activities are responsible for the dramatic reduction of the area of active duneland in New Zealand since the 1950s (M. Hilton

Table 1: The conservation status of endemic New Zealand birds associated with dune systems in Wellington. Adapted from Miskelly et al. (2008) and Milne and Sawyer (2002).

Scientific name	**Status**	**Breeding on dunes?**
Ardea novaehollandiae	Not Threatened	No
Circus approximans	Not Threatened	No
Halcyon sancta	Not Threatened	No
Hirundo tahitica	Not Threatened	No
Larus dominicanus	Not Threatened	Yes
Phalacrocorax carbo	Naturally Uncommon	No
Rhipidura fuliginosa	Naturally Uncommon	No
Sterna caspia	Not Threatened	Yes
Vanellus miles	Not Threatened	No
Zosterops lateralis	Not Threatened	No
Anthus novaeseelandiae	At Risk — Declining	Yes
Charadrius bicinctus	Nationally Vulnerable	Yes
Eudyptula minor	At Risk — Declining	Yes
Haematopus unicolor	At Risk — Recovering	Yes
Himantopus himantopus	At Risk — Declining	No
Larus novaehollandiae	Nationally Vulnerable	Yes
Sterna striata	At Risk — Declining	Yes

et al., 2000). The largest losses were recorded in those regions with originally vast areas of active duneland, such as Northland, Auckland, Manawatu and Waikato. As M. Hilton et al. (2000) note, this reduction is correlated to the afforestation of sand dunes by the New Zealand Forest Service.

Most of the active dunelands that remain have been heavily modified and only few dunes have retained their natural state (M. Hilton et al., 2000). According to Wardle (1991, p. 356), most of the western dunes in Northland have been planted in marram. The successful sand-binder has ousted native plants, such as the declining pingao, on many dunes. Originally introduced as a nitrogen fixer for marram, lupin (*Lupinus aboreus*) shades and thus limits the growth of native plants (Department of Conservation, 2005).

The change of vegetation also affects the dune fauna. Marram grass forms clumps that funnel winds, which erode the dune quicker (Esler, 1970; Esler, 1978), thereby reducing suitable habitat for dune fauna. Disturbance through recreational use (through dune surfing or the use of vehicles), habitat loss through residential development or grazing by animal pests (Department of Conservation, 2003), and sand mining are further threats to dune inhabitants (cf. Stephenson, 1999; Patrick, 2002; Braidwood, 2009).

1.7 Conclusions

The management of dunes has changed from efforts to stabilise them for productive land use to minimizing disturbance. Where previously marram grass was planted, now efforts are made to control its spread and replace it with native species (Bergin & Kimberley, 1999). Many native species depend on the ever-decreasing area of dunelands for habitat and breeding, and for some species like the katipo spider survival is contingent upon the protection and restoration of dunelands. As many threats to dune communities are the consequence of ignorance or carelessness, the protection of dunes and education about their importance must be a community effort to be successful.

1.8 References

Asplin, S., & Fuller, J. (1985–1986). Study of dune plant communities at the mouth of the Waipoua river. *TANE*, *31*.

Auckland Regional Council. (2007, October 16). Coastal Planting Guide: Dunes. Retrieved 23 August 2011, from `http://www.arc.govt.nz/albany/fms/main/Documents/Environment/Plants%20and%20animals/coastal%20planting%20guide%202.pdf`

Bergin, D., & Kimberley, M. (1999). *Rehabilitation of coastal foredunes in New Zealand using indigenous sand-binding species* (Science for conservation No. 122).

Braidwood, J. (2009). *Breeding biology and threats to the blue penguin (Eudyptula minor) in South Westland, New Zealand.* (Master's thesis, Lincoln University, Christchurch, New Zealand).

Breitwieser, I., & Ward, J. (1997). Transfer of *Cassinia leptophylla* (Compositae) to *Ozothamnus*. *New Zealand Journal of Botany*, *35*, 125–128. Retrieved from `http://www.royalsociety.org.nz/media/publications-journals-nzjb-1997-008.pdf`

Clayton, J. L. (1972). Salt spray and mineral cycling in two california coastal ecosystems. *Ecology*, *53*(1), 74–81. doi:`10.2307/1935711`

Cockayne, L. (1911). Report on the duneareas of New Zealand, their geology, botany, and reclamation. In *Appendices to House of Representatives, N.Z.*

Codrington, S. (2005). *Planet geography* (3rd ed.). Solid Star Press.

