

Conservation and the delivery of ecosystem services

A literature review

Kate G. McAlpine and Debra M. Wotton

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ABSTRACT

Ecosystem services are the benefits people obtain from ecosystems, such as clean air, fresh water, and the pollination of crops. The aim of this literature review was to find empirical data illustrating the ways in which conservation land and conservation management activities affect ecosystem services. The widely-held belief that natural ecosystems—such as those found on conservation land in New Zealand—provide a range of ecosystem services is generally supported by the literature. International studies show that natural vegetation can decrease air pollution, regulate local air temperatures, improve water quality, reduce shallow soil erosion, and retain natural nutrient cycles. It can also be beneficial for pest control and pollination on agricultural land. Wetlands can improve water quality and can play a role in drought and flood mitigation. Seagrasses, saltmarsh vegetation, and mangroves can reduce the height and force of waves and play a role in flood protection. In addition, maintaining biodiversity preserves genetic libraries and future options for discoveries of valuable biological compounds. The few studies investigating the effects of conservation management activities on ecosystem services indicate that restoring vegetation can improve water quality and water storage functions, can reverse soil degradation on a local scale, and can restore plant-insect interactions. Additionally, removing some invasive plant species can increase water yield. Unfortunately, very few studies of ecosystem services have been conducted in New Zealand to date, and only some of the international results are likely to be applicable under New Zealand conditions. Accordingly, while conservation is probably beneficial for a range of ecosystem services in New Zealand, the scarcity of local data makes it difficult to ascertain where and when, and to what extent, the majority of those benefits transpire.

Keywords: ecosystem services, air, climate, water, soil, pest control, disease regulation, pollination, natural hazard protection, nutrient cycling, fish stocks, biodiversity, conservation management, natural habitat, restoration

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1. Introduction to ecosystem services

Ecosystems can be defined as dynamic collections of plants, animals, and microorganisms interacting with each other and their abiotic environment. Ecosystem services are the benefits people obtain from ecosystems (Daily et al. 1997a). These benefits (ecosystem services) are commonly classified as being one of four types: provisioning, regulating, cultural, or supporting (Table 1) (MA 2005). Human survival and well-being depends utterly on these ecosystem services, and thus on the health of the ecosystems that provide them (Daily 1997; Costanza et al. 1998).

TABLE 1. ECOSYSTEM SERVICES AS CLASSIFIED BY THE MILLENIUM ECOSYSTEM ASSESSMENT (MA 2005).

CATEGORY	EXAMPLES
Provisioning	Food, fibre, water, fuel, genetic resources
Regulating	Air quality, climate, water flow, pollination, erosion control, pest and disease control
Cultural	Spiritual, aesthetic, recreational, educational
Supporting	Photosynthesis, soil formation, nutrient cycling

In general, natural, intact ecosystems provide the best ecosystem services. The Department of Conservation (DOC) manages 30% of the land area in New Zealand, and most of this DOC-managed land consists of natural, intact ecosystems and habitat. Accordingly, there is great potential for this land, and DOC's management of it, to be beneficial for ecosystem services in New Zealand. However, the ways in which conservation land and conservation management activities affect ecosystem services are not well understood or documented, so the

characteristics of these benefits—and where they occur—are largely unknown. This literature review is the first step in addressing this information gap, with the primary aim being to find out exactly how much is known (in the empirical sense) about the impacts of conservation on ecosystem services. This information may also enable the development of a new focus for conservation advocacy in New Zealand: the idea that conservation is beneficial for New Zealanders because it provides 'services' such as clean water, fresh air, and productive soils. If DOC can show that the general public benefits from conservation in this way, it may gain wider public support for its work. This novel focus requires a high level of confidence that such statements are in fact true. This literature review aims to sort out myth from reality, and pinpoint exactly what can and cannot be proclaimed about the impacts of conservation on ecosystem services.

The review focuses largely on the ecosystem services that are most likely to be affected by conservation activities, but are least likely to be within the realms of general public awareness. Accordingly, the review covers a subset of regulating and supporting ecosystem services (Table 1): air quality, climate regulation, water quality, quantity and flow, soil fertility and stability, pest and disease regulation, pollination, natural hazard protection, and nutrient cycling. One provisioning service—fish stocks—was included in the review, since this is a major issue in the marine environment, and one that is potentially affected by DOC's work in managing marine reserves. The harvest of exotic species such as deer and possums (*Trichosurus vulpecula*) could be considered another provisioning service that is potentially affected by the presence of conservation land. However, because one of the primary purposes of the review was to seek information that could be

used for conservation advocacy purposes, we did not include services that were contrary to conservation goals. A section on biodiversity is also included because a large component of DOC's role is the protection and management of biodiversity, and many scientists consider biodiversity to be an ecosystem service in itself. The review does not cover issues relating to carbon sequestration or climate change mitigation, since these topics are part of other DOC investigations currently underway. Terrestrial, freshwater, and marine ecosystems are all included in the review.

The ecosystem services included in this review span a vast topic range, and thus have an extensive literature. As a result, the list of search terms we used was lengthy (varying with the specific terminology associated with each ecosystem service). Because of this, the list is not included here. The search for relevant material was largely restricted to peer-reviewed published studies, although some 'grey' literature, where relevant and of sufficient quality, was also included. Particular emphasis was placed on locating New Zealand studies, but international evidence was also sought. New Zealand studies are identified as such in the text, but the country of origin for international studies is only identified when this is relevant. Most studies were located by using a range of search terms within the web-based database Google Scholar. Further relevant literature was frequently revealed by the references cited within these studies. Specific websites were searched in order to locate New Zealand studies; namely, those of Landcare Research, NIWA (National Institute of Water and Atmospheric Research), and DOC. A number of New Zealand scientists, both internal and external to DOC, were also consulted for advice on current research and relevant information for many of the topic areas. Additional information was found by conducting further, more general, web searches in Google. The literature search was largely completed by December 2008, although several papers published after this date were identified during the review process and the text was updated accordingly.

Two different scenarios were considered whilst searching the literature. Firstly, we looked for quantitative evidence showing that intact, natural ecosystems (as found on conservation land in New Zealand) provide ecosystem services. In other words, we looked for evidence that conservation land is beneficial for ecosystem services simply because it exists in a relatively undisturbed state. Secondly, we looked for quantitative evidence showing that conservation activities other than land protection (such as pest control and habitat restoration) affect the provision of ecosystem services. (Hereafter, these are called conservation management activities.) Substantial, reliable evidence under either scenario could be used to demonstrate how the protection of conservation land and/or the management of that land can provide benefits to New Zealanders in the form of ecosystem services.

2. Air

2.1 INTRODUCTION

Vegetation can improve air quality in a range of different ways, so there is potential for the forests and shrublands present on New Zealand conservation land to be beneficial in this respect. Conservation management activities might also affect air quality—albeit indirectly—if those activities impact on the ability of the vegetation to improve air quality in some way. For example, possum control might improve the condition of the canopy which, in turn, might improve the potential for pollutant interception. For this section we sought studies that quantify the ways in which vegetation affects air quality, and how and when it varies.

2.2 POLLUTION REDUCTION

There is widespread agreement in the literature that vegetation, especially trees, decreases air pollution concentrations both directly and indirectly. Plants absorb gaseous air pollutants mostly through stomata (pores) in their leaves. Airborne particles are physically intercepted and collect on plant surfaces (Nowak & Dwyer 2000). Some particles are then absorbed, but most are retained on plant surfaces and can be washed off by rain, dropped to the ground with leaves and twigs, or resuspended to the atmosphere (Nowak & Dwyer 2000). The degree of air pollution reduction varies depending on vegetation type, plant species, canopy extent, air pollutant characteristics, and local meteorological conditions (Fowler et al. 1999; Beckett et al. 2000; Nowak & Dwyer 2000; Freer-Smith et al. 2004). Computer simulations revealed that air pollution removal by trees in 14 cities in the USA ranged from 19 to > 1500 tonnes per year (Nowak & Dwyer 2000).

Air quality improvement by trees tends to increase as percentage tree cover increases (Nowak & Dwyer 2000; Jim & Chen 2008). In Guangzhou city in China, removal of sulphur dioxide, nitrous oxide and particulates by vegetation was estimated at 312.03 Megagrams per annum, with greater removal in areas with more trees (Jim & Chen 2008). In an effort to reduce air pollution for the 2008 Olympic Games, Chinese officials planted millions of trees covering an area of approximately 682 ha—or twice the size of Central Park in New York (Dominion Post, 23 July 2008). However, even a small area of trees can dramatically reduce particulate air pollution. For example, one Russian study showed that more than 50% of the dust from an open-cast coal mine was intercepted by a 15-m-wide stand of birch trees (Spitsyna & Skripal'shchikova 1991, cited in Beckett et al. 1998). Although much of this literature assesses the effect of trees on air quality in urban areas, atmospheric pollution can be dispersed over wide areas (Beckett et al. 1998). Larger particles fall to earth more quickly than finer particles because they are heavier, so tend to be concentrated close to the source (Beckett et al. 1998). Finer particles not only have a much longer residence time in the atmosphere (Beckett et al. 1998), but also appear to pose the greatest health risks (Beckett et al. 2000; Fisher et al. 2002).

Vegetation types vary in their effectiveness in removing air pollutants. Forests have the potential to remove larger amounts of air pollution than any other vegetation type (Fowler et al. 1999). Of all natural land cover classes, forests generate the greatest frictional drag and, consequently, turbulence at the earth's surface (Fowler et al. 1999). Because forests are aerodynamically rough surfaces, their rate of turbulent exchange is larger than grasslands by an order of magnitude or more (Fowler et al. 1999). A study from Europe found that forest vegetation removed significantly higher levels of sulphur and nitrogen pollutants from the air than moorland vegetation (Fowler et al. 1999). Trees also have a greater leaf area than other plant types, enabling greater pollutant uptake (Beckett et al. 2000).

Pollution capture efficiency can also vary among tree species. Species with a more complex stem structure and finer leaves are more effective at capturing particulate pollution (Beckett et al. 2000; Freer-Smith et al. 2004). Conifers are more effective at removing particulates than broadleaves, because they have more complex architecture and are usually evergreen (Beckett et al. 2000). Evergreen trees can continue to remove pollutants from the air year round, while only some deciduous trees can continue to capture pollutants (through their stems) after leaf fall (Freer-Smith et al. 2004). Air pollution removal by vegetation in Beijing was lower in winter despite increased particulate concentrations from coal fires, because the majority of tree species in the city are deciduous (Yang et al. 2005). Thus, New Zealand native trees, which are primarily evergreen, may be more effective at removing air pollutants than introduced deciduous trees. Large trees also remove more air pollutants than small trees (Nowak & Dwyer 2000), which provides an additional reason to protect larger, older trees and old-growth forests.

Trees also decrease the temperature in urban areas through shading and evapotranspiration (loss of water through leaf pores and subsequent evaporation to the atmosphere), which limits the production of temperature-dependent pollutants such as volatile organic compounds (VOC) (Beckett et al. 1998; Akbari et al. 2001). The temperature in a typical city in the USA has been estimated to be approximately 2.5°C warmer than in nearby rural areas on a clear summer afternoon (Akbari et al. 2001). This difference is due to darker surface areas, which absorb heat, and less vegetation in cities (Akbari et al. 2001). It has also been estimated that 12% of air pollution problems in cities are attributable to the higher temperatures found there (Moll 1996, cited in Beckett et al. 1998). Using simulation methods, Taha (1996) predicted that a 6.25% increase in vegetation cover would cause a 2°C decrease in air temperature across the Los Angeles Basin and result in smog reduction of up to 20%.

Trees can also be a source of air pollution, through pollen (which can be a health hazard for those allergic to it) and biogenic volatile organic compounds (BVOCs) (Nowak & Dwyer 2000; Yang et al. 2005). Chemical reactions between BVOCs and nitro oxides can form ozone and aerosol pollutants (Yang et al. 2005). However, air pollution models that incorporate both pollutant capture and emissions by trees indicate that the overall effect of trees on air quality is generally beneficial (Yang et al. 2005; Nowak 2006), although there are exceptions (e.g. Taha 1996). Thus, the beneficial effects from the removal of pollutants and the reduction in air temperature resulting from trees usually outweigh the emission of BVOCs, and trees improve overall air quality (Nowak & Dwyer 2000; Yang et al. 2005).

2.3 SUMMARY

International studies show that vegetation can reduce air pollution both directly, by intercepting and absorbing airborne particles and compounds, and indirectly, by decreasing temperature through shading and evapotranspiration, although the degree to which pollution is reduced can vary according to a range of factors. None of the studies referred to in this section were conducted in New Zealand, but the international data are likely to be generally applicable, since the characteristics of both pollution and vegetation in New Zealand are likely to be broadly comparable to those in other countries. However, it is difficult to assess the extent to which the vegetation on land managed by DOC might be affecting air pollution. Its role may be relatively minor, given that the largest blocks of conservation land, those with perhaps the most potential for removing air pollution, tend to be located far from the large cities where the majority of pollutants are produced. On the other hand, even small patches of vegetation can have a dramatic affect on air pollution, so small reserves of conservation land near cities may be beneficial to some extent. We found no studies that examined the effects of conservation management activities on air pollution. In summary, it is difficult to ascertain whether conservation land or conservation management activities affect air pollution in New Zealand.

3. Climate

3.1 INTRODUCTION

Vegetation can affect local climate in a range of different ways, so there is potential for the forests and shrublands present on conservation land to be having this sort of effect in New Zealand. Conservation management activities might also affect local climate if they impact on the ability of the vegetation to change climatic conditions in some way. For example, restoring forest to areas that have been cleared might reduce local temperatures through shading effects. For this section we sought studies that quantify the ways in which vegetation affects local climatic factors such as temperature and rainfall. We do not cover issues relating to carbon sequestration and global climate change, since these topics are part of other DOC investigations presently underway.

3.2 AIR TEMPERATURE

It is widely recognised that trees can regulate local air temperatures through shelter, shading, and evapotranspiration (Beckett et al. 1998; Nowak & Dwyer 2000; Akbari et al. 2001; Yang et al. 2005; Jim & Chen 2008). Shade from trees can decrease air temperatures by reducing solar heating of dark surfaces below the canopy (Nowak & Dwyer 2000). Some of the solar energy absorbed by trees results in water loss through leaf pores, and subsequent evaporation to the atmosphere. This evapotranspiration also has a cooling effect, which occurs not only directly below the canopy but also in surrounding areas, as air movement rapidly disperses cooled air (Nowak & Dwyer 2000). The temperature in urban

areas is generally 2.5°C warmer than in nearby rural areas on a clear summer afternoon, partly because there is less vegetation in cities (Akbari et al. 2001). The combined cooling effects of trees may be able to reduce air temperatures by as much as 5°C (Akbari et al. 1992). Trees can also dramatically reduce wind speed, with larger areas of trees having a more widespread effect (Nowak & Dwyer 2000). In cold climates, the sheltering effect of trees can substantially reduce building heating requirements (Akbari et al. 2001). In warm climates, the impacts of windbreaks on cooling are fairly small compared with the benefits of shading (Akbari et al. 2001).

3.3 RAINFALL

Whether the presence of forest results in increased rainfall has long been debated. It is thought that the high evapotranspiration and aerodynamic ‘roughness’ of forests leads to increased atmospheric humidity and moisture convergence, and thus to higher probabilities of cloud formation and rainfall generation (Andre et al. 1989). However, in many studies there is little, if any, evidence that forests can increase rainfall (Bruijnzeel 2004). Interestingly, both observational studies and climate models suggest that deforestation can result in reduced rainfall, particularly for very large tropical basins, such as that of the Amazon (Shukla et al. 1990; Salati & Nobre 1991; Cutrim et al. 1995; McGuffie et al. 1995; Costa & Foley 2000; Lawton et al. 2001; Pielke Sr 2001; Silva Dias et al. 2002; Ray et al. 2006), although there is considerable disagreement on the magnitude and nature of the changes (Bruijnzeel 2004; Pielke et al. 2007). It is well established that changes in key land surface characteristics, such as albedo, roughness, and water-holding capacity, can lead to changes in climate (Pitman 2003 and references therein), but these changes are only seen on a very large scale, and may not be detectable in a country the size of New Zealand. Furthermore, the fact that weather in New Zealand is so strongly controlled by maritime influences also means it is unlikely that our forests increase rainfall (Rowe et al. 2002b). The same has been said for southeast Asia, where prevailing maritime climatic conditions mean that effects of land-cover change on rainfall can be expected to be less pronounced than those of changes in sea-surface temperatures (Koster et al. 2000; Bruijnzeel 2004).

3.4 SUMMARY

International studies show that vegetation can regulate local air temperature through shelter, shading and evapotranspiration. It is far less certain whether forests can increase rainfall except, perhaps, on a very large scale. None of the studies referred to in this section were conducted in New Zealand, but the international data are likely to be generally applicable, since the effects of vegetation on air temperature and rainfall in New Zealand are likely to be broadly similar (depending on scale) to those in other countries. In summary, forests on conservation land in New Zealand may be affecting local air temperature, but where, and to what extent, is uncertain. Any effects of vegetation on rainfall are probably minimal, given New Zealand’s small size and strong maritime influence. We found no studies that examined the effect of conservation management activities on air temperature or rainfall.

4. Water

4.1 INTRODUCTION

Water quality, quantity (the amount of water that flows off the land), and the timing and rate of flow (often called flood and drought mitigation) can all be affected by a multitude of different aspects pertaining to the natural environment, so the potential for conservation land to affect water issues is wide-ranging and complex. The potential for conservation management activities to affect water issues is also large. For example, restoring or improving vegetation could affect both the quality of water and the rate at which it flows through the watershed—and could also affect soil condition which, in turn, has additional effects on water quality and flow. For this section we sought studies that quantify factors affecting water quality, water quantity, and the timing and rate of water flow.

4.2 WATER QUALITY

4.2.1 General effects of vegetation

The scientific literature is largely in agreement that terrestrial ecosystems with intact groundcover and root systems generally improve water quality within a catchment. Vegetation, microbes, and soils remove pollutants from overland flow and from groundwater by physically trapping water and sediments, adhering to contaminants, reducing water speed to enhance infiltration, biochemically transforming nutrients and contaminants, absorbing water and nutrients from the root zone, stabilising soils and eroding banks, and diluting contaminated water (Naiman & Decamps 1997; Rey 2003; Ludwig et al. 2005; Brauman et al. 2007). In general, undisturbed natural vegetation provides the highest quality water, since this vegetation produces the least amount of sediment and the fewest pollutants (Wiersum 1984; Lenat & Crawford 1994; Cooper 1995; Sliva & Dudley Williams 2001). The classic example illustrating the importance of natural vegetation for water supply comes from New York city, where it was determined that protecting and restoring the Catskill Mountain forests (at a cost of more than a billion US dollars) would purify the city's drinking water for a fraction of the price of a water filtration plant (Chichilnisky & Heal 1998).

New Zealand studies comparing the impact of alternative land-uses on water quality generally report that native forest streams have lower exports of sediments and nutrients and higher visual clarity than pasture or pine forest streams (Graynoth 1979; Dons 1987; Harding & Winterbourn 1995; Quinn et al. 1997; Quinn & Stroud 2002; Davies-Colley & Wilcock 2004; Larned et al. 2004). It has also been reported that water flowing from an ungrazed native tussock grassland catchment in New Zealand is of far higher quality than water flowing from pasture catchments (Buck et al. 2004). It should be noted, however, that even invasive, exotic plant species can improve water quality in some situations (Cooper & Cooke 1984; Lusby et al. 1998; Chambers et al. 1999).