Department of Conservation. (2003, March). Coastal foredunes vegetation in Wellington factsheet. Retrieved from `http://www.doc.govt.nz/upload/documents/conservation/marine-and-coastal/coastal-management/coastal-foredunes-in-wgtn.pdf`

Department of Conservation. (2005). Pikao (or Pingao) the Golden Sand Sedge. Retrieved 31 August 2011, from `http://www.doc.govt.nz/publications/conservation/native-plants/pikao-or-pingao-the-golden-sand-sedge/threats-to-pikao/`

DiBona, M., Williams, P., Buxton, R., & Forgie, S. (2011). Stable sand dunes. Retrieved 23 August 2011, from `http://www.landcareresearch.co.nz/research/ecosystems/rare/ecosystem_details.asp?Rare_Ecosystem_ID=23`

Esler, A. (1978). *Botany of the Manawatu District New Zealand*. E.C. Keating, Govt. Printer.

Esler, A. (1970). Manawatu sand dune vegetation. In *Proceedings of the New Zealand Ecological Society* (Vol. 17, pp. 41–46).

Freeman, A. B. (1997). Comparative ecology of two *Oligosoma* skinks in coastal Canterbury: a contrast with Central Otago. *New Zealand Journal of Ecology*, *21*(2), 153–160.

Hesp, P. A. (2001). The manawatu dunefield: environmental change and human impacts. *New Zealand Geographer*, *57*(2), 33–40. doi:`10.1111/j.1745-7939.2001.tb01607.x`

Hilton, M. J. (2006). The loss of New Zealand's active dunes and the spread of marram grass (*Ammophila arenaria*). *New Zealand Geographer*, *62*, 105–120.

Hilton, M., Macauley, U., & Henderson, R. (2000). *Inventory of New Zealand's active dunelands* (Science for Conservation No. 157).

Maze, K. M., & Whalley, R. D. B. (1992). Effects of salt spray and sand burial on *Spinifex sericeus* R. Br. *Australian Journal of Ecology*, *17*(1), 9–19. doi:`10.1111/j.1442-9993.1992.tb00775.x`

Milne, R., & Sawyer, J. (2002). *Coastal foredune vegetation in Wellington Conservancy: Current status and future management*.

Miskelly, C., Dowding, J., Elliott, G., Hitchmough, R., Powlesland, R., Robertson, H., … Taylor, G. (2008). Conservation status of New Zealand birds, 2008. *Notornis*, *55*, 117–135.

Packham, J., & Willis, A. (1997). *Ecology of dunes, salt marsh and shingle*. Chapman & Hall. Retrieved from `http://books.google.com/books?id=NK3tqmld12QC`

Patrick, B. (2002). *Conservation status of the New Zealand red katipo spider (Latrodectus katipo Powell, 1871)* (Science for conservation No. 194).

Stephenson, G. (1999). *Vehicle impacts on the biota of sandy beaches and coastal dunes: A review from a New Zealand perspective* (Science for conservation No. 121).

Towns, D. R. (1999). *Cyclodina spp. skink recovery plan 1999–2004* (Threatened species recovery plan series No. 27).

Towns, D. R., Neilson, K. A., & Whitaker, A. (2002). *North Island Oligosoma spp. skink recovery plan 2002–2012* (Threatened species recovery plan series No. 48).

van der Valk, A. G. (1974). Mineral Cycling in Coastal Foredune Plant Communities in Cape Hatteras National Seashore. *Ecology*, *55*(6), 1349–1358.

Wardle, P. (1991). *Vegetation of New Zealand*. Cambridge University Press. Retrieved from `http://books.google.com/books?id=iwc8AAAAIAAJ`

Watt, J. (1979). Conservation of the Cromwell chafer *Prodontria lewisi* (Coleoptera: Scarabaeidae). *New Zealand Journal of Ecology*, *2*, 22–29.

2 Rivers and streams

2.1 Introduction

The rivers and streams of New Zealand and associated vegetation zones provide habitat and sustenance for a great number of native species. Flowing through diverse geographic formations and at varying flow rates, a single river often comprises a number of unique habitats that different species—some of which are found nowhere else—are adapted to and thrive in. The many subtle factors that influence the composition of any river habitat and the sometimes very high degree of specialisation of inhabiting species, however, also mean that these ecosystem are rather intolerant to modification caused directly by land development or indirectly through human land use. This essay aims to provide an overview of the diverse habitats of river ecosystems and discuss the effects human activities have on them.

2.2 Characteristics

As a river flows from the mountains to the sea it passes through a variety of different landscapes which determine its characteristics and the properties of its riparian and aquatic habitat zones. The relation between streams and physical conditions is not trivial and in recent decades many different models have been proposed to describe river networks. The *riverine ecosystem synthesis* as presented by Thorp, Thoms, and Delong (2006, p. 126) describes rivers as “downstream arrays of large hydrogeomorphic patches formed by catchment geomorphology and flow characteristics”. According to Thorp et al., such patches are described by their composition of environmental conditions, such as climatic influences, flow regimes, geomorphological features as well as riparian and aquatic vegetation. Based on these variables Biggs et al. (1990) divide New Zealand’s rivers into five “ecoregions” with distinctive features (see Table 2). The braided rivers on the South Island, however, defy classification at such large scale as their dynamic landscape represents a “mosaic of micro-habitats” (Gray, Scarsbrook, & Harding, 2006) resulting in a high degree of biodiversity.

2.3 Plant communities

The plant communities associated with rivers are divided in *riparian vegetation*, i.e. plants on the shore and further uphill within the catchment, and *aquatic vegetation*, the plants growing in or on the water.

The **aquatic vegetation** of New Zealand’s rivers and streams is composed of algae and macrophytes. Algae are single-celled organisms capable of photosynthesis that are either on their own or organised in chains (Fleet, 1986, p. 141). Blue-green algae (or cyanobacteria) actually are ancient photosynthetic bacteria and are very tolerant to adverse environmental conditions (Whitton & Potts, 2000, pp. 1–3). Cyanobacteria are known to produce toxins

Table 2: Ecoregions of New Zealand's rivers and their distinctive features according to Biggs et al. (1990).

Ecoregion	Features
Northern	low-moderate mean catchment elevation moderate enrichment moderate-high mean annual water temperatures
Central	high mean elevation high amounts of volcanic ash low-conductivity waters low variability of flow
Eastern	moderate–high amounts of sedimentary rock high conductivities and enrichment high flow variability
South-western	small catchment size low amounts of pasture low conductivity
Southern	high catchment elevation low water temperatures high amounts of hard sedimentary rock low conductivity and enrichment

Table 3: An overview of the influence of riparian vegetation on the aquatic zone and the functions of vegetation for the riparian zone (cf. Collier et al., 1995, p. 11).

Feature	Location	Function
Dense roots	Banks	Reducing *sediment inputs* through bank stabilisation
	Slope	*Nutrient* reduction through filtering
Trees and Shrubs	Banks	Regulating *water temperature* and *plant growth* rates through shading
	Banks	Source of *leaf litter*
	Slope	Reduction of *runoff velocity*
	General	*Habitat* for associated fauna

which have potential harmful effects on other organisms associated with the riparian habitat (Whitton & Potts, 2000, p. 150).

The group of macrophytes includes bryophytes and vascular plants, such as aquatic ferns and angiosperms. The latter may take root in soft-bottomed streams while the former often float freely on the surface (Reeves, Collier, & Suren, 2004, p. 14.6). Only few submerged or floating plant species are indigenous (Fleet, 1986, p. 143).

Riparian vegetation influences stream conditions, such as nutrient concentration and water temperatures (see Table 3). Due to the number of properties affected by riparian vegetation, the extent of the riparian zone is rather fuzzy. Except the plants growing between low and high water marks, it may also include vegetation that provides habitat for fauna associated with the aquatic zone (Reeves et al., 2004, p. 14.4). The wide range of plants inhabiting the riparian zone includes native ferns, shrubs such as manuka (*Leptospermum scoparium*) and large trees such as kahikatea (*Dacrycarpus dacrydioides*). Figure 3 shoes typical vegetation of the riparian zone.