4.2.2 Mangroves

Mangrove forests also play an important role in the purification of water, because of their ability to trap and retain sediments (Scoffin 1970; Parkinson et al. 1994; Furukawa et al. 1997; Victor et al. 2004), transform nutrients (particularly nitrogen) (Rivera-Monroy & Twilley 1996; Kristensen et al. 1998), and immobilise microbes and chemicals such as pesticides (Corredor & Morell 1994; MacFarlane et al. 2003; Alongi et al. 2005). In many parts of the world, effluent is discharged directly into mangroves in order to take advantage of nature's 'free' wastewater treatment (Tam & Wong 1993; Wong et al. 1997; Chu et al. 2000; Meziane & Tsuchiya 2002; Boonsong et al. 2003). However, the ability of mangroves to receive sediments is limited, since trees are usually killed when the lenticels (spongy areas that act as pores) on their pneumatophores (aerial roots), prop roots, and young stems are buried (Ewel et al. 1998; Ellison 1999).

4.2.3 Wetlands

It is also well demonstrated that wetlands have a high and long-term capacity for improving water quality. They are particularly efficient at removing nutrients from through-flowing water (Johnston et al. 1990; Johnston 1991; Zedler 2003; Hogan et al. 2004), largely via the processes of sedimentation, soil adsorption, denitrification (in the soil), and nutrient uptake by vegetation (Johnston et al. 1990; Templer et al. 1998; Mitsch et al. 2001; Saunders & Kalff 2001; Verhoeven et al. 2006). Coastal wetlands and estuaries also play an important role in water quality regulation by capturing and filtering sediments and organic wastes in transit from inland regions to the ocean (Jansson et al. 1994; Merrill & Cornwell 2000; Tappin 2002; Soetaert et al. 2006). In fact, wetlands are so reliable at removing suspended solids, phosphorus, and nitrogen from wastewater that they have been integrated into wastewater treatment plants in many countries, including New Zealand (Cooke et al. 1990; Brix 1994; Chagué-Goff et al. 1999b; Sundaravadivel & Vigneswaran 2001; Yang et al. 2006). Unsurprisingly, this practice can be detrimental to the functioning of these wetland ecosystems (Cooke et al. 1990; Chagué-Goff et al. 1999a; Qualls & Richardson 2000; Scheffer et al. 2001; Verhoeven et al. 2006). Artificially constructed wetlands are a well-established technology for the treatment of wastewater all over the world (Bhamidimarri et al. 1991; García et al. 2004; Greenway 2005; Tanner et al. 2005), and there are at least 80 projects already in place in New Zealand (Sukias & Tanner 2004). New Zealand wetlands also frequently receive nitrogen and phosphorus runoff from agricultural land (Cooke 1988; Cooke & Cooper 1988; Burns & Nguyen 2002; Matheson et al. 2003; Zaman et al. 2008).

The conversion of wetlands to agricultural land has had a significant negative impact on water quality and storage in most parts of the world, including New Zealand (Gosselink et al. 1990; Patrick 1994; Bernert et al. 1999; Brinson & Malvárez 2002). International research shows that restoring vegetation and hydrology in natural wetlands can improve both water purification and storage functions (Turner & Lewis 1997; Pfadenhauer & Grootjans 1999; Craft 2001; Bruland et al. 2003; Hansson et al. 2005; Meyer et al. 2008), but we were unable to find similar studies from New Zealand. Nevertheless, effects on water quality and storage are likely to be similar where natural wetlands are restored in New Zealand, providing that climatic factors and hydrological regimes are broadly comparable to those studied elsewhere (Chris Tanner, NIWA, Hamilton, pers. comm.).

4.2.4 Riparian vegetation

Riparian zones (the areas of interface between waterways and the land) can have a significant effect on catchment hydrology (Smith 1992), so protection, retirement from grazing, and restoration of riparian vegetation may all improve water quality. It is well established that vegetation in the riparian zone can reduce bank erosion, slow surface flow, and filter out excess nutrients and sediment in the water (Vincent & Downes 1980; Lowrance et al. 1984; Cooper 1990; Smith 1992; Naiman & Decamps 1997; McKergow et al. 2003; Marden et al. 2005; Croke & Hairsine 2006).

Forested or retired pasture riparian strips can reduce nitrogen, phosphorus, and sediment in surface runoff from cropland and pasture (Peterjohn & Correll 1984; Smith 1989; Williamson et al. 1996). This is likely to be particularly important in New Zealand, where agriculture is the dominant land use in the middle and lower catchment areas of most streams and rivers (Quinn 2000). Certainly, runoff from agricultural land is a major pollutant of New Zealand's waterways (Hickey et al. 1989; Ryan 1991; Smith et al. 1993; Gillingham & Thorrold 2000; Vant 2001). Cooper & Cooke (1984) found that nitrate removal processes in two headwater catchments in New Zealand were particularly active where stream channels were vegetated with thick mats of the exotic grass species *Glyceria fluitans*. Another New Zealand study looking at the long-term effects of protecting riparian margins from pastoral farming found that stream nutrient concentrations declined significantly over the c. 30 years of protection (Howard-Williams & Pickmere 2005).

However, not all studies conclude that riparian planting improves water quality. A comparison of water quality in 75 catchment areas in the USA found that proximity of forested versus agricultural land to streams did not significantly affect stream nutrient levels (Omernik et al. 1981). In a New Zealand study of riparian afforestation with *Pinus radiata*, Smith (1992) found that water quality did not improve, but suggested that this might have been due to factors such as the lack of riparian wetlands, in-stream vegetation, and close riparian ground cover. Parkyn et al. (2003) reviewed nine riparian buffer zone planting schemes in New Zealand, and found that visual water clarity improved rapidly, but nutrient and faecal contamination responses were variable.

A myriad of interacting factors make it difficult to make general predictions about the effect of riparian planting on water quality. Watershed hydrology is perhaps the most important factor determining the effectiveness of riparian buffers for removing pollutants (Hill 1996); for example, removal of contaminants from surface runoff requires that runoff water be sufficiently slowed to allow sediment to settle (Dillaha et al. 1986; Haycock & Pinay 1993), or sufficiently deep to make contact with plant roots that take up pollutants or enable denitrification by bacteria (Correll et al. 1997). The width of the buffer also influences the extent to which pollutants are filtered out; Mayer et al. (2005) reviewed 14 published reviews on buffer effectiveness and concluded that buffers between c. 10–50-m wide were particularly effective. Other important factors influencing buffer effectiveness include season, climate, soil characteristics, vegetation type and age, depth of root zone, buffer length, and location of the buffer in relation to the overall watershed (Devito et al. 1996; McGlynn & Seibert 2003; Mayer et al. 2005).

4.2.5 Marine ecosystems

Marine ecosystems also involve the transformation, detoxification and sequestration of pollutants and societal wastes (Daily 1997). Seagrasses can reduce water flow, thereby enhancing sedimentation and improving water clarity (Fonseca & Cahalan 1992; Chen et al. 2007b; de Boer 2007), although these effects can vary over space and time (Koch et al. 2009) and even with species of seagrass (Koch et al. 2006). Marine microbes can detoxify anthropogenic pollution, including petroleum hydrocarbons from oil spills (Atlas 1981; Heath et al. 1997; Churchill et al. 1999; Roling et al. 2002). Phytoplankton can remove nitrogen, phosphorous, and other contaminants (including uranium from mining waste) from water (Hosetti & Frost 1998; Kalin et al. 2004), and seaweeds can perform a similar role (Troell et al. 1999; Lüning & Pang 2003). Oceanic hydrothermal systems are also important water quality regulators, removing about 50% of the pre-industrial dissolved phosphate from riverine sources (Wheat et al. 1996). Because shellfish filter water as they feed, they can remove excess levels of algae resulting from eutrophication, and thus improve water clarity (Daily 1997). Research done in Lake Tuakitoto in New Zealand showed that freshwater mussels (*Hyridella menziesi*) filtered a volume of water equal to that of the entire lake once every 32 hours (Ogilvie & Mitchell 1995). The benthic bivalve fauna also appeared to be regulating phytoplankton levels in San Francisco Bay, as levels were much lower than would be predicted based on the large quantities of effluent discharged into the bay (Officer et al. 1982). Limiting environmentally detrimental coastal activities also has the potential to limit sewerage input to marine and freshwater environments, limit nutrient runoff, and reduce the likelihood of algal blooms.

To some extent, estuarine and marine ecosystems can render heavy metals biologically unavailable by binding them with sediments (Kersten & Forstner 1986; Bryan & Langston 1992; Yu et al. 2001). However, these pollutants are not necessarily transformed into harmless compounds by marine ecosystem processes, and can still place wildlife and humans at risk (van Straalen & Ernst 1991; Bryan & Langston 1992; Chen et al. 2000). For example, Wang et al. (1999) found that polychaete worms can assimilate 5–96% of heavy metals contained in ingested sediments. Seagrasses accumulate pollutants, including heavy metals such as lead, from the water column and sediments (Ward 1987; Hoven et al. 1999), thus improving water quality (Turner & Schwarz 2006). However, heavy metal pollutants may be also be transferred higher up the food chain when seagrasses are consumed by other organisms (Ward et al. 1986; Barwick & Maher 2003; Marín-Guirao et al. 2005). Biomagnification of heavy metals, where concentrations are higher in predators than their prey, has been demonstrated for methylmercury (Bryan & Langston 1992; Gray 2002) and selenium copper (Barwick & Maher 2003).

4.3 WATER QUANTITY

4.3.1 General effects of vegetation

The link between vegetation and the quantity of water flowing through a catchment is also well-studied and well-accepted. In most cases, empirical evidence shows that the total volume of surface and groundwater flowing from forested watersheds is lower than from grass- or shrub-dominated watersheds (Huang et al. 2003; Andréassian 2004; Brown et al. 2005). This is generally because large

plants intercept more water and also ‘lose’ more water to the atmosphere by evapotranspiration than small plants do (Wilcox & Thurow 2006). Vegetation age is also an important component; young plants tend to have greater transpiration rates than mature vegetation, and thus use more water (Bruijnzeel 1990). Forest type can also make a difference to water yield; for example, deciduous forests can differ from evergreen (Sahin & Hall 1996; Peel et al. 2001).

Forest clearance certainly results in an increase in total water run-off (Ruprecht & Schofield 1989; Hornbeck et al. 1993; Sahin & Hall 1996; Fahey & Jackson 1997; Bruijnzeel 2004; Farley et al. 2005; Nosetto et al. 2005). However, the net increase can vary depending on soil and underlying geological properties and the level of surface disturbance created (Gilmour et al. 1987; Smith 1992; Bruijnzeel 2004; Brown et al. 2005; Farley et al. 2005). Afforestation in general reverses this effect after a number of years (Bosch & Hewlett 1982; Fahey & Jackson 1997; Irvine et al. 2004; Farley et al. 2005), but the time taken to reach a new water-flow equilibrium can vary considerably (Hornbeck et al. 1993; Cornish & Vertessy 2001; Vertessy et al. 2001; Irvine et al. 2004).

4.3.2 Atmospheric moisture

There is also good evidence that, in some situations, vegetation is capable of capturing atmospheric moisture from clouds or fog (Vogelmann 1973; Azevedo & Morgan 1974; Cavalier & Goldstein 1989; Becker 1999; Chang et al. 2002; Liu et al. 2004; Chang et al. 2006; Holwerda et al. 2006; Gomez-Peralta et al. 2008; Villegas et al. 2008). This is most commonly reported from cloud forest, except in New Zealand, where tussock grasslands have received the most attention (Mark & Holdsworth 1979; Campbell & Murray 1990; Holdsworth & Mark 1990; Fahey et al. 1996; Ingraham & Mark 2000). The idea that tussock grasslands play this role has been somewhat controversial within New Zealand, with considerable debate over the potential contribution to water yield of fog deposition versus reduced transpiration rates (Davie et al. 2006). Nevertheless, research shows that, when in good condition, tussock grasslands are particularly effective at maximising water yield—and, in many instances, are more effective than other vegetation cover types such as herbfields, exotic pasture grasslands and pine forests (Mark & Rowley 1976; Mark & Holdsworth 1979; Holdsworth & Mark 1990; Mark & Dickinson 2008). New Zealand studies also show that the conversion of tussock grassland to plantation pine tends to significantly reduce water yield (Fahey & Watson 1991; Fahey & Jackson 1997).

These results suggest that conservation management activities designed to protect or improve the condition of these plants—by removing stock or controlling animal pests, for example—may improve water yield, but we found no studies investigating such links. A recent review paper emphasises the vital role that tussock grasslands play in regional hydrological regimes within New Zealand, and recommends that this be more widely acknowledged when water resource planning decisions are made (Mark & Dickinson 2008). For example, in a 2006 report to DOC, Butcher (n.d.) estimated that the water flowing from the tussock grasslands of Te Papanui Conservation Park was worth around \$136 million to the people of Dunedin. A study from South Africa comparing biome type with the provision of ecosystem services found that grasslands were very important for all five ecosystem services considered, including both water supply and water flow regulation (Egoh et al. 2009).

4.3.3 Effects of invasive plants

Some invasive plant species can reduce water yield; for example, *Tamarix* spp. in North America (Loope et al. 1988; Shafroth et al. 2005), pines and eucalypts in South Africa (Le Maitre et al. 2002; Gørgens & van Wilgen 2004), and *Miconia calvescens* in Hawaii (Kaiser 2006) have all been shown to have this effect. In many cases, this impact can be explained by differences between the invasive and native species in transpiration rates, phenology, biomass of photosynthetic tissue, or rooting depth (Scott & Lesch 1997; Dyer & Rice 1999; Levine et al. 2003). In some situations, removing the invasive plant species reverses this impact, and improves water yield (e.g. Neill 1983, cited in Vitousek 1992; Dye & Poulter 1995; Prinsloo & Scott 1999), but this is not always the case (Shafroth et al. 2005). International studies also show that invasive grass species can increase the incidence and severity of fire (D'Antonio & Vitousek 1992; Lippincott 2000; Douglas & O'Connor 2004) which, in turn, can increase water yield—often to the extent that flooding becomes a problem (Scott 1993; Robichaud 2000; Moody & Martin 2001a, b). Interestingly, a New Zealand study looking at the hydrological effects of burning tussock grasslands found the opposite effect: water yield decreased (Duncan & Thomas 2004).

4.4 TIMING AND RATE OF WATER FLOW (FLOOD AND DROUGHT MITIGATION)

4.4.1 Forests

The link between forest cover and the timing and rate of water flow—often called flood and drought mitigation—is more variable. Although it is commonly assumed that forests act as ‘sponges’, absorbing water during storm events and gradually releasing it later, this is not necessarily true (Bruijnzeel 2004). Factors affecting the quantity and timing of water flow can vary according to a range of factors such as climate, soils, slope, vegetation type and age, the size of the watershed, and management practices (Cerda 1999). Additionally, the amount of water stored in the soil at any particular site depends upon soil depth, infiltration capacity, texture, structure and degree of previous saturation with water (Dunne et al. 1991; Franzluebbbers 2002; Bryant et al. 2007). Forests influence some of these characteristics; for example, vegetation tends to enhance infiltration capacity (Hibbert 1971; McGuinness & Harrold 1971; Scott & Lesch 1997). Indeed, undisturbed forests are usually thought to be the best type of cover for reducing storm flow volumes, lowering peak flows and delaying peaks (Dudley & Stolton 2003). Deforestation tends to increase flood peaks and flood volumes (Andréassian 2004), but this effect is variable, and not always ameliorated by reforestation (Caruso 2006). Deforestation also tends to increase low flows, and reforestation tends to decrease low flows (Johnson 1998), but these effects can also be variable, and change over time (Andréassian 2004; Brown et al. 2005; Brauman et al. 2007).

In a New Zealand study, Dons (1987) compared the hydrology and sediment regime of pasture, native, and pine forest catchments, and reported that the native forest catchment had the lowest stormflow yields, lowest peak flows, and highest low flows. These results lend support to the contention that natural

forests play an important role in flood and drought mitigation; however, the author posits that some of the differences in hydrologic responses from the native forest catchment could be explained by drainage density and channel location, rather than vegetation differences (Dons 1987). It should also be noted that vegetation cover really only mitigates flooding during lower-intensity, short-duration storm events; this effect is overridden in prolonged, high-intensity events (Bruijnzeel 2004). Also, while this protective effect may be significant in small watersheds with deep soils, it can diminish as the watershed size increases to river catchments and river basins (Bruijnzeel 1990).

4.4.2 Wetlands

It is well recognised that wetlands can play an important role in flood and drought mitigation by storing storm runoff and slowly releasing water to streams and groundwater (Thibodeau & Ostro 1981; Ogawa & Male 1986; Walbridge 1993; Abramovitz 1996; Ewel 1997; Malmqvist & Rundle 2002; Brody et al. 2007; Ming et al. 2007). However, after reviewing 169 studies worldwide, Bullock & Acreman (2003) concluded that this is not always the case, and that sometimes wetlands have the opposite effect; a significant number of studies showed that some types of wetland actually increase flood peaks and/or reduce the flow of water in downstream rivers during dry periods. Studies from New Zealand also show that wetlands do not necessarily play a major role in flood or drought mitigation (Jackson 1987; Fahey et al. 1998; Bowden et al. 2001; Stewart et al. 2007). Leibowitz (2003) suggests that the influence of wetlands in reducing flood peaks is greatest for small storm events occurring when wetlands have a large capacity for storage, and least for large floods when soil and wetland storage are saturated before the flood peak.

Despite this potential for variation in the level of flood protection afforded by wetlands, the estimated economic value of this protection can be considerable. For example, Thibodeau & Ostro (1981) estimated that the loss of 8442 acres of wetlands within the Charles River system (Massachusetts) would result in annual flood damages of over US\$17 million. A recent study from the USA reported that coastal wetlands are self-maintaining 'horizontal levees' that provide US\$23.2 billion worth of protection from hurricane-related flooding each year (Costanza et al. 2008). In New Zealand, the Whangamarino Wetland in Waikato was estimated to have saved NZ\$5.2 million in flood control costs during a 100-year flood in 1998. Without the wetland storing the floodwaters on 12 July 1998, an extra 73 km² of land adjoining the wetland would have been flooded (Waugh 2007).

4.5 SUMMARY

Conservation land and conservation management activities both affect water in a range of ways, but impacts can be highly variable, and not always beneficial for people. There is a large body of consistent evidence, including several studies from New Zealand, showing that the natural, largely undisturbed vegetation and healthy soils on conservation land are beneficial for water quality. Marine systems also involve the transformation, detoxification and sequestration of wastes, but we found no studies linking these processes to the protection of land or marine areas, or any conservation management activities. Most evidence shows that the

presence of vegetation in the riparian zone improves water quality, but data can be highly variable and often site-specific, so it is difficult to make general predictions about this link.

There is good evidence showing that the quantity of water flowing off the land is affected by the vegetation present; in most cases, less water flows from forested watersheds than from grass- or shrub-dominated watersheds. Whether this is a positive or negative impact from a human perspective may depend on local water requirements and water resource planning goals. New Zealand studies show that tussock grasslands can be particularly effective at maximising water yield. Evidence showing that forests and wetlands play a role in flood and drought mitigation is variable, and dependent on a range of site- and weather-related factors. In summary, the intact natural vegetation present on conservation land is certainly beneficial for water quality in New Zealand, and does affect water yield. It is more difficult to ascertain how that vegetation is likely to affect the timing and rate of water flow in New Zealand, since data are more variable, and often site-specific.

We found a range of studies that examined the effects of conservation management activities on water issues, but data were variable, and effects were not always beneficial. International studies show that restoring wetland vegetation can restore water purification and storage functions, and these results are likely to be applicable under New Zealand conditions. International and New Zealand studies show that riparian plantings can improve water quality, but this is not always the case. Similarly, international studies investigating whether the removal of invasive plants improves water quality and/or water yield report variable results. This limited evidence, with variable results, means that it is difficult to ascertain how conservation management activities affect water issues in New Zealand.

5. Soil

5.1 INTRODUCTION

Soils, and the organisms within them, provide a range of interrelated ecosystem services, such as cleansing of water, detoxification of wastes, provision of substrate and nutrients to plants, and decay of organic matter (Daily et al. 1997b; Sparling 1997; Wall & Virginia 2000). In fact, the majority of ecosystem processes, and thus ecosystem services, in both natural and managed ecosystems have the soil as the critical and dynamic regulatory centre (Barrios 2007). Despite this, knowledge of soil biodiversity and function is incomplete—in large part because the hugely abundant and diverse soil biota is difficult to identify and study, and difficult to link to soil function (Wall & Virginia 2000; Barrios 2007). Accordingly, this section is relatively narrow in focus, and is largely limited to the effects of natural vegetation and organisms characteristic of conservation land on soil stability and fertility. Conservation management activities might also affect soil stability and fertility. For example, controlling pest animals might improve the condition of the forest understorey which might, in turn, improve both soil stability (more roots binding the soil) and fertility (more leaf litter incorporated into the soil).

5.2 SOIL EROSION

Erosion by water and wind is the primary cause of soil degradation (Lal 1994). Erosion adversely affects soil quality and productivity by reducing infiltration rates, water-holding capacity, nutrients, organic matter, soil biota, and soil depth (Morin & Van Winkel 1996; Belnap & Gillette 1998; Pimentel 1998). The widely-held view that the presence of intact vegetation minimises these negative effects is largely supported by the scientific evidence (Meeuwig 1970; Wiersum 1984; Greenway 1987; Maass et al. 1988; Bruijnzeel 1990; Pimentel 1998; Durán Zuazo et al. 2004; Sidle et al. 2006).

In general, undisturbed forest with its understorey, leaf litter, and organically enriched soil is the best vegetative cover for minimising soil erosion by water (Wiersum 1984), although other vegetation types can also play a significant role, even at low levels of cover (Loch 2000; Durán Zuazo et al. 2004; Durán Zuazo et al. 2006; Raya et al. 2006). The mechanisms by which this protection is afforded can be broadly classified as either hydrological or mechanistic in nature (Phillips et al. 2000). Hydrological factors that reduce surface water runoff, and hence reduce erosion, include interception of rainfall by foliage (Brandt 1988; Hall & Calder 1993) and transpiration of water from the soil (Islam & Weil 2000; Loch 2000; Sánchez et al. 2002; Bruijnzeel 2004). Soils beneath undisturbed vegetation also tend to contain high levels of organic matter which, in turn, improve water-holding capacity (Pritchett & Fisher 1979; Daily et al. 1997b). Vegetation reduces erosion mechanistically by way of root networks that ‘anchor’ the soil in place (O’Loughlin 1984; Watson et al. 1999; Ekanayake & Phillips 2002; Sidle et al. 2006). In many cases it is the presence of ground cover, rather than canopy,

that affords protection from erosion, so low-growing vegetation—or even a well-developed litter layer—can also have a major effect (López-Bermúdez et al. 1998; Chomitz & Kumari 2001; Faucette et al. 2004). However, vegetative protection only reduces shallow landslides; forest cover has no influence on the occurrence of deep-seated mass movements, which are entirely controlled by geologic and climatic factors (Grant 1989; Bruijnzeel 1990).

There is good evidence showing that deforestation tends to promote soil erosion (Islam & Weil 2000; Sidle et al. 2006). Several studies from New Zealand have shown that landslides are far more likely to occur on deforested lands (Pain & Stephens 1990; Marden & Rowan 1993; Glade 2003; Dymond et al. 2006), although slope angle, storm rainfall, and soil strength also play a role (Dymond et al. 2006). An assessment of landslips in New Zealand during cyclone Bola (1988) showed that the incidence of landslips was 1% of the land area where forests older than 5 years were present, compared with 30% for cleared lands (Trustum & Page 1992). Dymond et al. (2006) also showed that forest cover (both native and exotic) in New Zealand reduces landslide susceptibility by 90%, and scrub cover reduces it by 80%. Heavy grazing and overgrazing can also promote soil erosion, largely because grazing reduces plant biomass and cover, and increases the amount of bare ground exposed (Takar et al. 1990; Villamil et al. 2001; Fuhlendorf et al. 2002). Animals also have a direct effect on grasslands by trampling and compacting the soil surface, which can decrease water infiltration and thus increase runoff and soil erosion (Dunford 1949; Nguyen et al. 1998; Greenwood & McKenzie 2001). The extent to which exotic animals such as deer and goats affect surface soil erosion in New Zealand is largely unknown.

5.3 SOIL FERTILITY

Soil fertility can be degraded by unsustainable practices such as deforestation, overgrazing and poor cultivation techniques (Compton & Boone 2000; Saviozzi et al. 2001; Villamil et al. 2001; Dupouey et al. 2002; Fuhlendorf et al. 2002). Deforestation tends to cause a loss in organic matter and nutrient stocks (Bormann et al. 1968; Morris & Moses 1987; Kutiel & Inbar 1993; Shakesby et al. 1993; Hajabbasi et al. 1997; Sahani & Behera 2001), particularly when followed by cultivation (Chidumayo & Kwibisa 2003). Ross et al. (1999) examined the effects of land-use change on soil nutrient pools and fluxes in New Zealand, and found that changes in total and microbial carbon and nitrogen pools were greatest after conversion of native forest to pasture. The same study also showed that net nitrification and phosphorus concentrations were lowest in the native forest soils, although many of the other parameters measured did not show consistent differences between land-use types (native forest, plantation pine, pasture) (Ross et al. 1999). The loss of soil carbon is of current interest in relation to atmospheric CO₂ concentrations and global warming, since soils are the major global reservoir of terrestrial carbon (Post et al. 1982). Conversion from natural to agricultural ecosystems can deplete the soil organic carbon by 50% in approximately 5 years in the tropics, and 50 years in temperate regions (Lal 1999).

Dune systems and seagrass meadows also play a role in trapping sediments (acting as sediment reserves) and stabilising shorelines (Scoffin 1970). Seagrasses can reduce water flow, thereby enhancing sedimentation and reducing the

re-suspension of particles (Fonseca & Cahalan 1992; Terrados & Duarte 2000; de Boer 2007). The loss of seagrasses results in sediment erosion and subsequent erosion of the shoreline (Duarte 2000). In some cases, seagrasses also appear to play a role in dune formation when seagrass litter is deposited on land and acts as a sediment trap (Hemminga & Nieuwenhuize 1990). Sediment trapping has also been recorded for kelp forests, bryozoan meadows, and other macrophyte vegetation (de Boer 2007). Kelps reduce water flow beneath their canopy. Sediment deposition rates are greater in these areas than in open areas, probably because particles are retained for longer periods beneath kelps (Eckman et al. 1989). After protection, an increase in the abundance of sea urchin predators (lobster and snapper) at Cape Rodney–Okakari Point Marine Reserve (sometimes called Leigh Marine Reserve) resulted in a shift from domination by sea urchins to domination by seaweed (Kelly et al. 2000; Shears & Babcock 2003; Willis et al. 2003a). This shift to seaweed dominance may have had a positive impact on water quality, if the seaweed reduced water flow and subsequently increased sediment deposition.

Fire tends to cause a loss in soil organic matter and nutrients (Stromgaard 1984; Kauffman et al. 1995; Chidumayo & Kwibisa 2003), and increases the likelihood of soil erosion (Morris & Moses 1987; Shakesby et al. 1993; Moody & Martin 2001a; Williams 2001; Wondzell & King 2003). High-intensity fires, in particular, have a negative impact on the physical properties of soil which, in turn, affects other properties such as water infiltration rates (Neary et al. 1999; Kennard & Gholz 2001; Certini 2005). The work that DOC does to minimise fire risk, and fighting fires when they do occur, likely reduces these negative impacts, but there are no data to confirm this.

Studies show that some weed invasions increase fire risk (D’Antonio & Vitousek 1992; Lippincott 2000; Douglas & O’Connor 2004), so managing those weeds might indirectly benefit soil fertility. However, fire can also increase nutrient availability and thus improve seedling growth rates (Kennard & Gholz 2001), so may have positive effects on ecosystem services—in the short-term, at least (Neary et al. 1999; Wan et al. 2001).

Soil biota are also likely to be drastically affected when forest is cleared or burnt because, like above-ground organisms, soil-dwelling species have habitat preferences, and disruption of their soil habitat changes the community composition (Freckman & Virginia 1989; Freckman & Ettema 1993). However, soil biota remain poorly known and understood (Wall & Virginia 2000), so it is difficult to estimate the impacts of human-induced change and, therefore, the importance of retaining undisturbed tracts of land such as those managed by DOC.

5.4 REVERSAL OF SOIL DEGRADATION

International studies show that soil fertility and structure can improve significantly when previously cultivated sites are revegetated (either artificially, or by natural succession), although this can take many decades (Bormann et al. 1974; Burke et al. 1995; Fuhlendorf et al. 2002; Gong et al. 2006). Even highly degraded soils, such as those in areas mined for bauxite, can be restored to near-natural

levels of litter accumulation, nutrient content, and decomposition rates (Grant et al. 2007). Restoring vegetation also re-sequesters depleted soil organic carbon, although the rate can be slow, or even negative, during the first few decades of recovery (Paul et al. 2002; Vesterdal et al. 2002; Chen et al. 2007a). The rate at which soil carbon is accumulated can also vary according to the productivity of the recovering vegetation, the physical and biological conditions in the soil, and past land-use history (Lal 1999; Post & Kwon 2000; Silver et al. 2000, 2004; Resh et al. 2002). Studies from New Zealand and Australia show that retirement from grazing also enables soil recovery, although this too tends to be a slow process (Braunack & Walker 1985; McIntosh et al. 1994; Basher & Lynn 1996). Two New Zealand studies showed that excluding grazing animals had only small effects on soils, even 16 years after removal (McIntosh et al. 1997; McIntosh & Allen 1998). There is also evidence from a study done in Colombia that restoring vegetation can slow soil erosion to near natural levels (Vanacker et al. 2007).

5.5 SUMMARY

There is good evidence from both New Zealand and international studies showing that the presence of intact vegetation minimises soil erosion by water and wind, so conservation land is undoubtedly beneficial for both the stability and fertility of soil in New Zealand. Although limited in number, New Zealand and international studies also show that soil degradation can be reversed—albeit slowly—on a local scale by restoring vegetation and/or removing grazing stock.

6. Pest and disease regulation

6.1 INTRODUCTION

This section deals with two broad aspects of pest and disease control in relation to conservation land and conservation management activities. The first is the control of invertebrate crop pests by their natural invertebrate enemies. These natural enemies might benefit from the resources and habitat provided by conservation land which, in turn, might result in improved control of the crop-damaging pests on adjacent agricultural land. Conservation management activities might also be beneficial in this respect, if those activities improve conditions for the natural enemies in some other way. For example, restoring or improving the condition of native vegetation might improve the availability of suitable habitat for the invertebrates that control crop pests.

The second aspect dealt with in this section is the potential impact of conservation land and conservation management activities on animal-vector human disease. If the natural habitat and organisms present on conservation land affect animal vectors in some way, they may also be affecting the prevalence and distribution of disease outbreaks in humans. For this section we sought studies that quantify the ways in which the natural habitat on conservation land and/or conservation management activities affect the natural enemies of agricultural pests, or affect the prevalence and distribution of the animal vectors of human disease.

6.2 AGRICULTURAL PESTS AND THEIR NATURAL ENEMIES

The availability of natural habitat can increase the abundance and diversity of the natural enemies of agricultural pests by providing food resources, shelter and nesting sites, and alternative parasite hosts (Landis et al. 2000). In a recent review of 26 international studies covering a wide range of cropping systems and arthropod groups, Kremen & Chaplin-Kramer (2007) found that, in all cases, at least some natural enemies of crop pests increased in abundance with increasing natural habitat or landscape complexity. Similarly, a meta-analysis of 62 taxa from 43 studies (none from New Zealand) demonstrated that natural enemy abundance increases with increasing habitat structural complexity (Langellotto & Denno 2004).

There are many other international studies that illustrate the benefits of natural or unmanaged habitat for pest control. For example, in managed apple orchards adjacent to woodlands in California, USA, predatory arthropod abundance and predator removal rates of experimental prey were greater on trees close to woodlands (native forest) than at the centre of orchards (Altieri & Schmidt 1986). Dambach (1948; cited in van Emden 1965) found that woody vegetation in the field borders harboured many beneficial insects and relatively few pests, and found a lower proportion of crop pests hibernating in the litter of uncultivated field borders than in crop fields. In a UK study, the proportion of carnivorous insects increased with decreasing hedgerow management (van Emden 1965). Abandoned

fields adjacent to canola crops were associated with increased mortality of pest beetles due to parasitism, and mortality increased with increasing size and age of old fields (Thies & Tscharrntke 1999). Old, undisturbed habitat enabled parasitoid populations to build up and enhanced their dispersal into crop fields (Thies & Tscharrntke 1999). Natural habitat may also have a positive effect on agricultural systems by interrupting the dispersal of crop diseases (Altieri 1999; Blua & Morgan 2003), but data appear to be limited. It should also be noted that, in many cases, natural habitat can benefit both crop pests and their natural enemies, so any effects on crop management may be neutral (van Emden 1965).

It is unknown whether natural habitat is beneficial for the enemies of agricultural pests in New Zealand, since little relevant research has been conducted to date. Results from international studies may not apply under New Zealand conditions, since most crop pests originate from the northern hemisphere and are, therefore, more likely to be found on exotic, northern hemisphere vegetation than on native New Zealand vegetation (Nicholas Martin, Crop & Food Research, Auckland, pers. comm.). However, Lincoln University is leading a new research programme aimed at determining the attributes and value of ecosystem services in New Zealand's arable, pastoral and horticultural sectors. Collaboration with Landcare Research and 45 Canterbury vineyards has resulted in the 'Greening Waipara' project, which will investigate whether native plants enhance pest control in New Zealand vineyards (Meurk et al. 2008). Part of this research includes a PhD study (Jean Tompkins, Lincoln University) that aims to identify the abundance and diversity of beneficial and pest invertebrates in native plantings and remnant native vegetation within the agricultural landscape, pasture, and vineyards. Initial findings indicate that New Zealand jasmine, *Parsonsia capsularis*, shows some promise in providing beneficial floral resources to natural enemies of vineyard pests (Meurk et al. 2008). There have been several small studies that considered whether native habitat might be beneficial for a natural enemy (the parasite *Proscissio cana*) of one of New Zealand's main pasture pests, the grass grub (*Costelytra zelandica*) (Given 1945; Thomas 1963; Merton 1980), but few data were recorded, results were inconclusive, and little further research has been done since.

Several studies have examined the effect of exotic plants on beneficial parasitoids in New Zealand. One study showed increased rates of parasitism in wheat fields that were close to buckwheat floral resources (Tylianakis et al. 2004). The presence of flowering buckwheat also enhanced leafroller parasitism rates by more than 50% in one of two Marlborough vineyards studied (Berndt et al. 2006). The vineyard where no effect was detected had been partially treated with pesticides and had much lower levels of aphids. In New Zealand apple orchards, leafroller parasitism levels increased and damage caused by leafrollers decreased when floral resources were enhanced using buckwheat and alyssum (Irvin et al. 2006). However, these extra resources can also be beneficial for pest fitness; in the previous study, leafrollers had increased longevity and egg production in the presence of alyssum (Irvin et al. 2006).

Any effects of natural habitat on agricultural pest control also depend on dispersal of invertebrates between natural habitat and crop fields. Thiele (1964; cited in van Emden 1965) found little movement of carabid beetles between hedgerows and adjacent crops. In a Swiss study, only 6% of common arthropod species were restricted to semi-natural habitats; most dispersed, to some extent, into cultivated

areas (Duelli & Obrist 2003). Some studies have shown that invertebrate natural enemies appear to have poorer dispersal abilities than invertebrate herbivores (Zabel & Tscharrntke 1998; Kruess & Tscharrntke 2000; Thies et al. 2005). Although densities of both cereal aphids and their parasitoids were positively correlated with percentage of uncultivated land, aphids were affected at landscape scales of 1–6 km in diameter, while parasitoid densities responded at scales of 0.5–2 km, and thus appear to be more limited by dispersal (Thies et al. 2005). Zabel & Tscharrntke (1998) also found evidence of dispersal limitation in insect predators, which were more affected by habitat isolation than herbivores. The New Zealand PhD study by Jean Tompkins (mentioned above) may include investigations into invertebrate dispersal between native remnants and agricultural habitat, and the effect of distance to native remnants on the natural control of vineyard pests.

Increases in natural enemy abundance and predation rates do not always result in improved pest control or crop yield (Gurr et al. 2000). Pests can compensate for decreasing densities by increasing reproduction or dispersal, with no overall reduction in the pest population (Kremen & Chaplin-Kramer 2007). For example, in a study done in Germany, Thies et al. (2005) found greater aphid mortality due to parasitism in complex landscapes containing a high proportion of semi-natural habitat than in simple landscapes with less semi-natural habitat. However, this was compensated for by higher levels of aphid colonisation in complex landscapes, resulting in similar aphid densities across landscapes (Thies et al. 2005). Rodenhouse et al. (1992) found that the presence of uncultivated corridors between soybean fields was correlated with more pest enemies and fewer crop pests, but this did not result in higher soybean yields (Rodenhouse et al. 1992). Conversely, Mols & Visser (2002) found a beneficial effect of insectivorous birds in reducing pest densities and increasing crop production in the Netherlands. Great tits (*Parus major*) had a small but significant effect on caterpillar damage to apples (proportion of damaged fruit reduced from 13.8% to 11.2%), and increased fruit yield significantly (from 4.7 kg to 7.8 kg of apples per tree) (Mols & Visser 2002).

6.3 HUMAN DISEASE

Ecological degradation can drive a range of infectious disease outbreaks and can also modify the transmission of endemic infections (Patz et al. 2000). Approximately 61% of human diseases are zoonotic (transferred between animals and humans) in origin, and have a link to wildlife and domestic animals (Taylor et al. 2001), although most of these diseases and their vectors are not currently present in New Zealand. To date, there have been no confirmed cases of locally acquired human illness caused by an arbovirus (arthropod-borne virus) in New Zealand (Derraik & Maguire 2005). However, this will almost certainly occur in the future, since infected travellers regularly arrive in New Zealand (Derraik & Calisher 2004; Derraik 2006), and several known and potential mosquito vectors of arboviruses are already established in New Zealand (Derraik & Slaney 2007). Additionally, new mosquito species are regularly intercepted at the New Zealand border, mostly in cargo on incoming ships and aircraft, so there is a high chance that new vectors—and new diseases—could become established

here in the future (Derraik 2004). This risk may be even greater if the likely rises in temperature, rainfall and humidity due to climate change extend the availability of breeding sites and enhance mosquito survival (Derraik 2006).

There are a number of mosquito-borne pathogens that could become established in New Zealand, including Japanese encephalitis virus, Barmah Forest virus, Ross River virus (RRV) and West Nile Virus (Derraik & Slaney 2007). Ross River virus is perhaps the most likely to arrive and establish, since it is the most common agent of arboviral disease in Australia, and two of its known mosquito vectors are already established here (Derraik 2006). Additionally, possums and wallabies (*Macropus* spp.) could contribute to the spread of this virus throughout New Zealand, since they are both competent hosts of RRV (Boyd 2001; Old & Deane 2005; Derraik et al. 2007). The benefits of controlling these species may, therefore, expand to include human health in the future (Nye 2007).