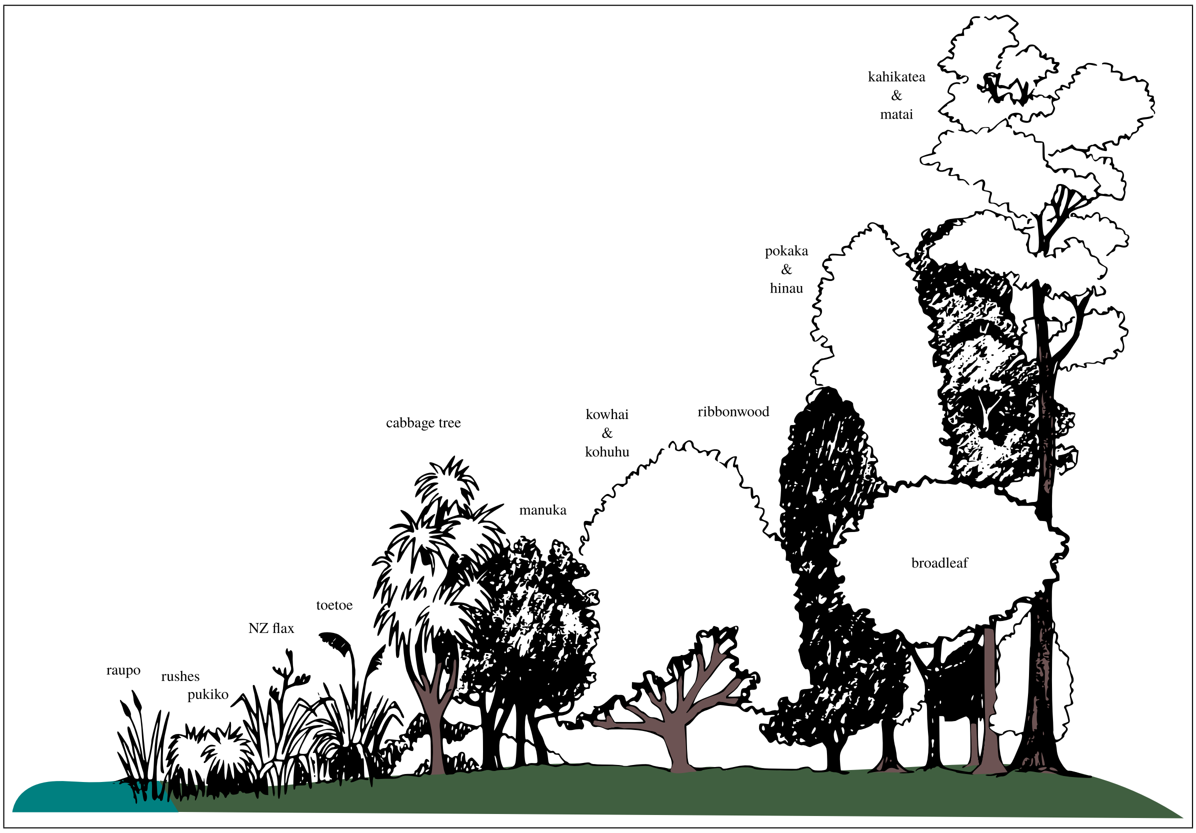

Figure 3: Typical mature riparian vegetation. Adapted from Davis and Meurk (2001)

2.4 Fauna

The invertebrate fauna of New Zealand's rivers is markedly different from those elsewhere in the world. While food partitioning and specialisation can be observed in many rivers of North America, New Zealand's diverse topography and the quickly changing climatic conditions it gives rise to has favoured opportunistic invertebrate communities with flexible life histories (Winterbourn, Rounick, & Cowie, 1981). According to Winterbourn et al. (1981), 44% of New Zealand's invertebrate genera are browsers feeding on plant debris. Research by Usio and Townsend (2001) has shown that leaf litter decomposition in headwater streams is almost exclusively performed by crayfish (*Paranephrops zealandicus*). Invertebrate predators are found in both aquatic and riparian zones. The Dobsonfly larvae, for example, are common aquatic predators (Winterbourn & Gregson, 1981). On the edge of the water nocturnal spiders of the genus *Dolomedes* angle for invertebrates. They can float on water and for short periods even get underwater (Fleet, 1986, p. 156).