Anthropogenic environmental changes, such as deforestation and agricultural development, often coincide with increases in the prevalence of mosquito-borne diseases (Gratz 1999; Martens et al. 2000; Patz et al. 2000; Norris 2004), so the presence of large, intact ecosystems may help to slow the introduction and spread of these diseases (LoGuidice et al. 2003; Leisnham et al. 2004; Foley et al. 2007). It is possible that conservation land could help to slow the spread and abundance of exotic mosquitoes in New Zealand. Results from a recent, as-yet unpublished, study in New Zealand indicate that exotic mosquitoes may be more likely to establish in small, disturbed forest remnants, rather than large, intact forest blocks (Mary McIntyre, Otago University, Wellington, pers. comm.). Other studies have also shown that anthropogenic changes such as those described above favour exotic mosquitoes in New Zealand (Leisnham et al. 2004; Leisnham et al. 2005; Derraik & Slaney 2007). On the other hand, exotic mosquitoes do live and breed in native forest in New Zealand (Derraik 2005; Derraik et al. 2005), so conservation land may in fact be beneficial for them. Current research into the distribution and habitat requirements of exotic mosquitoes in New Zealand (Mary McIntyre, Otago University, Wellington) may help to improve our understanding of the impacts of conservation land on exotic mosquitoes.

6.4 SUMMARY

International studies show that the control of agricultural pests by their natural enemies is often enhanced by the close proximity of natural habitat, but there is insufficient evidence to assess whether this may also be true in New Zealand. However, further information may be forthcoming in the next few years, since several New Zealand studies are currently underway. In the meantime, it is unknown whether the natural habitat on conservation land is beneficial for natural pest control on agricultural land. We were unable to find any studies that examined the affect of conservation management activities on crop pest control.

It is also uncertain whether conservation land might affect the prevalence and spread of human disease in New Zealand, if vector-borne diseases were to become established here. International studies indicate a greater risk from mosquito-borne diseases in modified environments, but New Zealand data are lacking. Accordingly, it is unknown whether the presence of intact, undisturbed ecosystems on conservation land might help to minimise the introduction and spread of arboviral diseases in New Zealand.

7. Pollination

7.1 INTRODUCTION

Pollinating insects, and hence the pollination services they provide, might benefit from the native habitat present on conservation land. Conservation management activities might also have an impact on pollination services if those activities affect the resources available to pollinating insects. For example, deer and possum control could improve the condition of the native vegetation which, in turn, could improve the availability of floral resources for pollinating insects. For this section we sought studies that quantify the ways in which natural vegetation affects pollinating insects.

7.2 POLLINATOR DECLINES

There is a growing global awareness of the extent to which both agricultural systems and natural plant communities critically depend on pollination services (Buchmann & Nabhan 1996; Allen-Wardell et al. 1998; Kevan 1999; Klein et al. 2007). Unfortunately, a wide range of pollinating animals, including insects, mammals and birds, appear to be in decline all over the world (Thomas & Abery 1995; Buchmann & Nabhan 1996; Nabhan 1996; Cox & Elmqvist 2000; Maes & Van Dyck 2001; Şekercioğlu et al. 2004; Thomas et al. 2004; Biesmeijer et al. 2006). These declines are having a negative impact on plant reproductive success and fruit production in both natural and agricultural systems (Allen-Wardell et al. 1998; Cunningham 2000; Klein 2003). International studies reveal that these declines, particularly for insects, are generally related to habitat loss and the use of herbicides and pesticides (Parker et al. 1987; Rathcke & Jules 1993; Kearns & Inouye 1997; Kearns et al. 1998; Kremen et al. 2002; Thomas et al. 2004; Goulson et al. 2005; Öckinger & Smith 2006; Fitzpatrick et al. 2007; Kremen & Chaplin-Kramer 2007), and to a range of introduced pests and diseases (Kraus & Page 1995; Scott Schneider et al. 2004).

Managed and feral populations of the honey bee, *Apis mellifera*, are declining markedly in many countries (Westrich et al. 1996; Allen-Wardell et al. 1998), a phenomenon termed Colony Collapse Disorder (CCD) (Mussen 2007). This is cause for great concern, given that the majority of agricultural and horticultural crops around the world rely on this species for pollination (Nabhan & Buchmann

1997; Klein et al. 2007). The cause of CCD remains largely unknown (Stokstad 2007), although it is thought to be partially due to infestation by the *Varroa* mite (Martin 1998) and another, less well-known microbe, the Israeli Acute Paralysis Virus (Cox-Foster et al. 2007).

Although CCD has not yet been observed in New Zealand, it is causing serious reductions in crop production around the world, and serious costs for farmers who are having to 'buy in' pollinating services (Watanabe 1994; Sumner & Boriss 2006; Kremen & Chaplin-Kramer 2007). Recent research attention has been focused on the role of native wild pollinators—which, in many cases, are not susceptible to honey bee-specific diseases and parasites—and how best to encourage and sustain populations on farmland (Cunningham et al. 2002; Kremen et al. 2002; Goulson 2003; Klein 2003; Kremen et al. 2004; Morandin & Winston 2005; Greenleaf & Kremen 2006a, 2006b; Klein et al. 2007; Winfree et al. 2007b; Winfree et al. 2008). Research is also underway in New Zealand, due to growing concern about the potential impact of the varroa mite on crop pollination (Goodwin 2004; Foundation for Arable Research 2007; Howlett et al. n.d. b).

7.3 POLLINATION IN NEW ZEALAND

In New Zealand, little is known about the role of both native and introduced pollinators in transferring pollen in crops or in the native environment (Craig et al. 2000; Brad Howlett, Crop & Food Research, Christchurch, pers. comm.). In other countries, introduced honey bees tend to be the most important pollinators of crops (Kearns & Inouye 1997; Newstrom & Robertson 2005). This is also largely the case in New Zealand (Donovan 1980), but there is growing evidence that New Zealand native insects also provide pollination services for a range of commercial crops and agriculturally beneficial plants. For example, native bees have been recorded visiting flowers of lucerne, sweet clover kiwifruit (*Actinidia* spp.), broccoli, squashes, courgettes, and onions, among others (Donovan 1980; Howlett et al. 2005). Native insects including *Lasioglossum* bees also visit flowers of carrot crops (Howlett & Walker n.d.). Native bees, flies, beetles, butterflies, bugs, thrips, lacewings, dragonflies, and spiders have been shown to be common onion flower visitors at six sites in Marlborough, Canterbury and Central Otago (Howlett et al. 2005). At two of the sites, native bee flower visits outnumbered visits by introduced honey bees (Howlett et al. 2005). Subsequent research has shown that a range of native bees and flies are effective pollinators of onion and *Brassica* flowers (Howlett & Teulon n.d.; Howlett et al. n.d. b). In a national survey of kiwifruit orchards, Macfarlane & Ferguson (1983) found over 150 species of invertebrates visiting kiwifruit flowers, including native bees, flies, thrips, and beetles. Native bees have also been recorded visiting white clover and parsnip crops (Palmer-Jones et al. 1962; Quinn 1984).

There are fewer studies on insect visitation to native plants, but a recent summary of both published and unpublished data indicated that approximately three quarters of flower visits were made by native insects, with the remaining quarter made by exotic honey bees, bumble bees, and wasps (Kelly et al. 2006). Additionally, a review of the use of native New Zealand plants by honey bees concluded that honey bees collect pollen or nectar from 224 native plant taxa (Butz Huryn 1995).

Certainly, there is evidence of pollination failure in native plants, both in New Zealand (Robertson et al. 1999; Montgomery et al. 2001; Anderson et al. 2006) and elsewhere in the world (Burd 1994; Ehrlén & Eriksson 1995; Johnson & Bond 1997; Wagenius 2006). Most pollination systems tend to be generalised (Waser et al. 1996; Kearns & Inouye 1997), in that plants can be pollinated by a range of different pollinators. This is also largely the case in New Zealand (Godley 1979; Lloyd 1985), but there are examples of specialised pollination systems (Kelly et al. 2004). Insects are by far the most common pollinators in New Zealand, and even though there are native plants that are clearly adapted to bird pollination (such as *Fuchsia* spp., *Sophora* spp., and *Phormium* spp.), most are also visited by bees, butterflies, and moths (Godley 1979). Despite this, pollen-limitation appears to be frequent on the mainland, occurring in six out of seven bird-pollinated species studied to date (Ladley & Kelly 1996; McNutt 1998; Robertson et al. 1999; Montgomery et al. 2001; Anderson et al. 2006). Pollination limitation may be due to a scarcity of pollinating birds in many areas of the New Zealand mainland, so conservation management activities aimed at protecting and improving populations and habitats have the potential to improve this service. In a recent attempt to elucidate this link, Kelly et al. (2005) tested the effects of stoat (*Mustela erminea*) control on bellbird (*Anthornis melanura*) breeding success, and looked for subsequent effects on bellbird pollination of native mistletoes. Stoat control certainly led to an increase in bellbird nest survival and density, but the study did not detect any improvement in mistletoe pollination (Kelly et al. 2005).

Conservation management activities have the potential to maintain plant-pollinator interactions in another way: a recent study from Britain found that restoration of heathland vegetation led to the re-establishment of functional pollinator communities (Forup et al. 2008). Although not specifically looking at plant-pollinator relationships, several other studies from New Zealand and the USA have shown that insect-plant interactions can recover rapidly from habitat loss with restoration management (Gratton & Denno 2005; Watts et al. 2008).

7.4 PROXIMITY OF NATURAL HABITAT

A number of international studies show that the presence of natural and semi-natural habitat near agricultural and horticultural systems can increase the abundance and diversity of pollinating insects, improve pollination services, and improve fruit production (e.g. Scott-Dupree & Winston 1987; Steffan-Dewenter & Tschardt 1999; Duelli & Obrist 2003; De Marco & Coelho 2004; Kremen et al. 2004; Ricketts 2004; Balvanera et al. 2005; Blanche & Cunningham 2005; Blanche et al. 2006; Chacoff & Aizen 2006; Kleijn & van Langevelde 2006; Brosi et al. 2007; Goldman et al. 2007; Öckinger & Smith 2007; Kohler et al. 2008; Ricketts et al. 2008). The implications for pollinator services are evident: farms near natural habitats are likely to benefit from more diverse and sustainable communities of pollinators (Kremen et al. 2002).

It is possible that the natural habitat on conservation land provides similar benefits to crop pollination services in New Zealand, depending on where it occurs in relation to agricultural land. One current study of pollination services across five New Zealand regions shows that the least intensively farmed region (Wanaka) had the highest proportion of native pollinators, and the greatest species richness

(Howlett et al. n.d. a). Another ongoing study suggests that insect pollinators (excluding honeybees) are consistently less abundant in pasture than around landscape features including water, pine hedgerows, gorse hedgerows, and gardens (Walker et al. n.d.). A current PhD study (Romina Rader, James Cook University, Australia) looking at pollinator assemblages associated with different land uses in New Zealand (natural vegetation, cropping, orcharding, pasture) may shed further light on this aspect. Interestingly, some international studies show an increase in pollinator abundance and/or diversity in, or near to, agriculture, possibly due to the mass floral resources and/or additional habitat heterogeneity provided in these areas (Westphal et al. 2003; Winfree et al. 2007a).

How close does natural habitat have to be to improve insect pollinator assemblages in farm or cropland? Kremen et al. (2004) found that crop pollination services provided by native bees in California, USA, strongly depended on the proportion of natural habitat within 1–2.5 km of the farm site. Kohler et al. (2008) found that remnant nature reserves and other artificially created flower-rich habitats do enhance biodiversity on nearby farmland, but only if they are within 150 m of the site. Kremen et al. (2004) also modelled area requirements, assuming farmers were to depend entirely on native bees for watermelon pollination, and estimated that their farms would need to be situated in areas containing more than 40% of natural habitat within a 2.4-km radius, or more than 30% within a 1.2-km radius.

In summary, while critical distances appear to vary widely, perhaps because of site-specific characteristics and varying life history traits of the pollinators (Steffan-Dewenter et al. 2002; Bilde & Topping 2004; Öckinger & Smith 2007), the presence of natural habitat does appear to improve pollinating insect abundance and diversity. Habitat ‘corridors’ that connect patches of similar habitat have also been shown to facilitate pollen transfer in fragmented landscapes (Tewksbury et al. 2002; Townsend & Levey 2005), so conservation land may also be beneficial in this way.

7.5 SUMMARY

International studies show that close proximity of natural habitat can increase the abundance and diversity of pollinating insects in agricultural and horticultural systems, and can improve pollination services and fruit production. It is unknown whether this is also the case in New Zealand, since little local research has been conducted to date. However, new research is underway (both in New Zealand and elsewhere) into the role of wild native pollinators and how populations of these can be encouraged and sustained on farmland. The many native insects that are known to visit agricultural crops in New Zealand may become increasingly important pollinators if honey bee populations decline significantly, as they are doing elsewhere in the world. In summary, it is uncertain whether conservation land is beneficial for pollination in New Zealand. We found no studies linking conservation management activities and pollination services.

8. Natural hazard protection

8.1 INTRODUCTION

Natural hazards can be defined as any natural occurrences (such as earthquakes, tsunamis, and volcanic and geothermal activity) that adversely affect human life, property or other aspects of the environment. Protection from natural hazards can be provided by natural structures and organisms, so conservation land may be beneficial in this respect. In particular, this review considers protection from ocean-based hazards such as storm surges or tidal waves, since these are likely the most common type of natural hazard. Furthermore, it is these types of relatively minor hazards that might be mitigated by some aspect of conservation land or conservation management activities. For example, mangroves—whether naturally occurring or replanted—might protect coastal areas from flooding and erosion associated with storm surges. For this section we sought studies that quantify the ways in which natural aspects of the coastal environment provide protection from ocean-based natural hazards.

8.2 COASTAL HAZARDS

Coastal sand dunes play an important role in the mitigation of coastal hazards such as erosion and flooding (Wijetunge 2006; Houser et al. 2008; Mascarenhas & Jayakumar 2008). Human-induced disturbance, such as pedestrian trampling, offroad 4WD activity, and housing development can cause significant erosion of sand dunes (Hesp 2002 and references therein). Protecting sand dunes for conservation purposes may, therefore, prevent or reduce these impacts and potentially enhance natural hazard protection. Natural dune repair after storms is critically dependent on the presence of appropriate sand-trapping vegetation on the seaward face of the dune (Snyder & Boss 2002; Dahm et al. 2005; Feagin et al. 2005). While many exotic species have been used to stabilise dunes in New Zealand (e.g. marram grass, ice plant, kikuyu), experience has shown that native sand-binding species (e.g. spinifex and pingao (*Desmoschoenus spiralis*)) are more effective at repairing storm-damaged frontal dunes (Dahm et al. 2005). Thus, restoring and maintaining natural dune systems could well be beneficial for natural hazard protection, but we were unable to find any studies to confirm this.

Living marine biota can also play a valuable role in the protection of coastal regions from natural hazards. There is good evidence that seagrasses, saltmarsh vegetation, and mangroves play a key role in flood protection by dissipating wave energy and reducing erosion (Fonseca & Cahalan 1992; Moller & Spencer 2002; Quartel et al. 2007), although these effects can be variable over both time and space (Mazda et al. 2006; Chen et al. 2007b; Koch et al. 2009). Recent analyses of the protective role that different types of coastal vegetation played in the 2004 Indian Ocean tsunami indicate that areas covered by seagrass beds were less impacted than areas covered by other types of vegetation (Chatenoux & Peduzzi 2007). Protection of human infrastructure from storm surges, tidal waves, and

floods is one of the most widely touted services provided by wetlands (Barbier 1994; Mitsch & Gosselink 2000; Turner et al. 2000; Pethick 2002). This is largely because wetland vegetation decreases the rate at which water passes over land, thereby slowing the destructive forces of abnormal storm surges or floodwaters (Whigham et al. 1988; Johnston 1993; Koskiaho 2003). However, the presence of a wetland also indicates the extent of natural flooding, thereby indicating where human development should cease (Ewel et al. 1998).

Despite the popular and widely held belief that mangroves provide protection from tsunamis, there is surprisingly little data available to test this hypothesis (Dahdouh-Guebas et al. 2006). Mangrove forests appear to provide protection from tsunamis in some circumstances—some models using realistic forest variables suggest a significant reduction in tsunami wave flow pressure for forests at least 100 m in width (Alongi 2008). The magnitude of energy absorption depends on tree density, stem and root diameter, shore slope, bathymetry, spectral characteristics (height, period, etc.) of incident waves, and tidal stage upon entering the forest (Alongi 2008).

Proximity to the tsunami epicentre will also determine the extent to which coastal vegetation plays a protective role. For example, the presence of coastal vegetation made no difference to the impact of the 2004 Indian Ocean tsunami in coastal areas close to the epicentre (Chatenoux & Peduzzi 2007), but in areas further from the epicentre, the energy of smaller waves appeared to be reduced by these natural barriers (Adger et al. 2005). The presence of intact mangrove forests also provided protection from the tsunami in Sri Lanka, reducing damage compared with areas that had degraded mangrove forests and areas lacking mangroves altogether (Dahdouh-Guebas et al. 2005). Pre- and post-tsunami satellite image analyses of the Tamil Nadu coast in India also indicated that mangrove forests provided protection from tsunami damage (Danielsen et al. 2005), although this study has been criticised for not accounting for distance from the coast when comparing damage among villages (Dahdouh-Guebas et al. 2006; Kerr & Baird 2007). Re-analyses of the data gave mixed results, with one study reporting no relationship between human mortality and the extent of coastal forest when distance from shore and elevation were accounted for (Kerr et al. 2006), while another study confirmed the original findings (Vermaat & Thampanya 2006). Clearly, the degree to which coastal vegetation provides natural hazard protection is somewhat variable, and is dependant upon a range of different factors.

8.3 SUMMARY

There is good evidence from international studies that seagrasses, saltmarsh vegetation, wetlands, and mangroves can all play a key role in flood protection. Mangrove forests can also provide protection against tsunamis, but only under certain circumstances. Both statements are probably largely true for coastal areas anywhere in the world, but we found no studies from New Zealand. We also found no studies linking conservation management activities and natural hazard protection. Accordingly, it is difficult to ascertain whether conservation land or conservation management activities are beneficial for natural hazard protection in New Zealand.

9. Nutrient cycling

9.1 INTRODUCTION

Nutrient cycling describes the movement within and between the various biotic and abiotic entities in which nutrients occur, and entails a balance of inputs (such as the weathering of rock, carbon and nitrogen fixation, and nutrient release from live and dead organisms) and outputs (such as soil erosion, leaching, and gaseous emissions through decomposition) (Begon et al. 2006). This supply of nutrients is required for life and all ecological services (Bolin et al. 1983), and thus provides substantial benefits to people (MA 2005).

Much is known about soil development and nutrient cycling within natural ecosystems in New Zealand (e.g. New Zealand Soil Bureau 1968; Molloy 1988). It is also well established, both internationally and in New Zealand, that the destruction of natural forest causes soil fertility to decline (Williams & Haynes 1990; Lumbanraja et al. 1998; Lemenih et al. 2005; Mainville et al. 2006). However, to explain the intricacies of this highly complex, variable area of science is beyond the purpose and scope of this literature review. Accordingly, for this section we focussed our search effort on locating nutrient cycling studies that compared natural systems with managed systems, and/or looked at the impacts of conservation management activities on nutrient cycling. Examples of such activities could include anything that contributes to the restoration or maintenance of plant and animal populations that are known to affect nutrient cycles.

9.2 DISRUPTED NUTRIENT CYCLES

Over the last two centuries, human activities have resulted in large-scale changes to all of the major nutrient cycles (Pham et al. 1996; Vitousek et al. 1997a; Falkowski et al. 2000; Smil 2000). Specifically, shifts in land use patterns, increasing rates of fertiliser application, and translocations of nutrients across ecosystem boundaries have dramatically changed the rate, pathways, and efficiency of nutrient cycling (Bolin & Cook 1983; MA 2005). For example, nitrogen inputs to the global nitrogen cycle have approximately doubled over the past 200 years (Vitousek et al. 1997a), largely through combustion of fossil fuels, the application of nitrogen fertiliser, and extensive use of nitrogen-fixing crops (MA 2005).

The contemporary phosphorus cycle is also out of balance. Unlike the other elements, natural mobilisation of phosphorus is slow. Human activities have intensified releases of phosphorus to the extent that the global mobilisation of the nutrient has roughly tripled compared with its natural flows (Smil 2000). This has been largely due to applications of inorganic fertilisers, but also to increased soil erosion and runoff from fields, recycling of crop residues and manures, and discharges of urban and industrial wastes (Smil 2000). This elevates the potential phosphorus run-off to freshwater ecosystems which, in turn, results in eutrophication (Bennett et al. 2001).

The main human perturbation to the global sulphur cycle results from the burning of sulphur-containing coal and oil, and the smelting of sulphite ores (MA 2005). The global carbon cycle is also out of balance, mainly as a result of the burning of fossil fuels, but also because of the conversion of forests and grasslands to agricultural systems (Schimel 1995; Potter 1999).

Deforestation causes major disruptions to all these cycles (Bormann et al. 1968; Vitousek 1983; Fuller et al. 1987; Rasmussen 1998; Potter 1999; Lemenih et al. 2005), which suggests that the intact vegetation on conservation land is important for the maintenance of natural nutrient cycling processes. Studies from New Zealand (Goh & Phillips 1991; Ross et al. 1999) and elsewhere (e.g. Bormann et al. 1968; Covington 1981; Hajabbasi et al. 1997; Williams et al. 1997) show that deforestation can result in soil nutrient losses. There is also evidence that converting native forest to pine plantation or pasture in New Zealand can increase nutrient levels in streamwater (Neary et al. 1978; Cooper & Thomsen 1988; Quinn & Stroud 2002). Levett et al. (1985) looked at litterfall and its macronutrient concentrations in native and exotic forests in New Zealand, but got variable results and few consistent differences between forest types. International studies show that if land protection enables natural recovery of previously degraded vegetation, nutrient cycling systems can be restored (Toky & Ramakrishnan 1983; Brown & Lugo 1990; Hughes et al. 1999; McDonald & Healey 2000; Craft 2001). Active replanting schemes may have the same effect, but we did not find any studies that measured this.

9.3 RESTORING SEABIRD POPULATIONS

The loss of animal populations can also cause disruptions to nutrient cycles. It has long been recognised that seabirds transport large amounts of nutrients from the sea to the land in their guano, feathers, carcasses, eggs, and food for their young (Leamy & Blakemore 1960; Mizutani & Wada 1988; Furness 1991; Anderson & Polis 1999). This has a major impact on soil fertility (and thus nutrient cycling) which, in turn, can affect a wide range of other organisms and ecosystems (Onuf et al. 1977; Mulder & Keall 2001; Markwell & Daugherty 2002; Harding et al. 2004; Barrett et al. 2005; Hawke et al. 2005; Hawke & Holdaway 2005; Payne & Moore 2006; Mulder et al. in press). Accordingly, the loss of seabird colonies can result in dramatic reductions in the nutrient levels in soils (Hawke & Powell 1995; Fukami et al. 2006), although the chemical signatures of former seabird inputs can remain evident in soil for decades to hundreds of years (Moors et al. 1988; Mizutani et al. 1991; Hawke et al. 1999).

It is likely that restoring seabird populations will increase soil nutrient concentrations, and thus restore natural rates of nutrient cycling, although there do not appear to be any published studies that attempt to quantify this effect. However, a PhD student (Holly Jones, Yale University) is currently examining this very issue on islands around the world with various restoration histories, including Mana Island in New Zealand, where three species of burrowing seabirds have been reintroduced (Miskelly & Taylor 2004; Miskelly et al. in press). Jones expects to see an increase in soil fertility at sites where seabirds are being restored, but her preliminary results suggest that it is too early in the restoration process for any major effects to be evident (Holly Jones, Yale University, Connecticut, pers. comm.).

9.4 EFFECTS OF INVASIVE SPECIES

Introduced predators can also affect soil nutrients, although not always directly. Rats consume eggs, chicks and adult seabirds, and have severely reduced or extinguished seabird populations and species throughout the world (Atkinson 1985; Holdaway & Worthy 1994; Booth et al. 1996; Holdaway 1996; Worthy 1998; Pierce 2002; Blackburn et al. 2004; Caut et al. 2008; Jones et al. 2008). Stoats and pigs also prey upon seabird eggs, chicks, and adults, and pigs destroy nesting sites (Cuthbert 2001). Flow-on ecosystem effects have recently been demonstrated; comparisons of offshore islands in New Zealand reveal that predation of seabirds by rats disrupts sea-to-land nutrient transportation which, in turn, has a range of effects on below-ground organisms and the ecosystem processes they drive (Fukami et al. 2006; Towns et al. 2009). Similarly, Maron et al. (2006) showed that fox predation on seabirds reduced the delivery of nutrient-rich guano to the land with consequent dramatic effects on plant communities.

These examples suggest that the many pest eradications that DOC has carried out on islands to protect seabird populations may also be fortuitously restoring or improving natural rates of nutrient cycling. There is certainly good evidence, from New Zealand and elsewhere, showing that rat control or eradication can dramatically improve seabird breeding success (e.g. Pierce 2002; Imber et al. 2003; Whitworth et al. 2005; Igual et al. 2006; Jones et al. 2006), so flow-on effects on nutrient cycling could be expected. A recent paper by Mulder et al. (in press) showed that rat eradication *per se* had no effect on a range of ecological attributes measured, including soil nutrient levels. The authors concluded that soil nutrient levels are unlikely to recover without seabird recolonisation. Holly Jones (mentioned above) will also examine the effects of rat eradication on soil nutrients as part of her PhD study.

Controlling exotic species may also have positive effects on soil nutrients in other ways. Pig rooting can accelerate leaching of a range of nutrients from leaf litter and soil (Singer et al. 1984), and introduced browsing mammals, such as goats and deer, can have a negative effect on some soil processes and organisms (Wardle et al. 2001). Evidence from New Zealand and elsewhere shows that grazing tends to result in topsoil nutrient decline over time, although effects can be variable (Bauer et al. 1987; Milchunas & Lauenroth 1993; McIntosh et al. 1996; Yong-Zhong et al. 2005).

Controlling or removing the browsing animals might reverse these effects, but there appear to be few published studies that examine this aspect of animal control, particularly for natural habitats. Several New Zealand studies have looked at the effects on soil nutrients of removing sheep from unimproved and managed grasslands, but with variable results. For example, Basher & Lynn (1996) looked at soil characteristics in unimproved grassland plots where grazers and hares had been excluded for 45 years, and concluded that there were few consistent differences between the exclosures and the surrounding grazed area. Two other studies found that excluding sheep and rabbits in managed grasslands for 16 years had only small effects on soil nutrients (McIntosh et al. 1997; McIntosh & Allen 1998). Coomes et al. (2003) suggest that removing deer will not necessarily lead to complete forest recovery in New Zealand, largely because deer browsing has the potential to fundamentally and irreversibly alter a wide range of forest processes.

Indeed, there are a whole range of reasons relating to multi-trophic interactions and site-specific characteristics that suggest that ecosystem recovery might not necessarily follow animal control in New Zealand (Coomes et al. 2006).

It is also well documented that invasive plant species can alter nutrient cycles in a range of different ways (Mack et al. 2001; Ehrenfeld 2003; Allison & Vitousek 2004; Ashton et al. 2005; Bellingham et al. 2005; Hawkes et al. 2005; Leary et al. 2006; Drenovsky & Batten 2007; Van der Putten et al. 2007; Martin et al. in press; Peltzer et al. in press).

Several international studies have found that controlling invasive plant species can begin to reverse these effects, although results and timeframes to recovery are variable. In a study of dune systems in Portugal, Marchante et al. (2009) found that soil chemical and microbial properties were beginning to recover four and a half years after the invasive tree species *Acacia longifolia* had been removed, although complete recovery was likely to be slow. Yelenik et al. (2004) found little change in nitrogen cycling regimes in the year following clearance of the invasive tree species *Acacia saligna* in South Africa, whereas Haubensak & D'Antonio (2006) found that nitrogen availability returned to pre-invasion levels c.18 months after removal of invasive, nitrogen-fixing broom species in California. Findlay et al. (2003) studied the effect of *Pbragmites australis* removal on marsh nutrient cycling in the northeast United States and got mixed results: in the first year, reed removal resulted in higher concentrations of ammonium, but lower denitrification potentials. Denitrification activity had 'recovered' by the second season following removal, but pore-water ammonium continued to accumulate (Findlay et al. 2003). In a study from England, Marrs & Lowday (1992) hypothesised that bracken control and heathland restoration would result in a return to naturally low soil nutrient levels, but they found no evidence to confirm this. There is a New Zealand study underway looking at the effects of removing the exotic heather *Calluna vulgaris* on below-ground properties, including nutrient stocks and availability (Duane Peltzer, Landcare Research).

9.5 SUMMARY

Conservation land is likely to be important for the maintenance of natural nutrient cycling processes, given what is known about the detrimental effects of human-induced disturbances for all of the major nutrient cycles. There is also evidence from international studies showing that reforestation through natural successional processes can restore degraded nutrient cycling systems. Restoring vegetation by replanting may have the same effect, but we could find no studies to confirm this. Conservation management activities that restore burrowing seabird populations are likely to have flow-on effects on nutrient cycling, but this has yet to be confirmed. It is uncertain what effects controlling invasive plants or animals will have on nutrient cycling in New Zealand. In summary, the presence of intact vegetation on conservation land is undoubtedly important for the maintenance of natural nutrient cycles in New Zealand. It is unknown, however, how conservation management activities might affect nutrient cycling.

10. Fish stocks

10.1 INTRODUCTION

The focus of this section is the effect of conservation activities on fish stocks. It is the only 'provisioning' ecosystem service covered by the literature review since, in most other cases in New Zealand, the natural resources managed by DOC are not harvested or extracted from the environment. The main conservation activity likely to be influencing fish stocks is the establishment of marine reserves, so for this section we sought studies that quantify the effects of marine reserves on fish stocks. These effects on fish stocks might originate inside the reserve where the fish are protected, but they may also 'spill over' into areas outside the reserve, where they then become a resource available to fishers. We also looked for evidence that conservation land and/or conservation management activities affect whitebait stocks.

10.2 IMPACTS INSIDE MARINE RESERVES

The evidence that marine reserves can enhance commercial fish species' density, size, and diversity within reserves is relatively consistent in international studies (Wantiez et al. 1997; Edgar & Barrett 1999; McClanahan & Arthur 2001; Schroeter et al. 2001; Barrett et al. 2007; Guidetti et al. 2008) and New Zealand studies (Kelly et al. 2000; Davidson et al. 2002; Denny et al. 2003; Willis et al. 2003a). A recent review of 44 no-take marine reserves and four large-scale fisheries closures in countries other than New Zealand demonstrated that marine reserves enhance diversity of target and non-target species, with an average 23% increase in species richness (Worm et al. 2006).

In a New Zealand study, Willis et al. (2003a) found that snapper density and egg production was greater inside three marine reserves (Cape Rodney-Okakari Point, Te Whanganui-a-Hei (Cathedral Cove), and Tawharanui Marine Park) than in non-reserve areas. It has also been shown that snapper are bigger and more abundant in the Poor Knights Islands Marine Reserve than they are outside the reserve (Denny et al. 2003). Similarly, crayfish increased in abundance, size and egg production inside Tonga Island Marine Reserve (Davidson et al. 2002) and four marine reserves in north-eastern New Zealand compared with nearby areas outside reserves (Kelly et al. 2000). A number of other New Zealand studies have attempted to ascertain the effects of marine reserves on fish stocks, but results were inconclusive because of design limitations or illegal fishing (Pande 2001; Kelly et al. 2002; Davidson & Richards 2005; Shears & Usmar 2006a, b)

10.3 IMPACTS OUTSIDE MARINE RESERVES

The contribution of 'no take' marine reserves to fisheries management is a contentious issue, and evidence is more limited and variable. The review by Worm et al. (2006) showed that increases in biodiversity inside reserves were

also associated with a fourfold increase in catch per unit of effort in fished areas around the reserves. Other researchers argue that there are, in fact, relatively few robust data to support the claim that marine reserves are an effective way to achieve sustainable fisheries (e.g. Roberts et al. 2005). Gell & Roberts (2003) report that poor study design has fuelled the debate. For example, common design flaws include poorly located experimental control sites, inadequate replication, non-random placement of reserves, and a lack of data prior to reserve establishment (Gell & Roberts 2003; Willis et al. 2003b).

A few relatively well-designed international studies show a beneficial effect of marine reserves on local fisheries (Roberts et al. 2001; Russ et al. 2004; Abesamis & Russ 2005), but this effect has yet to be demonstrated in New Zealand. Recent research by Guidetti et al. (2008) indicates that marine reserve enforcement is an important factor influencing the effectiveness of marine reserves as a fisheries management tool.

10.4 WHITEBAIT

The annual upstream migration of whitebait creates an important recreational and commercial fishery in New Zealand. This whitebait catch is made up of five species of juvenile diadromous (migratory between fresh and salt waters) galaxiids: inanga (*Galaxias maculatus*), koaru (*Galaxias brevipinnis*), banded kokopu (*Galaxias fasciatus*), giant kokopu (*Galaxias argenteus*), and shortjaw kokopu (*Galaxias postvectis*) (McDowell 1990). The whitebait fishery has probably been in decline since the early 1900s (McDowell 1984), with major contributing factors being the destruction of habitat, barriers to migration and competition with introduced species (Hanchet 1990; McDowell 1990; Minns 1990; Townsend & Crowl 1991) (all studies included in this section are from New Zealand). DOC is involved in management of the whitebait fishery, and conservation of the five galaxiid species that make up the catch, so there is much potential for both conservation land and conservation management activities to be beneficial for whitebait stocks.

Studies have shown that vegetative cover plays an extremely important role in providing habitat for adult galaxiids (Bonnett & Sykes 2002; Richardson 2002), so the intact riparian vegetation on conservation land is likely to be important. However, we were unable to find studies that compare the effects of native and non-native vegetation types on galaxiid abundance, so it is difficult to know whether native is best. Additionally, it has been suggested that vegetation structure, rather than species, is the most important factor influencing galaxiid spawning, and that most types of dense vegetation that provide moist, even temperatures at ground level are likely to be suitable (Mike Hickford, University of Canterbury, Christchurch, pers. comm.).

Water pollution and, in particular, turbidity (murkiness) from silt and clay erosion, is another issue that can have a negative effect on galaxiids (Rowe et al. 2000; Richardson et al. 2001), although some species are more tolerant of turbidity than others (Boubée et al. 1997; Rowe & Dean 1998). In New Zealand, agriculture and urbanisation are major contributors to increased turbidity as a result of the suspended solids load that occur in many waterways (Ryan 1991), so

it could be expected that galaxiids would be more common in undeveloped areas on conservation land, and less common in developed areas. However, although some galaxiid species tend to be most abundant in the relatively pristine streams that originate in native forest (Hanchet 1990; Swales & West 1991), others are now commonly found in streams that drain exotic forest and even pasture (Minns 1990; Jowett et al. 1996; Rowe et al. 1999; Rowe et al. 2002a).

Conservation management activities such as riparian restoration and protection from stock probably improve the availability and quality of galaxiid habitat (Charteris et al. 2003), although evidence to date appears to be limited and variable. Eikaas et al. (2005) found that koaro occurred more frequently in New Zealand catchments with higher proportions of riparian forest cover, although this effect was only seen where the dominant position of non-riparian forest was in the upper (rather than the lower) part of the catchment. Rowe et al. (2002a) looked at the effects of pine forest logging, with and without a riparian buffer strip, on the native fish fauna (including banded kokopu). Banded kokopu were more abundant at logged sites with riparian buffers than they were at logged sites without riparian buffers, but they were also more abundant at logged pine sites than they were at native forest sites (Rowe et al. 2002a).

In a small study, Mitchell (1994) showed that fencing off a single inanga spawning site resulted in an initial increase in spawning in the following two seasons, then a gradual decline as exotic grasses grew into a dense sward in the absence of grazers. However, the fenced site was not compared with adjacent non-fenced control sites, so it is possible that these changes were simply due to natural fluctuations in the general inanga population. There is new experimental research underway investigating the effects of fencing off and restoring riparian vegetation on inanga spawning (Mike Hickford, University of Canterbury, Christchurch, pers. comm.) that should add considerably to current knowledge. It has also been noted that mice (Baker 2006) and exotic slugs (Mitchell et al. 1992) prey upon inanga eggs, so controlling or excluding such predators could be beneficial to inanga spawning success. However, soon to be published research suggests that unless predator densities are very high, predation is not the most important factor in determining spawning success and egg survival (Mike Hickford, University of Canterbury, Christchurch, pers. comm.). In summary, there are not yet sufficient data to assess how conservation land or conservation management activities affect galaxiid stocks in New Zealand, but new information is likely to be available in the near future.

10.5 SUMMARY

There is good evidence, from both from international and New Zealand studies, that marine reserves can enhance commercial fish species' density, size and diversity within reserves. Studies showing that this also results in similar gains outside reserves are fewer in number, and more variable in conclusions reached. Accordingly, it is difficult to ascertain whether marine reserves are beneficial for harvestable fish stocks. We found no studies that investigated the effects of conservation management activities on marine fish stocks. Conservation land and conservation management activities could both be beneficial for whitebait stocks, but quantitative data are currently limited.

11. Biodiversity

11.1 INTRODUCTION

Biodiversity—the diversity of genes, populations, species, communities, and ecosystems—is fundamental to universal ecosystem functions such as the absorption and transfer of energy and the uptake and loss of carbon dioxide, water, and nutrients (Woodward 1993; MA 2005) which, in turn, deliver ecosystem services. Many scientists argue that biodiversity is an ecosystem service in itself, although this remains difficult to argue from an empirical basis, since knowledge of the links between biodiversity and ecosystem function is incomplete (Loreau et al. 2001; Hooper et al. 2005; Kremen & Ostfeld 2005; Balvanera et al. 2006; Egoh et al. 2009; Luck et al. 2009). Nevertheless, the Millenium Ecosystem Assessment (MA 2005) states with ‘high certainty’ that biodiversity strongly influences the provision of ecosystem services, and cites pollination, seed dispersal, climate regulation, carbon sequestration, agricultural pest and disease control, and human health regulation as the processes most frequently affected by changes in biodiversity. Also, by affecting ecosystem processes such as primary production, nutrient and water cycling, and soil formation and retention, biodiversity indirectly supports the production of food, fibre, potable water, shelter and medicines (MA 2005). Thus, as the lead agency tasked with the protection and management of native biodiversity in New Zealand, DOC could be having significant indirect effects on ecosystem services. For this section, we sought studies that link some aspect of biodiversity; for example, species or functional diversity, with ecosystem services.

11.2 SPECIES DIVERSITY

Recent research shows an apparent link between biodiversity (defined as species diversity for this section) and ecosystem functions and services. For example, a recent global-scale study relating benthic biodiversity to indicators of ecosystem functioning and efficiency at 116 deep-sea sites found that deep-sea ecosystem functioning was exponentially related to species diversity (Danovaro et al. 2008). Similarly, Naeem et al. (1995) showed that experimentally manipulating species diversity in artificial systems produced communities that differed in their ecosystem processes. In an example from a terrestrial system, Kremen et al. (2002) found that a diverse set of pollinators was necessary for sufficient crop pollination, because of year-to-year variation in community composition; relatively unimportant species in one year became crucial functional dominants in the next year. Meta-analyses of 32 local-scale experiments in the marine environment showed that increased biodiversity enhanced primary and secondary production, resource use, nutrient cycling, and ecosystem stability (Worm et al. 2006).