Only about 30 species of native fish inhabit New Zealand's rivers; most of them are endemic (Fleet, 1986, p. 157). Fish are mainly predators to invertebrates but larger specimens of the two species of eel (*Anguilla* spp.) also feed on other fish and even small birds (Marples, 1962, p. 138). Many of these fish species, like some galaxiids (*Galaxias* spp.) and the eels, are diadromous and migrate upstream as juveniles after early development in the sea (Fleet, 1986, p. 157).

More than 160 bird species are associated with New Zealand's freshwater rivers and many species have evolved special adaptations for spending most of their lives on rivers (O'Donnell, 2004). While only few of them are restricted to river habitats, all spend important periods of their life histories on or near rivers (O'Donnell, 2004). Many of these birds feed on invertebrates, but some like the Black Shag (*Phalocrocorax carbo*) also feed on eels and other fish (Falla & Stokell, 1945).

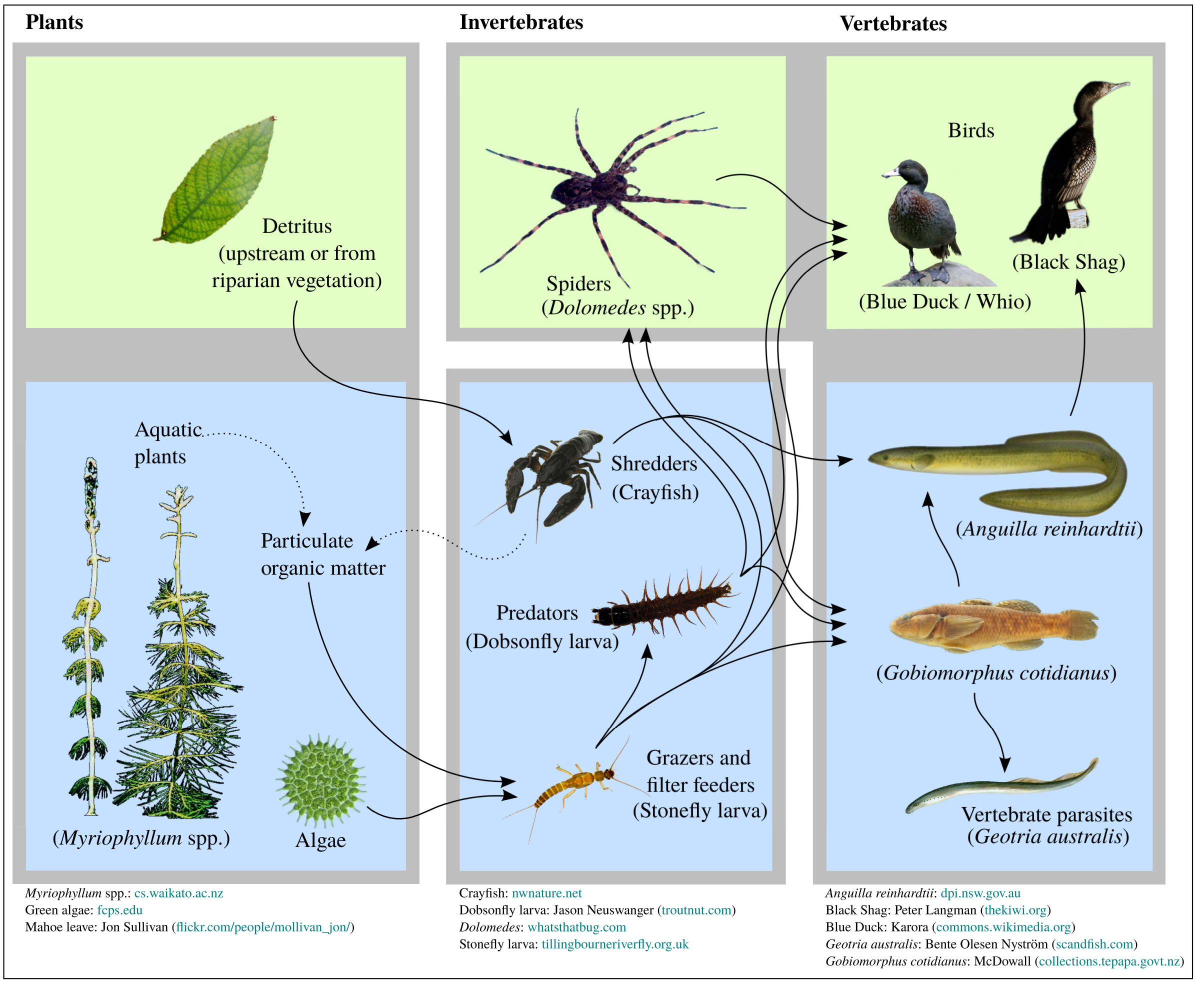

Figure 4: A generalised food web of a typical New Zealand river. Blue shading indicates that species inhabit the aquatic zone, green indicates the riparian zone.