Primary production can also decrease with declining biodiversity in terrestrial ecosystems (Tilman et al. 2001). Correlations of long-term trends in coastal and estuarine ecosystems in 12 regions in Europe, North America and Australia showed increased stability in systems with higher diversity, with lower rates

of collapse and extinction of commercial species (Worm et al. 2006). Regional biodiversity losses were also associated with a reduction in a range of ecosystem services including viable fisheries, provision of nursery habitats, and filtering and detoxification by suspension feeders, submerged vegetation, and wetlands (Worm et al. 2006). The loss of ecosystem services with decreasing diversity was reflected in increased beach closures, toxic algal blooms, fish kills, shellfish closures, eutrophication, coastal flooding and species invasions (Worm et al. 2006). Likewise, data from global fisheries showed that species-poor ecosystems had more frequent fisheries collapses, lower average catches, and reduced recovery rates compared with species-rich ecosystems (Worm et al. 2006).

Conversely, two other reviews concluded that high species richness does not necessarily contribute significantly to ecosystem stability or function (Schwartz et al. 2000; Thompson & Starzomski 2007). This might be because the relationship between biodiversity and ecosystem function is likely to be inconsistent across scales and systems (Thompson & Starzomski 2007). Another explanation could be that many communities are dominated by a few species that provide the vast majority of the biomass (Schwartz et al. 2000).

Several recent studies have considered the extent to which hotspots of biodiversity overlap spatially with hotspots of ecosystem services. In South Africa, a study comparing biome type with the provision of five ecosystem services found a positive, although generally low, correlation between ecosystem services hotspots and species richness and vegetation diversity hotspots (Egoh et al. 2009). Chan et al. (2006) evaluated the spatial correspondence of biodiversity and the provision of seven ecosystem services in California, and found a generally low correlation and a moderate overlap. Nelson et al. (2009) used a modelling approach to predict the provision of ecosystem services and biodiversity conservation under three different land-use policy scenarios: current policies remain, policies change to allow more land development, and policies change to encourage ecosystem protection and restoration (conservation scenario). They found that the conservation scenario produced the largest gains (or the smallest losses) in ecosystem services, and that scenarios that enhanced biodiversity conservation also enhanced the production of ecosystem services (Nelson et al. 2009).

In general, it seems that the relationship between biodiversity and the provision of ecosystem services is generally positive, but the evidence is variable. Thus, it remains unclear how ecosystem services relate to different aspects of biodiversity, and whether the conservation of biodiversity will also ensure the provision of ecosystem services.

11.3 FUNCTIONAL DIVERSITY

An alternative, but not necessarily mutually exclusive, argument is that rather than species diversity, it is functional diversity that is the greatest determinant of ecosystem processes (Hooper & Vitousek 1997; Tilman 1997). In other words, it is not the number of species, but the identity—and thus functional type—of the species present that is most influential.

In a global study of 116 deep-sea sites, Danovaro et al. (2008) found that deep-sea ecosystem functioning was exponentially linked to functional biodiversity. An experimental study of artificial marine systems (in perspex tanks) also showed that diversity effects on ecosystem function were influenced partly by species identity (Ieno et al. 2006). Because species identity can have a strong influence, species richness *per se* should have no direct relationship to ecological functioning in a community (Duarte 2000). Nevertheless, Duarte (2000) argued that high species richness is likely to be correlated with high functional performance due to an increasing probability that the functional range of species will increase with increasing diversity. This is illustrated by an example from seagrass communities, where meadows with the most seagrass species have greater structural diversity and the highest productivity (Duarte 2000).

In addition, positive interactions among species may enhance their functional performance at a faster rate than if their individual effects were simply added together (Duarte 2000). These synergistic effects may partly explain the exponential decline in fish stocks, ecosystem stability, and water quality with decreasing biodiversity (Worm et al. 2006). The species redundancy hypothesis predicts that where multiple species are performing the same functional role (e.g. primary production, nutrient cycling), changes in biodiversity will not affect ecosystem processes, although ecosystems will be more stable (Naeem 1998). However, Worm et al. (2006) found no evidence of species redundancy at high biodiversity levels, with continued enhancement of ecosystem services with increasing biodiversity.

11.4 MANAGING BIODIVERSITY

Because of the apparent relationship between biodiversity and ecosystem function, measures that protect or enhance biodiversity may also be beneficial for the provision of ecosystem services. Habitat and species protection improves the chance of sustaining a diverse flora and fauna which, in turn, provides the benefits of biodiversity (Dobson et al. 2006). Management of individual species may be particularly important in terms of ecosystem services for top predators, important links in the food web, species that act as ecosystem engineers, or species that have an obvious direct effect such as water filtration by shellfish (Power et al. 1996; Chapin et al. 1997; Diaz et al. 2006; Dobson et al. 2006).

Marine reserves are one of the key tools for biodiversity protection in the marine environment, and have been shown to increase species richness, and thus biodiversity (Worm et al. 2006). Understanding the consequences of biodiversity changes on ecosystem functioning is becoming increasingly critical. Human activity is having a profound—and largely negative—influence on natural ecosystems in a myriad of ways, many of which have the potential to degrade the goods and services that humans depend on (Vitousek et al. 1997b; Daily et al. 2000; Giller et al. 2004). See Hooper et al. (2005) for a more comprehensive review of current knowledge of the effects of biodiversity on ecosystem functioning.

11.5 MAINTAINING FUTURE OPTIONS

Maintaining biodiversity also preserves future options for new discoveries of valuable biological compounds. For example, Newman et al. (2000) reported that more than 50% of the most-prescribed drugs in the USA are either a natural product (in other words, derived from a living organism) or have their synthesis or design based on a natural product. Approximately 62% of anti-cancer drugs in the USA have a natural product origin (Newman et al. 2000). In theory, marine organisms should offer the greatest opportunity of discovering unique compounds with pharmaceutical potential, because marine ecosystems include representation from 90% of animal phyla (Munro et al. 1999). Compounds found in a variety of marine organisms, including algae, corals, molluscs, sponges, and cyanobacteria, show promise as treatments for cancer (Newman et al. 2000; Harada et al. 2002; Amador et al. 2003; Takamatsu et al. 2003; Umemura et al. 2003), pain, and malaria (Newman et al. 2000). A New Zealand sponge species found only off the coast of Kaikoura shows potential as an anti-cancer therapy (Munro et al. 1999). Marine algae produce a wide range of chemically active metabolites, which have antibacterial, antialgal, antifouling, and antifungal properties (Bhadury & Wright 2004). These compounds are effective in preventing biofouling and could provide more environmentally friendly antifouling paints for ships' hulls (Bhadury & Wright 2004). Terrestrial organisms including plants, bacteria, and soil microbes, also provide rich sources of natural products for pharmaceuticals (Newman et al. 2000).

11.6 SUMMARY

Clearly, this is a complex subject, with many remaining uncertainties. Without biodiversity, there would be few ecosystem services, since these services are largely provided by living organisms. However, there are very few data that quantify the links between biodiversity and the provision of ecosystem services. Accordingly, it is difficult to argue, on an empirical basis, that biodiversity must be protected because it plays a role in the provision of ecosystem services. The idea that ecosystem function depends on the *full* complement of biodiversity is also difficult to prove, although it is an area of considerable current interest and investigation. In summary, it is difficult to ascertain how biodiversity affects ecosystem services in New Zealand.

12. Conclusions

12.1 CONSERVATION LAND

Land protection is the conservation activity that has the biggest documented impact on ecosystem services as, almost without exception, intact, natural ecosystems provide the best ecosystem services. However, almost all quantitative data come from studies done outside New Zealand, so it is difficult to ascertain the extent to which they are likely to apply under New Zealand conditions. There are, however, several areas where the strong international evidence is likely to apply in New Zealand and, in some cases, is supplemented by New Zealand data:

- Intact natural vegetation, such as forests, mangroves, wetlands and other vegetation types can improve water quality.
- Forests and wetlands can help to mitigate floods and droughts in some situations.
- Natural vegetation cover helps to preserve soil fertility and reduce erosion.
- Seagrasses, saltmarsh vegetation, wetlands and mangroves can reduce the height and force of waves and play a role in flood protection.

International research showing that forests can reduce air pollution probably applies in New Zealand, but the extent to which conservation land plays this role may be limited, given that the largest blocks of intact vegetation tend to occur far from the cities where pollution is produced. International research also indicates that natural habitat can improve pest control and pollination services in nearby agricultural land. However, it is uncertain whether this might also be true in New Zealand, given the different mix of plants and animals.

In summary, the protection of land for conservation purposes is almost certainly beneficial for a range of ecosystem services, largely because it limits disturbance and thereby preserves the natural organisms and processes, although New Zealand-specific data is sparse or lacking in most areas. Table 2 summarises and classifies the evidence for natural habitat on conservation land providing ecosystem services into the following categories: consistent (where many studies provide consistent results), ambiguous (where many studies provide conflicting results), or limited (where few studies exist).

12.2 CONSERVATION MANAGEMENT ACTIVITIES

Conservation management activities may also affect the provision of ecosystem services, but this does not appear to have been widely investigated to date. There is a vast literature documenting the negative impacts that human-induced changes have had on native species and natural ecosystems, but there appear to be very few studies that investigate subsequent effects on ecosystem services. This may be largely because the field of ecosystem services is a relatively new area of research interest. Additionally, there are inevitable difficulties involved in identifying and measuring changes in ecosystem services (many of which may

take decades or even millennia to become evident), and in attributing causality to any changes measured. It is also possible that additional relevant studies do exist, but we were unable to find them because they did not contain the search words or links we used.

The few international studies that have been done suggest that, under some circumstances, restoring vegetation can improve water quality and water storage functions, and can reverse soil degradation and erosion on a local scale (Table 3). There is also a small body of international evidence indicating that removing certain invasive plant species can improve water yield and/or restore natural nutrient cycles, but results are variable. Researchers in New Zealand and elsewhere are currently investigating whether restoring seabirds to islands can restore natural levels of nutrient input and cycling, although studies have yet to yield results. The notion that biodiversity *per se* is fundamental for all ecosystem services is largely accepted as a general concept, but this field of research is in its infancy and considerable uncertainties remain around the mechanisms underpinning this complex relationship. In summary, given the scarcity of quantitative data, it is difficult to ascertain how conservation management activities affect ecosystem services in New Zealand.

TABLE 2. SUMMARY OF EVIDENCE SHOWING THAT ECOSYSTEM SERVICES ARE PROVIDED BY NATURAL HABITAT CHARACTERISTIC OF CONSERVATION LAND.

SERVICE	CONSISTENT EVIDENCE	AMBIGUOUS EVIDENCE	LIMITED EVIDENCE
<i>Air quality</i>	<ul style="list-style-type: none"> • Forests and other vegetation types can reduce air pollution 		
<i>Climate regulation</i>	<ul style="list-style-type: none"> • Forests can regulate local air temperature 	<ul style="list-style-type: none"> • Very large forests may increase rainfall 	
<i>Water quality</i>	<ul style="list-style-type: none"> • Forests and other vegetation types can improve water quality* • Wetlands and mangroves can improve water quality • Marine microbes and shellfish can detoxify pollution and improve water clarity* 	<ul style="list-style-type: none"> • Riparian vegetation can improve water quality* • Seagrasses can improve water quality 	
<i>Water quantity and timing of flow</i>	<ul style="list-style-type: none"> • Vegetation affects water yield* 	<ul style="list-style-type: none"> • Forests and wetlands can help to mitigate floods and droughts 	<ul style="list-style-type: none"> • Healthy tussock grasslands can maximise water yield*
<i>Soil</i>	<ul style="list-style-type: none"> • Vegetation cover can reduce soil erosion and shallow landslides* 		
<i>Crop pest control and human disease regulation</i>	<ul style="list-style-type: none"> • Natural vegetation can enhance pest control in nearby agricultural land† 		
<i>Pollination</i>	<ul style="list-style-type: none"> • Natural vegetation can enhance pollination services in nearby agricultural land† 		
<i>Natural hazard regulation</i>	<ul style="list-style-type: none"> • Seagrasses, saltmarsh vegetation, wetlands, and mangroves can reduce wave energy and create natural sea defences 	<ul style="list-style-type: none"> • Mangroves can provide protection against tsunamis 	
<i>Nutrient cycling</i>	<ul style="list-style-type: none"> • The presence of intact ecosystems helps to retain natural nutrient cycles 		
<i>Fish stocks</i>	<ul style="list-style-type: none"> • Marine reserves can benefit local fish stocks inside reserves* 	<ul style="list-style-type: none"> • Marine reserves can benefit local fish stocks outside reserves • Intact native vegetation is beneficial for whitebait stock 	
<i>Biodiversity</i>	<ul style="list-style-type: none"> • Maintaining biodiversity preserves genetic libraries and future options for discoveries of useful compounds 		

* Includes evidence from New Zealand studies.

† New Zealand studies underway, but no data available.

TABLE 3. SUMMARY OF EVIDENCE SHOWING THAT ECOSYSTEM SERVICES ARE AFFECTED BY CONSERVATION MANAGEMENT ACTIVITIES.

SERVICE	CONSISTENT EVIDENCE	AMBIGUOUS EVIDENCE	LIMITED EVIDENCE
<i>Air quality</i>			
<i>Climate regulation</i>			
<i>Water quality</i>			<ul style="list-style-type: none"> Restoring vegetation, including wetland and riparian, can improve water quality*
<i>Water quantity and timing of flow</i>	<ul style="list-style-type: none"> Afforestation can decrease water yield* 		<ul style="list-style-type: none"> Removing some invasive plant species can increase water yield
<i>Soil</i>			<ul style="list-style-type: none"> Restoring vegetation and/or removing grazing stock can reverse soil degradation and slow soil erosion*
<i>Crop pest control and human disease regulation</i>			
<i>Pollination</i>			
<i>Natural hazard regulation</i>			
<i>Nutrient cycling</i>		<ul style="list-style-type: none"> Removing some invasive plant species can restore natural nutrient cycles† 	
<i>Fish stocks</i>			
<i>Biodiversity</i>			

* Includes evidence from New Zealand studies.

† New Zealand studies underway, but no data available.

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14. References

- Abesamis, R.A.; Russ, G.R. 2005: Density-dependent spillover from a marine reserve: long-term evidence. *Ecological Applications* 15: 1798-1812.
- Abramovitz, J.N. 1996: Imperiled waters, impoverished future: the decline of freshwater ecosystems. Worldwatch Paper 128. Worldwatch Institute, Washington DC, USA. 80 p.
- Adger, W.N.; Hughes, T.P.; Folke, C.; Carpenter, S.R.; Rockstrom, J. 2005: Social-ecological resilience to coastal disasters. *Science* 309: 1036-1039.
- Akbari, H.; Davis, S.; Huang, J.; Dorsano, S.; Winnett, S. (Eds) 1992: Cooling our communities: a guidebook on tree planting and light-colored surfacing. Lawrence Berkeley National Laboratory Report No. LBL-31587. U.S. Environmental Protection Agency, Office of Policy Analysis, Climate Change Division, Washington DC. 217 p.
- Akbari, H.; Pomerantz, M.; Taha, H. 2001: Cool surfaces and shade trees to reduce energy use and improve air quality in urban areas. *Solar Energy* 70: 295-310.
- Allen-Wardell, G.; Bernhardt, P.; Bitner, R.; Burquez, A.; Buchmann, S.; Cane, J.; Cox, P.A.; Dalton, V.; Feinsinger, P.; Ingram, M. 1998: The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. *Conservation Biology* 12: 8-17.
- Allison, S.D.; Vitousek, P.M. 2004: Rapid nutrient cycling in leaf litter from invasive plants in Hawai'i. *Oecologia* 141: 612-619.
- Alongi, D.M. 2008: Mangrove forests: resilience, protection from tsunamis, and responses to global climate change. *Estuarine, Coastal and Shelf Science* 76: 1-13.
- Alongi, D.M.; Pfitzner, J.; Trott, L.A.; Tirendi, F.; Dixon, P.; Klumpp, D.W. 2005: Rapid sediment accumulation and microbial mineralization in forests of the mangrove *Kandelia candel* in the Jiulongjiang Estuary, China. *Estuarine, Coastal and Shelf Science* 63: 605-618.
- Altieri, M.A. 1999: The ecological role of biodiversity in agroecosystems. *Agriculture, Ecosystems and Environment* 74: 19-31.
- Altieri, M.A.; Schmidt, L.L. 1986: The dynamics of colonizing arthropod communities at the interface of abandoned organic and commercial apple orchards and adjacent woodland habitats. *Agriculture, Ecosystems and Environment* 16: 29-43.

- Amador, M.L.; Jimeno, J.; Paz-Ares, L.; Cortes-Funes, H.; Hidalgo, M. 2003: Progress in the development and acquisition of anticancer agents from marine sources. *Annals of Oncology* 14: 1607-1615.
- Anderson, S.H.; Kelly, D.; Robertson, A.W.; Ladley, J.J.; Innes, J.G. 2006: Birds as pollinators and dispersers: a case study from New Zealand. *Acta Zoologica Sinica* 52(s): 112-115.
- Anderson, W.B.; Polis, G.A. 1999: Nutrient fluxes from water to land: seabirds affect plant nutrient status on Gulf of California islands. *Oecologia* 118: 324-332.
- Andre, J.C.; Bougeault, P.; Mahfouf, J.F.; Mascart, P.; Noilhan, J.; Pinty, J.P. 1989: Impact of forests on mesoscale meteorology. *Philosophical Transactions of the Royal Society of London B* 324: 407-422.
- Andréassian, V. 2004: Waters and forests: from historical controversy to scientific debate. *Journal of Hydrology* 291: 1-27.
- Ashton, I.W.; Hyatt, L.A.; Howe, K.M.; Gurevitch, J.; Lerdau, M.T. 2005: Invasive species accelerate decomposition and litter nitrogen loss in a mixed deciduous forest. *Ecological Applications* 15: 1263-1272.
- Atkinson, I.A.E. 1985: The spread of commensal species of *Rattus* to oceanic islands and their effects on island avifaunas. Pp. 35-81 in Moors, P.J. (Ed.): Conservation of island birds. ICBP, Cambridge, UK.
- Atlas, R.M. 1981: Microbial degradation of petroleum hydrocarbons: an environmental perspective. *Microbiological reviews* 45: 180-209.
- Azevedo, J.; Morgan, D.L. 1974: Fog precipitation in coastal California forests. *Ecology* 55: 1135-1141.
- Baker, C.F. 2006: Predation of inanga (*Galaxias maculatus*) eggs by field mice (*Mus musculus*). *Journal of the Royal Society of New Zealand* 36: 143-147.
- Balvanera, P.; Kremen, C.; Martínez-Ramos, M. 2005: Applying community structure analysis to ecosystem function: examples from pollination and carbon storage. *Ecological Applications* 15: 360-375.
- Balvanera, P.; Pfisterer, A.B.; Buchmann, N.; He, J.S.; Nakashizuka, T.; Raffaelli, D.; Schmid, B. 2006: Quantifying the evidence for biodiversity effects on ecosystem functioning and services. *Ecology Letters* 9: 1146-1156.
- Barbier, E.B. 1994: Valuing environmental functions: tropical wetlands. *Land Economics* 70: 155-173.
- Barrett, K.; Anderson, W.B.; Wait, D.A.; Grismer, L.L.; Polis, G.A.; Rose, M.D. 2005: Marine subsidies alter the diet and abundance of insular and coastal lizard populations. *Oikos* 109: 145-153.
- Barrett, N.S.; Edgar, G.J.; Buxton, C.D.; Haddon, M. 2007: Changes in fish assemblages following 10 years of protection in Tasmanian marine protected areas. *Journal of Experimental Marine Biology and Ecology* 345: 141-157.
- Barrios, E. 2007: Soil biota, ecosystem services and land productivity. *Ecological Economics* 64: 269-285.
- Barwick, M.; Maher, W. 2003: Biotransference and biomagnification of selenium copper, cadmium, zinc, arsenic and lead in a temperate seagrass ecosystem from Lake Macquarie Estuary, NSW, Australia. *Marine Environmental Research* 56: 471-502.
- Basher, L.R.; Lynn, I.H. 1996: Soil changes associated with cessation of sheep grazing in the Canterbury high country, New Zealand. *New Zealand Journal of Ecology* 20: 179-189.
- Bauer, A.; Cole, C.V.; Black, A.L. 1987: Soil property comparisons in virgin grasslands between grazed and nongrazed management systems. *Soil Science Society of America Journal* 51: 176-182.
- Becker, C.D. 1999: Protecting a Garúa forest in Ecuador: the role of institutions and ecosystem valuation. *Ambio* 28: 156-161.
- Beckett, K.P.; Freer-Smith, P.H.; Taylor, G. 1998: Urban woodlands: their role in reducing the effects of particulate pollution. *Environmental Pollution* 99: 347-360.

- Beckett, K.P.; Freer-Smith, P.H.; Taylor, G. 2000: Particulate pollution capture by urban trees: effect of species and windspeed. *Global Change Biology* 6: 995–1003.
- Begon, M.; Townsend, C.R.; Harper, J.L. 2006: Ecology: from individuals to ecosystems. Fourth Edition. Blackwell Publishing, Oxford. 738 p.
- Bellingham, P.J.; Peltzer, D.A.; Walker, L.R. 2005: Contrasting impacts of a native and invasive exotic shrub on flood-plain succession. *Journal of Vegetation Science* 16: 135–142.
- Belnap, J.; Gillette, D.A. 1998: Vulnerability of desert biological soil crusts to wind erosion: the influences of crust development, soil texture, and disturbance. *Journal of Arid Environments* 39: 133–142.
- Bennett, E.M.; Carpenter, S.R.; Caraco, N.F. 2001: Human impact on erodable phosphorus and eutrophication: a global perspective. *BioScience* 51: 227–234.
- Berndt, L.A.; Wratten, S.D.; Scarratt, S.L. 2006: The influence of floral resource subsidies on parasitism rates of leafrollers (Lepidoptera: Tortricidae) in New Zealand vineyards. *Biological Control* 37: 50–55.
- Bernert, J.A.; Eilers, J.M.; Eilers, B.J.; Blok, E.; Daggett, S.G.; Bierly, K.E. 1999: Recent wetlands trends (1981/82–1994) in the Willamette Valley, Oregon, USA. *Wetlands* 19: 545–559.
- Bhadury, P.; Wright, P.C. 2004: Exploitation of marine algae: biogenic compounds for potential antifouling applications. *Planta* 219: 561–578.
- Bhamidimarri, R.; Shilton, A.; Armstrong, I.; Jacobson, P.; Scarlet, D. 1991: Constructed wetlands for wastewater treatment: the New Zealand experience. *Water Science and Technology WSTEDA* 24: 247–253.
- Biesmeijer, J.C.; Roberts, S.P.M.; Reemer, M.; Ohlemuller, R.; Edwards, M.; Peeters, T.; Schaffers, A.P.; Potts, S.G.; Kleukers, R.; Thomas, C.D. 2006: Parallel declines in pollinators and insect-pollinated plants in Britain and the Netherlands. *Science* 313: 351–354.
- Bilde, T.; Topping, C. 2004: Life history traits interact with landscape composition to influence population dynamics of a terrestrial arthropod: a simulation study. *Ecoscience* 11: 64–73.
- Blackburn, T.M.; Cassey, P.; Duncan, R.P.; Evans, K.L.; Gaston, K.J. 2004: Avian extinction and mammalian introductions on oceanic islands. *Science* 305: 1955–1958.
- Blanche, K.R.; Ludwig, J.A.; Cunningham, S.A. 2006: Proximity to rainforest enhances pollination and fruit set in orchards. *Journal of Applied Ecology* 43: 1182–1187.
- Blanche, R.; Cunningham, S.A. 2005: Rain forest provides pollinating beetles for atemoya crops. *Journal of Economic Entomology* 98: 1193–1201.
- Blua, M.J.; Morgan, D.J.W. 2003: Dispersion of *Homalodisca coagulata* (Hemiptera: Cicadellidae), a vector of *Xylella fastidiosa*, into vineyards in Southern California. *Journal of Economic Entomology* 96: 1369–1374.
- Bolin, B.; Cook, R.B. (Eds) 1983: The major biogeochemical cycles and their interactions. John Wiley & Sons, Chichester. 551 p.
- Bolin, B.; Crutzen, P.J.; Vitousek, P.M.; Woodmansee, R.G.; Goldberg, E.D.; Cook, R.B. 1983: Interactions of biogeochemical cycles. Pp. 1–39 in Bolin, B.; Cook, R.B. (Eds): The major biogeochemical cycles and their interactions. John Wiley & Sons, Chichester.
- Bonnett, M.L.; Sykes, J.R.E. 2002: Habitat preferences of giant kokopu, *Galaxias argenteus*. *New Zealand Journal of Marine and Freshwater Research* 36: 13–24.
- Boonsong, K.; Piyatiratitivorakul, S.; Patanaponpaiboon, P. 2003: Potential use of mangrove plantation as constructed wetland for municipal wastewater treatment. *Water Science Technology* 48: 257–266.
- Booth, A.M.; Minot, E.O.; Fordham, R.A.; Innes, J.G. 1996: Kiore (*Rattus exulans*) predation on the eggs of the little shearwater (*Puffinus assimilis baurakiensis*). *Notornis* 43: 147–153.
- Bormann, F.H.; Likens, G.E.; Fisher, D.W.; Pierce, R.S. 1968: Nutrient loss accelerated by clear-cutting of a forest ecosystem. *Science* 159: 882–884.

- Bormann, F.H.; Likens, G.E.; Siccama, T.G.; Pierce, R.S.; Eaton, J.S. 1974: The export of nutrients and recovery of stable conditions following deforestation at Hubbard Brook. *Ecological Monographs* 44: 255-277.
- Bosch, J.; Hewlett, J. 1982: A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration. *Journal of Hydrology* 55: 3-23.
- Boubée, J.A.T.; Dean, T.L.; West, D.W.; Barrier, R.F.G. 1997: Avoidance of suspended sediment by the juvenile migratory stage of six New Zealand native fish species. *New Zealand Journal of Marine and Freshwater Research* 31: 61-70.
- Bowden, W.B.; Fahey, B.D.; Ekanayake, J.; Murray, D.L. 2001: Hillslope and wetland hydrodynamics in a tussock grassland, South Island, New Zealand. *Hydrological Processes* 15: 1707-1730.
- Boyd, A.M. 2001: Experimental infection of Australian brushtail possums, *Trichosurus vulpecula* (Phalangeridae: Marsupialia), with Ross River and Barmah Forest viruses by use of a natural mosquito vector system. *The American Journal of Tropical Medicine and Hygiene* 65: 777-782.
- Brandt, J. 1988: The transformation of rainfall energy by a tropical rain forest canopy in relation to soil erosion. *Journal of Biogeography* 15: 41-48.
- Brauman, K.A.; Daily, G.C.; Duarte, T.K.; Mooney, H.A. 2007: The nature and value of ecosystem services: an overview highlighting hydrologic services. *Annual Review of Environment and Resources* 32: 67-89.
- Braunack, M.V.; Walker, J. 1985: Recovery of some surface soil properties of ecological interest after sheep grazing in a semi-arid woodland. *Austral Ecology* 10: 451-460.
- Brinson, M.M.; Malvárez, A.I. 2002: Temperate freshwater wetlands: types, status, and threats. *Environmental Conservation* 29: 115-133.
- Brix, H. 1994: Use of constructed wetlands in water pollution control: Historical development, present status, and future perspectives. *Water Science and Technology* 30: 209-223.
- Brody, S.D.; Highfield, W.E.; Ryu, H.C.; Spanel-Weber, L. 2007: Examining the relationship between wetland alteration and watershed flooding in Texas and Florida. *Natural Hazards* 40: 413-428.
- Brosi, B.J.; Daily, G.C.; Ehrlich, P.R. 2007: Bee community shifts with landscape context in a tropical countryside. *Ecological Applications* 17: 418-430.
- Brown, A.E.; Zhang, L.; McMahon, T.A.; Western, A.W.; Vertessy, R.A. 2005: A review of paired catchment studies for determining changes in water yield resulting from alterations in vegetation. *Journal of Hydrology* 310: 28-61.
- Brown, S.; Lugo, A.E. 1990: Tropical secondary forests. *Journal of Tropical Ecology* 6: 1-32.
- Bruijnzeel, L.A. 1990: Hydrology of moist tropical forests and effects of conversion: a state of knowledge review. Faculty of Earth Sciences, Free University, Amsterdam. 224 p.
- Bruijnzeel, L.A. 2004: Hydrological functions of tropical forests: not seeing the soil for the trees? *Agriculture, Ecosystems and Environment* 104: 185-228.
- Bruland, G.L.; Hanchey, M.F.; Richardson, C.J. 2003: Effects of agriculture and wetland restoration on hydrology, soils, and water quality of a Carolina bay complex. *Wetlands Ecology and Management* 11: 141-156.
- Bryan, G.W.; Langston, W.J. 1992: Bioavailability, accumulation and effects of heavy metals in sediments with special reference to United Kingdom estuaries: a review. *Environmental Pollution* 76: 89-131.
- Bryant, R.; Doerr, S.H.; Hunt, G.; Conan, S. 2007: Effects of compaction on soil surface water repellency. *Soil Use and Management* 23: 238-244.
- Buchmann, S.L.; Nabhan, G.P. 1996: The forgotten pollinators. Island Press, Washington DC, USA. 320 p.
- Buck, O.; Niyogi, D.K.; Townsend, C.R. 2004: Scale-dependence of land use effects on water quality of streams in agricultural catchments. *Environmental Pollution* 130: 287-299.

- Bullock, A.; Acreman, M. 2003: The role of wetlands in the hydrological cycle. *Hydrology and Earth System Sciences* 7: 358–389.
- Burd, M. 1994: Bateman's principle and plant reproduction: the role of pollen limitation in fruit and seed set. *The Botanical Review* 60: 83–139.
- Burke, I.C.; Lauenroth, W.K.; Coffin, D.P. 1995: Soil organic matter recovery in semiarid grasslands: implications for the conservation reserve program. *Ecological Applications* 5: 793–801.
- Burns, D.A.; Nguyen, L. 2002: Nitrate movement and removal along a shallow groundwater flow path in a riparian wetland within a sheep-grazed pastoral catchment: results of a tracer study. *New Zealand Journal of Marine and Freshwater Research* 36: 371–385.
- Butcher, G. n.d.: Economic benefits of water in Te Papanui Conservation Park. Unpublished report. Butcher Partners Limited, Christchurch, New Zealand. 13 p.
- Butz Huryn, V.M. 1995: Use of native New Zealand plants by honey bees (*Apis mellifera* L.): a review. *New Zealand Journal of Botany* 33: 497–512.
- Campbell, D.I.; Murray, D.L. 1990: Water balance of snow tussock grassland in New Zealand. *Journal of Hydrology* 118: 229–245.
- Caruso, B.S. 2006: Project River Recovery: restoration of braided gravel-bed river habitat in New Zealand's high country. *Environmental Management* 37: 840–861.
- Caut, S.; Angulo, E.; Courchamp, F. 2008: Dietary shift of an invasive predator: rats, seabirds and sea turtles. *Journal of Applied Ecology* 45: 428–437.
- Cavalier, J.; Goldstein, G. 1989: Mist and fog interception in elfin cloud forests in Colombia and Venezuela. *Journal of Tropical Ecology* 5: 309–322.
- Cerda, A. 1999: Parent material and vegetation affect soil erosion in eastern Spain. *Soil Science Society of America Journal* 63: 362–368.
- Certini, G. 2005: Effects of fire on properties of forest soils: a review. *Oecologia* 143: 1–10.
- Chacoff, N.P.; Aizen, M.A. 2006: Edge effects on flower-visiting insects in grapefruit plantations bordering premontane subtropical forest. *Journal of Applied Ecology* 43: 18–27.
- Chagué-Goff, C.; Rosen, M.R.; Eser, P. 1999a: Sewage effluent discharge and geothermal input in a natural wetland, Tongariro Delta, New Zealand. *Ecological Engineering* 12: 149–170.
- Chagué-Goff, C.; Rosen, M.R.; Roseleur, M. 1999b: Water and sediment chemistry of a wetland treating municipal wastewater. *New Zealand Journal of Marine and Freshwater Research* 33: 649–660.
- Chambers, R.M.; Meyerson, L.A.; Saltonstall, K. 1999: Expansion of *Phragmites australis* into tidal wetlands of North America. *Aquatic Botany* 64: 261–273.
- Chan, K.M.A.; Shaw, M.R.; Cameron, D.R.; Underwood, E.C.; Daily, G.C. 2006: Conservation planning for ecosystem services. *PLoS Biology* 4: e379.
- Chang, S.C.; Lai, I.L.; Wu, J.T. 2002: Estimation of fog deposition on epiphytic bryophytes in a subtropical montane forest ecosystem in northeastern Taiwan. *Atmospheric Research* 64: 159–167.
- Chang, S.C.; Yeh, C.F.; Wu, M.J.; Hsia, Y.J.; Wu, J.T. 2006: Quantifying fog water deposition by in situ exposure experiments in a mountainous coniferous forest in Taiwan. *Forest Ecology and Management* 224: 11–18.
- Chapin, F.S.; Walker, B.H.; Hobbs, R.J.; Hooper, D.U.; Lawton, J.H.; Sala, O.E.; Tilman, D. 1997: Biotic control over the functioning of ecosystems. *Science* 277: 500–504.
- Charteris, S.C.; Allibone, R.M.; Death, R.G. 2003: Spawning site selection, egg development, and larval drift of *Galaxias postvectis* and *G. fasciatus* in a New Zealand stream. *New Zealand Journal of Marine and Freshwater Research* 37: 493–505.
- Chatenoux, B.; Peduzzi, P. 2007: Impacts from the 2004 Indian Ocean tsunami: analysing the potential protecting role of environmental features. *Natural Hazards* 40: 289–304.

- Chen, C.Y.; Stemberger, R.S.; Klaue, B.; Blum, J.D.; Pickhardt, P.C.; Folt, C.L. 2000: Accumulation of heavy metals in food web components across a gradient of lakes. *Limnology and Oceanography* 45: 1525-1536.
- Chen, L.; Gong, J.; Fu, B.; Huang, Z.; Huang, Y.; Gui, L. 2007a: Effect of land use conversion on soil organic carbon sequestration in the loess hilly area, loess plateau of China. *Ecological Research* 22: 641-648.
- Chen, S.N.; Sanford, L.P.; Koch, E.W.; Shi, F.; North, E.W. 2007b: A nearshore model to investigate the effects of seagrass bed geometry on wave attenuation and suspended sediment transport. *Estuaries and Coasts* 30: 296-310.
- Chichilnisky, G.; Heal, G. 1998: Economic returns from the biosphere. *Nature* 391: 629-630.
- Chidumayo, E.N.; Kwibisa, L. 2003: Effects of deforestation on grass biomass and soil nutrient status in miombo woodland, Zambia. *Agriculture, Ecosystems and Environment* 96: 97-105.
- Chomitz, K.M.; Kumari, K. 2001: The domestic benefits of tropical forests: a critical review. *The World Bank Research Observer* 13: 13-35.
- Chu, H.Y.; Tam, N.F.Y.; Lam, S.K.S.; Wong, Y.S. 2000: Retention of pollutants by mangrove soil and the effects of pollutants on *Kandelia candel*. *Environmental Technology* 21: 755-764.
- Churchill, S.A.; Harper, J.P.; Churchill, P.F. 1999: Isolation and characterization of a mycobacterium species capable of degrading three- and four-ring aromatic and aliphatic hydrocarbons. *Applied and Environmental Microbiology* 65: 549-552.
- Compton, J.E.; Boone, R.D. 2000: Long-term impacts of agriculture on soil carbon and nitrogen in New England forests. *Ecology* 81: 2314-2330.
- Cooke, J.G. 1988: Sources and sinks of nutrients in a New Zealand hill pasture catchment II. Phosphorus. *Hydrological Processes* 2: 123-133.
- Cooke, J.G.; Cooper, A.B. 1988: Sources and sinks of nutrients in a New Zealand hill pasture catchment III. Nitrogen. *Hydrological Processes* 2: 135-149.
- Cooke, J.G.; Cooper, A.B.; Clunie, N.M.U. 1990: Changes in the water, soil, and vegetation of a wetland after a decade of receiving a sewage effluent. *New Zealand Journal of Ecology* 14: 37-47.
- Coomes, D.A.; Allen, R.B.; Forsyth, D.M.; Lee, W.G. 2003: Factors preventing the recovery of New Zealand forests following control of invasive deer. *Conservation Biology* 17: 450-459.
- Coomes, D.A.; Mark, A.F.; Bee, J. 2006: Animal control and ecosystem recovery. Pp. 339-353 in Allen, R.B.; Lee, W.G. (Eds): *Biological invasions in New Zealand*. Springer, Berlin.
- Cooper, A.B. 1990: Nitrate depletion in the riparian zone and stream channel of a small headwater catchment. *Hydrobiologia* 202: 13-26.
- Cooper, A.B.; Cooke, J.G. 1984: Nitrate loss and transformation in 2 vegetated headwater streams. *New Zealand Journal of Marine and Freshwater Research* 18: 441-450.
- Cooper, A.B.; Thomsen, C.E. 1988: Nitrogen and phosphorus in streamwaters from adjacent pasture, pine, and native forest catchments. *New Zealand Journal of Marine and Freshwater Research* 22: 279-291.
- Cooper, S.R. 1995: Chesapeake Bay watershed historical land use: impact on water quality and diatom communities. *Ecological Applications* 5: 703-723.
- Cornish, P.M.; Vertessy, R.A. 2001: Forest age-induced changes in evapotranspiration and water yield in a eucalypt forest. *Journal of Hydrology* 242: 43-63.
- Corredor, J.E.; Morell, J.M. 1994: Nitrate depuration of secondary sewage effluents in mangrove sediments. *Estuaries and Coasts* 17: 295-300.
- Correll, D.L.; Jordan, T.E.; Weller, D.E. 1997: Failure of agricultural riparian buffers to protect surface waters from groundwater nitrate contamination. Pp. 162-165 in Gilbert, J.; Mathieu, J.; Fournier, F. (Eds): *Groundwater/surface water ecotones: biological and hydrological interactions and management options*. Cambridge University Press, Cambridge (UK).