2.5 Anthropogenic effects

Before human settlement, New Zealand was covered by indigenous forests whose large trees shaded most of the rivers. By 1875 much of the original forest had been cleared (Vogel, 1875, p. 188) and continued deforestation throughout the 20th century has left two thirds of the land with less than 30% of indigenous vegetation cover (Walker, Price, Rutledge, Stephens, & Lee, 2006). As riparian vegetation strongly influences the characteristics of a stream (see section 2.3), its loss changed the environmental conditions for inhabiting species. Bush clearance has had detrimental effects on birds nesting close to the water's edge like the New Zealand Scaup (*Aythya novaeseelandiae*), and fish that depend on well-shaded waters like the galaxiids (Fleet, 1986, pp. 157,161). Increased water temperatures, runoff quantities and accelerated flow can affect a wide range of interdependent river functions and may lie outside the narrow tolerance of some invertebrates and plants (Knight & Bottorff, 1984).

Light conditions in unshaded rivers also favour the growth of algae. In combination with increased nutrient levels caused by the runoff from agricultural lands and the lack of nutrient filtering through plants in the riparian zone, the limits on aquatic primary production are virtually lifted (Knight & Bottorff, 1984). During blooms algae can form large mats on the water surface (Whitton & Potts, 2000, p. 150), blocking sunlight and inhibiting oxygen entry into the water (Fleet, 1986, p. 142). Pesticides used in agriculture also find their way into rivers through runoff waters where they may, according to Relyea (2005), reduce overall biodiversity of aquatic communities. River banks that have been cleared of vegetation are prone to erosion resulting in an increase of sediments (Bennett & Selby, 1977), affecting flow patterns and water clarity.

As Woolmore and Sanders (2005) state, exotic plants quickly displace native plant communities, reduce nesting habitat for birds on exposed river beds and reduce water flow speeds. Introduced predators like cats represent a major threat to birds nesting in the riparian zone (Woolmore & Sanders, 2005). Aquatic communities also suffer from introduced fish. The feeding habits of the koi carp (*Cyprinus carpio*), for example, destroy native aquatic species and their habitat (Koehn, Brumley, & Gehrke, 2000, p. 55).

River engineering is a direct way by which humans modify river environments. Dams for hydro-electric power generation represent insurmountable obstacles to the many migratory species of fish, reducing their reproductive success (M. C. Freeman, Pringle, Greathouse, & B. J. Freeman, 2003). Channel straightening increases flow velocity, which may lead to erosion of river bed sediments (Erskine, 1992).

2.6 Conclusions

New Zealand's river and stream ecosystems are of great importance to native flora and fauna. These ecosystems have sustained considerable damage as a consequence of agriculture and forestry since human settlement. Due to complex interactions between the many characteristics of river ecosystems it is hard to accurately predict their response to modification. Hence, sustainable human land use is a requirement in order for the protection and restoration of these environments to have a lasting effect.

2.7 References

Bennett, J., & Selby, M. (1977). Induced channel instability and hydraulic geometry of the Mangawhara stream New Zealand. *New Zealand Journal of Hydrology*, *16*(2), 134–147.

Biggs, B. J. F., Duncan, M. J., Jowett, I. G., Quinn, J. M., Hickey, C. W., Davies-Colley, R. J., & Close, M. E. (1990). Ecological characterisation, classification, and modelling of New Zealand rivers: An introduction and synthesis. *New Zealand Journal of Marine and Freshwater Research*, *24*(3), 277–304. doi:10.1080/00288330.1990.9516426

Collier, K., Cooper, A., Davies-Colley, R., Rutherford, J., Smith, C., & Williamson, R. (1995). *Managing riparian zones: a contribution to protecting New Zealand's rivers and streams* (Science Investigation No. 983).

Davis, M., & Meurk, C. (2001). *Protecting and restoring our natural heritage — a practical guide*. Retrieved 3 September 2011, from http://www.doc.govt.nz/publications/conservation/protecting-and-restoring-our-natural-heritage-a-practical-guide/native-ecosystems-and-their-management/

Erskine, W. D. (1992). Channel response to large-scale river training works: hunter river, Australia. *Regulated Rivers: Research & Management*, *7*(3), 261–278. doi:10.1002/rrr.3450070305

Falla, R., & Stokell, G. (1945). Investigation of the Stomach Contents of New Zealand Freshwater Shags. In *Transactions of the Royal Society of New Zealand* (Vol. 74, *4*, pp. 320–331).

Fleet, H. (1986). *The concise natural history of New Zealand*. Auckland, New Zealand: Heinemann.

Freeman, M. C., Pringle, C. M., Greathouse, E. A., & Freeman, B. J. (2003). Ecosystem-Level Consequences of Migratory Faunal Depletion Caused by Dams. *American Fisheries Society Symposium*, *35*, 255–266.

Gray, D., Scarsbrook, M. R., & Harding, J. S. (2006). Spatial biodiversity patterns in a large New Zealand braided river. *New Zealand Journal of Marine and Freshwater Research*, *40*(4), 631–642. doi:10.1080/00288330.2006.9517451

Knight, A., & Bottorff, R. (1984). *The importance of riparian vegetation*. University of California Press. Retrieved from http://books.google.com/books?id=UhjbO_CC_VoC

Koehn, J., Brumley, A., & Gehrke, P. (2000). *Managing the Impacts of Carp* (M. Bomford, Ed.). Bureau of Rural Sciences (Department of Agriculture, Fisheries and Forestry – Australia), Canberra.

Marples, B. (1962). *An introduction to freshwater life in New Zealand*. Whitcombe and Tombs. Retrieved from `http://books.google.com/books?id=0FfwAAAAMAAJ`

O'Donnell, C. (2004). *River bird communities* (J. Harding, P. Mosley, C. Pearson & B. Sorrell, Eds.). New Zealand Hydrological Society; New Zealand Limnological Society.

Reeves, P., Collier, K., & Suren, A. (2004). *Aquatic and riparian vegetation of rivers and streams* (J. Harding, P. Mosley, C. Pearson & B. Sorrell, Eds.). New Zealand Hydrological Society; New Zealand Limnological Society.

Relyea, R. A. (2005). The impact of insecticides and herbicides on the biodiversity and productivity of aquatic communities. *Ecological Applications*, *15*(2), 618–627.

Thorp, J. H., Thoms, M. C., & Delong, M. D. (2006). The riverine ecosystem synthesis: biocomplexity in river networks across space and time. *River Research and Applications*, *22*(2), 123–147. doi:`10.1002/rra.901`

Usio, N., & Townsend, C. R. (2001). The significance of the crayfish *Paranephrops zealandicus* as shredders in a New Zealand headwater stream. *Journal of Crustacean Biology*, *21*(2), 354–359.

Vogel, J. (1875). *The official handbook of New Zealand: a collection of papers by experienced colonists on the colony as a whole and on the several provinces*. Printed for the Government of New Zealand by Wyman & Sons. Retrieved from `http://books.google.com/books?id=XMwNAAAAQAAJ`

Walker, S., Price, R., Rutledge, D., Stephens, R., & Lee, W. G. (2006). Recent loss of indigenous cover in New Zealand. *New Zealand Journal of Ecology*, *30*(2), 169–177.

Whitton, B., & Potts, M. (2000). *The ecology of cyanobacteria: their diversity in time and space*. Kluwer Academic. Retrieved from `http://books.google.com/books?id=O_q5c8L-L2IC`

Winterbourn, M. J., & Gregson, K. L. D. (1981). Guide to the aquatic insects of New Zealand. *Bulletin of the Entomological Society of New Zealand*, *5*, 80 p.

Winterbourn, M. J., Rounick, J. S., & Cowie, B. (1981). Are New Zealand stream ecosystems really different? *New Zealand Journal of Marine and Freshwater Research*, *15*(3), 321–328. doi:`10.1080/00288330.1981.9515927`

Woolmore, C., & Sanders, M. (2005). *Project River Recovery — Strategic plan 2006–2012* (Project river recovery report No. 04/05).