- Costa, M.H.; Foley, J.A. 2000: Combined effects of deforestation and doubled atmospheric CO₂ concentrations on the climate of Amazonia. *Journal of Climate* 13: 18-34.
- Costanza, R.; d'Arge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O'Neill, R.V.; Paruelo, J. 1998: The value of the world's ecosystem services and natural capital. *Ecological Economics* 25: 3-15.
- Costanza, R.; Pérez-Maqueo, O.; Martínez, M.L.; Sutton, P.; Anderson, S.J.; Mulder, K. 2008: The value of coastal wetlands for hurricane protection. *Ambio* 37: 241-248.
- Covington, W.W. 1981: Changes in forest floor organic matter and nutrient content following clear cutting in northern hardwoods. *Ecology* 62: 41-48.
- Cox, P.A.; Elmqvist, T. 2000: Pollinator extinction in the Pacific Islands. *Conservation Biology* 14: 1237-1239.
- Cox-Foster, D.L.; Conlan, S.; Holmes, E.C.; Palacios, G.; Evans, J.D.; Moran, N.A.; Quan, P.L.; Briese, T.; Hornig, M.; Geiser, D.M. 2007: A metagenomic survey of microbes in honey bee colony collapse disorder. *Science* 318: 283-287.
- Craft, C.B. 2001: Soil organic carbon, nitrogen, and phosphorus as indicators of recovery in restored *Spartina* marshes. *Ecological Restoration* 19: 87-91.
- Craig, J.; Anderson, S.; Clout, M.; Creese, B.; Mitchell, N.; Ogden, J.; Roberts, M.; Ussher, G. 2000: Conservation issues in New Zealand. *Annual Reviews in Ecology and Systematics* 31: 61-78.
- Croke, J.C.; Hairsine, P.B. 2006: Sediment delivery in managed forests: a review. *Environmental Reviews* 14: 59-87.
- Cunningham, S.A. 2000: Depressed pollination in habitat fragments causes low fruit set. *Proceedings of the Royal Society B: Biological Sciences* 267: 1149-1152.
- Cunningham, S.A.; FitzGibbon, F.; Heard, T.A. 2002: The future of pollinators for Australian agriculture. *Australian Journal of Agricultural Research* 53: 893-900.
- Cuthbert, R.J. 2001: Conservation and ecology of Hutton's shearwater (*Puffinus huttoni*). *Conservation Advisory Science Notes No. 335*. Department of Conservation, Wellington, New Zealand. 35 p.
- Cutrim, E.; Martin, D.W.; Rabin, R. 1995: Enhancement of cumulus clouds over deforested lands in Amazonia. *Bulletin of the American Meteorological Society* 76: 1801-1805.
- D'Antonio, C.M.; Vitousek, P.M. 1992: Biological invasions by exotic grasses, the grass-fire cycle, and global change. *Annual Review of Ecology and Systematics* 23: 63-87.
- Dahdouh-Guebas, F.; Jayatissa, L.P.; Di Nitto, D.; Bosire, J.O.; Lo Seen, D.; Koedam, N. 2005: How effective were mangroves as a defence against the recent tsunami? *Current Biology* 15: R443-R447.
- Dahdouh-Guebas, F.; Koedam, N.; Danielsen, F.; Sorensen, M.K.; Olwig, M.F.; Selvam, V.; Parish, F.; Burgess, N.D.; Topp-Jorgensen, E.; Hiraishi, T. 2006: Coastal vegetation and the Asian tsunami. *Science* 311: 37-38.
- Dahm, J.; Jenks, G.; Bergin, D. 2005: Community-based dune management for the mitigation of coastal hazards and climate change effects: a guide for local authorities. Report for the New Zealand Ministry for the Environment. 36 p.
- Daily, G.C. 1997: Nature's services: societal dependence on natural ecosystems. Island Press, Washington, USA. 392 p.
- Daily, G.C.; Alexander, S.; Ehrlich, P.R.; Goulder, L.; Lubchenco, J.; Matson, P.A.; Mooney, H.A.; Postel, S.; Schneider, S.H.; Tilman, D. 1997a: Ecosystem services: benefits supplied to human societies by natural ecosystems. *Issues in Ecology* 1: 1-18.
- Daily, G.C.; Matson, P.A.; Vitousek, P. 1997b: Ecosystem services supplied by soil. Pp. 113-132 in Daily, G. (Ed.): Nature's services: societal dependence on natural ecosystems. Island Press, Washington DC, USA.

- Daily, G.C.; Söderqvist, T.; Aniyar, S.; Arrow, K.; Dasgupta, P.; Ehrlich, P.R.; Folke, C.; Jansson, A.M.; Jansson, B.O.; Kautsky, N. 2000: The value of nature and the nature of value. *Science* 289: 395–396.
- Dambach, C.A. 1948: Ecology of crop field borders. Ohio State University Press, Columbus, Ohio, USA. 140 p.
- Danielsen, F.; Sorensen, M.K.; Olwig, M.F.; Selvam, V.; Parish, F.; Burgess, N.D.; Hiraishi, T.; Karunakaran, V.M.; Rasmussen, M.S.; Hansen, L.B. 2005: The Asian tsunami: a protective role for coastal vegetation. *Science* 310: 643.
- Danovaro, R.; Gambi, C.; Dell'Anno, A.; Corinaldesi, C.; Fraschetti, S.; Vanreusel, A.; Vincx, M.; Gooday, A.J. 2008: Exponential decline of deep-sea ecosystem functioning linked to benthic biodiversity loss. *Current Biology* 18: 1–8.
- Davidson, R.; Richards, L. 2005: Comparison of fish at reserve and control sites from Long Island-Kokomohua and Tonga Island Marine Reserves using baited underwater video (BUV), catch, measure, release (CMR) and underwater visual counts (UVC). Research, Survey and Monitoring Report. Nelson/Marlborough Conservancy, Department of Conservation, Nelson, NZ. 35 p.
- Davidson, R.J.; Villouta, E.; Cole, R.G.; Barrier, R.G.F. 2002: Effects of marine reserve protection on spiny lobster (*Jasus edwardsii*) abundance and size at Tonga Island Marine Reserve, New Zealand. *Aquatic Conservation: Marine and Freshwater Ecosystems* 12: 213–227.
- Davie, T.J.A.; Fahey, B.D.; Stewart, M.K. 2006: Tussock grasslands and high water yield: a review of the evidence. *Journal of Hydrology (NZ)* 45: 83–94.
- Davies-Colley, R.; Wilcock, B. 2004: Water quality and chemistry in running waters. Pp. 11.11–11.17 in Harding, J.; Mosley, P.; Pearson, C.; Sorrell, B. (Eds): Freshwaters of New Zealand. New Zealand Hydrological Society Inc. and New Zealand Limnological Society Inc., Christchurch.
- de Boer, W.F. 2007: Seagrass-sediment interactions, positive feedbacks and critical thresholds for occurrence: a review. *Hydrobiologia* 591: 5–24.
- De Marco, P.; Coelho, F.M. 2004: Services performed by the ecosystem: forest remnants influence agricultural cultures' pollination and production. *Biodiversity and Conservation* 13: 1245–1255.
- Denny, C.M.; Willis, T.J.; Babcock, R.C. 2003: Effects of Poor Knights Islands Marine Reserve on demersal fish populations. *DOC Science Internal Series 142*. Department of Conservation, Wellington, NZ. 34 p.
- Derraik, J.G.; Ji, W.; Slaney, D. 2007: Mosquitoes feeding on brushtail possums (*Trichosurus vulpecula*) and humans in a native forest fragment in the Auckland region of New Zealand. *The New Zealand Medical Journal* 120: 48–51.
- Derraik, J.G.B. 2004: Exotic mosquitoes in New Zealand: a review of species intercepted, their pathways and ports of entry. *Australian and New Zealand Journal of Public Health* 28: 433–444.
- Derraik, J.G.B. 2005: Mosquitoes breeding in phytotelmata in native forests in the Wellington region, New Zealand. *New Zealand Journal of Ecology* 29: 185–191.
- Derraik, J.G.B. 2006: A scenario for invasion and dispersal of *Aedes albopictus* (Diptera: Culicidae) in New Zealand. *Journal of Medical Entomology* 43: 1–8.
- Derraik, J.G.B.; Calisher, C.H. 2004: Is New Zealand prepared to deal with arboviral diseases? *Australian and New Zealand Journal of Public Health* 28: 27–31.
- Derraik, J.G.B.; Maguire, T. 2005: Mosquito-borne diseases in New Zealand: has there ever been an indigenously acquired infection? *Journal of the New Zealand Medical Association* 118: 1670.
- Derraik, J.G.B.; Slaney, D. 2007: Anthropogenic environmental change, mosquito-borne diseases and human health in New Zealand. *EcoHealth* 4: 72–81.
- Derraik, J.G.B.; Snell, A.E.; Slaney, D. 2005: Vertical distribution of adult mosquitoes in native forest in Auckland, New Zealand. *Journal of Vector Ecology* 30: 334–336.

- Devito, K.J.; Hill, A.R.; Roulet, N. 1996: Groundwater-surface water interactions in headwater forested wetlands of the Canadian Shield. *Journal of Hydrology* 181: 127-147.
- Diaz, S.; Fargione, J.; Chapin, F.S.; Tilman, D. 2006: Biodiversity loss threatens human well-being. *PLoS Biology* 4: 1300-1305.
- Dillaha, T.A.; Sherrard, J.H.; Lee, D. 1986: Long-term effectiveness and maintenance of vegetative filter strips. *Water Environment Society* 153: 419-421.
- Dobson, A.; Lodge, D.; Alder, J.; Cumming, G.S.; Keymer, J.; McGlade, J.; Mooney, H.; Rusak, J.A.; Sala, O.; Wolters, V. 2006: Habitat loss, trophic collapse, and the decline of ecosystem services. *Ecology* 87: 1915-1924.
- Donovan, B.J. 1980: Interactions between native and introduced bees in New Zealand. *New Zealand Journal of Ecology* 3: 104-116.
- Dons, A. 1987: Hydrology and sediment regime of a pasture, native forest, and pine forest catchment in the Central North Island, New Zealand. *New Zealand Journal of Forestry Science* 17: 161-178.
- Douglas, M.M.; O'Connor, R.A. 2004: Weed invasion changes fuel characteristics: Para Grass (*Urochloa mutica* (Forssk.) TQ Nguyen) on a tropical floodplain. *Ecological Management & Restoration* 5: 143-145.
- Drenovsky, R.E.; Batten, K.M. 2007: Invasion by *Aegilops triuncialis* (barb goatgrass) slows carbon and nutrient cycling in a serpentine grassland. *Biological Invasions* 9: 107-116.
- Duarte, C.M. 2000: Marine biodiversity and ecosystem services: an elusive link. *Journal of Experimental Marine Biology and Ecology* 250: 117-131.
- Dudley, N.; Stolton, S. 2003: Running pure: the importance of forest protected areas to drinking water. A research report for the World Bank/WWF Alliance for Forest Conservation and Sustainable Use. WWF International, Gland, Switzerland. 114p.
- Duelli, P.; Obrist, M.K. 2003: Regional biodiversity in an agricultural landscape: the contribution of seminatural habitat islands. *Basic and Applied Ecology* 4: 129-138.
- Duncan, M.J.; Thomas, M.B. 2004: Hydrological effects of burning tall tussock grassland on the Lammermoor Range, East Otago, New Zealand. *Journal of Hydrology* 43: 125-139.
- Dunford, E.G. 1949: Relation of grazing to runoff and erosion on bunchgrass ranges. *Rocky Mountain Forest and Range and Experimental Station Notes* 7: 1-2.
- Dunne, T.; Zhang, W.; Aubry, B.F. 1991: Effects of rainfall, vegetation, and microtopography on infiltration and runoff. *Water Resources Research* 27: 2271-2285.
- Dupouey, J.L.; Dambrine, E.; Laffite, J.D.; Moares, C. 2002: Irreversible impact of past land use on forest soils and biodiversity. *Ecology* 83: 2978-2984.
- Durán Zuazo, V.H.; Martínez, J.R.F.; Pleguezuelo, C.R.R.; Martínez Raya, A.; Rodríguez, B.C. 2006: Soil-erosion and runoff prevention by plant covers in a mountainous area (SE Spain): implications for sustainable agriculture. *The Environmentalist* 26: 309-319.
- Durán Zuazo, V.H.D.; Martínez, J.R.F.; Raya, A.M. 2004: Impact of vegetative cover on runoff and soil erosion at Hillslope Scale in Lanjaron, Spain. *The Environmentalist* 24: 39-48.
- Dye, P.J.; Poulter, A.G. 1995: A field demonstration of the effect on streamflow of clearing invasive pine and wattle trees from a riparian zone. *South African Forestry Journal* 173: 27-30.
- Dyer, A.R.; Rice, K.J. 1999: Effects of competition on resource availability and growth of a California bunchgrass. *Ecology* 80: 2697-2710.
- Dymond, J.R.; Ausseil, A.G.; Shepherd, J.D.; Buettner, L. 2006: Validation of a region-wide model of landslide susceptibility in the Manawatu-Wanganui region of New Zealand. *Geomorphology* 74: 70-79.
- Eckman, J.E.; Duggins, D.O.; Sewell, A.T. 1989: Ecology of understory kelp environments. 1. Effects of kelps on flow and particle transport near the bottom. *Journal of Experimental Marine Biology and Ecology* 129: 173-187.

- Edgar, G.J.; Barrett, N.S. 1999: Effects of the declaration of marine reserves on Tasmanian reef fishes, invertebrates and plants. *Journal of Experimental Marine Biology and Ecology* 242: 107-144.
- Egoh, B.; Reyers, B.; Rouget, M.; Bode, M.; Richardson, D.M. 2009: Spatial congruence between biodiversity and ecosystem services in South Africa. *Biological Conservation* 142: 553-562.
- Ehrenfeld, J.G. 2003: Effects of exotic plant invasions on soil nutrient cycling processes. *Ecosystems* 6: 503-523.
- Ehrlén, J.; Eriksson, O. 1995: Pollen limitation and population growth in a herbaceous perennial legume. *Ecology* 76: 652-656.
- Eikaas, H.S.; McIntosh, A.R.; Kliskey, A.D. 2005: Catchment- and site-scale influences of forest cover and longitudinal forest position on the distribution of a diadromous fish. *Freshwater Biology* 50: 527-538.
- Ekanayake, J.C.; Phillips, C. 2002: Slope stability thresholds for vegetated hillslopes: a composite model. *Canadian Geotechnical Journal* 39: 849-862.
- Ellison, J.C. 1999: Impacts of sediment burial on mangroves. *Marine Pollution Bulletin* 37: 420-426.
- Ewel, K. 1997: Water quality improvement: evaluation of an ecosystem service. Pp. 329-344 in Daily, G. (Ed.): *Nature's services: societal dependence on natural ecosystems*. Island Press, Washington DC, USA.
- Ewel, K.C.; Twilley, R.R.; Ong, J.E. 1998: Different kinds of mangrove forests provide different goods and services. *Global Ecology and Biogeography Letters* 7: 83-94.
- Fahey, B.; Jackson, R. 1997: Hydrological impacts of converting native forests and grasslands to pine plantations, South Island, New Zealand. *Agricultural and Forest Meteorology* 84: 69-82.
- Fahey, B.D.; Bowden, W.B.; Smith, J.; Murray, D.L. 1998: Hillslope-wetland hydrological linkages in the headwaters of a tussock grassland catchment at Glendhu, South Island, New Zealand. Pp. 157-164 in: *Hydrology, water resources, and ecology of headwaters*. Proceedings of the HeadWater '98 Conference, Meran/Merano, Italy. IAHS Publication No. 248.
- Fahey, B.D.; Murray, D.L.; Jackson, R.M. 1996: Detecting fog deposition to tussock by lysimetry at Swampy Summit near Dunedin, New Zealand. *Journal of Hydrology, New Zealand* 35: 87-104.
- Fahey, B.D.; Watson, A.J. 1991: Hydrological impacts of converting tussock grassland to pine plantation, Otago, New Zealand. *Journal of Hydrology, New Zealand* 30: 1-15.
- Falkowski, P.; Scholes, R.J.; Boyle, E.; Canadell, J.; Canfield, D.; Elser, J.; Gruber, N.; Hibbard, K.; Hogberg, P.; Linder, S. 2000: The global carbon cycle: a test of our knowledge of earth as a system. *Science* 290: 291-296.
- Farley, K.A.; Jobbagy, E.G.; Jackson, R.B. 2005: Effects of afforestation on water yield: a global synthesis with implications for policy. *Global Change Biology* 11: 1565-1576.
- Faucette, L.B.; Risse, L.M.; Nearing, M.A.; Gaskin, J.W.; West, L.T. 2004: Runoff, erosion, and nutrient losses from compost and mulch blankets under simulated rainfall. *Journal of Soil and Water Conservation* 59: 154-160.
- Feagin, R.A.; Sherman, D.J.; Grant, W.E. 2005: Coastal erosion, global sea-level rise, and the loss of sand dune plant habitats. *Frontiers in Ecology and the Environment* 3: 359-364.
- Findlay, S.; Groffman, P.; Dye, S. 2003: Effects of *Phragmites australis* removal on marsh nutrient cycling. *Wetlands Ecology and Management* 11: 157-165.
- Fisher, G.; Rolfe, K.A.; Kjellstrom, T.; Woodward, A.; Hales, S.; Sturman, A.P.; Kingham, S.; Petersen, J.; Shrestha, R.; King, D. 2002: Health effects due to motor vehicle air pollution in New Zealand. Report to the Ministry of Transport, Wellington, New Zealand. 66p.
- Fitzpatrick, Ú.; Murray, T.E.; Paxton, R.J.; Breen, J.; Cotton, D.; Santorum, V.; Brown, M.J.F. 2007: Rarity and decline in bumblebees—a test of causes and correlates in the Irish fauna. *Biological Conservation* 136: 185-194.

- Foley, J.A.; Asner, G.P.; Costa, M.H.; Coe, M.T.; DeFries, R.; Gibbs, H.K.; Howard, E.A.; Olson, S.; Patz, J.; Ramankutty, N. 2007: Amazonia revealed: forest degradation and loss of ecosystem goods and services in the Amazon Basin. *Frontiers in Ecology and the Environment* 5: 25-32.
- Fonseca, M.S.; Cahalan, J. 1992: A preliminary evaluation of wave attenuation by four species of seagrass. *Estuarine, Coastal and Shelf Science* 35: 565-576.
- Forup, M.L.; Henson, K.S.E.; Craze, P.G.; Memmott, J. 2008: The restoration of ecological interactions: plant-pollinator networks on ancient and restored heathlands. *Journal of Applied Ecology* 45: 742-752.
- Foundation for Arable Research 2007: Bees busted by varroa but natives and other pollinators carry on. Press release 3 Feb 2007. Foundation for Arable Research, Lincoln, New Zealand.
- Fowler, D.; Cape, J.N.; Coyle, M.; Flechard, C.; Kuylenstierna, J.; Hicks, K.; Derwent, D.; Johnson, C.; Stevenson, D. 1999: The global exposure of forests to air pollutants. *Water, Air, & Soil Pollution* 116: 5-32.
- Franzluebbers, A.J. 2002: Water infiltration and soil structure related to organic matter and its stratification with depth. *Soil & Tillage Research* 66: 197-205.
- Freckman, D.W.; Ettema, C.H. 1993: Assessing nematode communities in agroecosystems of varying human intervention. *Agriculture, Ecosystems and Environment* 45: 239-261.
- Freckman, D.W.; Virginia, R.A. 1989: Plant-feeding nematodes in deep-rooting desert ecosystems. *Ecology* 70: 1665-1678.
- Freer-Smith, P.H.; El-Khatib, A.A.; Taylor, G. 2004: Capture of particulate pollution by trees: a comparison of species typical of semi-arid areas (*Ficus nitida* and *Eucalyptus globulus*) with European and North American species. *Water, Air, & Soil Pollution* 155: 173-187.
- Fuhlendorf, S.D.; Zhang, H.; Tunnell, T.R.; Engle, D.M.; Cross, A.F. 2002: Effects of grazing on restoration of southern mixed prairie soils. *Restoration Ecology* 10: 401-407.
- Fukami, T.; Wardle, D.A.; Bellingham, P.J.; Mulder, C.P.H.; Towns, D.R.; Yeates, G.W.; Bonner, K.I.; Durrett, M.S.; Grant-Hoffman, M.N.; Williamson, W.M. 2006: Above-and below-ground impacts of introduced predators in seabird-dominated island ecosystems. *Ecology Letters* 9: 1299-1307.
- Fuller, R.D.; Driscoll, C.T.; Lawrence, G.B.; Nodvin, S.C. 1987: Processes regulating sulphate flux after whole-tree harvesting. *Nature* 325: 707-710.
- Furness, R.W. 1991: The occurrence of burrow-nesting among birds and its influence on soil fertility and stability. Pp. 53-65 in Meadows, P.S.; Meadows, A. (Eds): The environmental impact of burrowing animals and animal burrows. Oxford University Press, Oxford, UK.
- Furukawa, K.; Wolanski, E.; Mueller, H. 1997: Currents and sediment transport in mangrove forests. *Estuarine, Coastal and Shelf Science* 44: 301-310.
- García, J.; Aguirre, P.; Mujeriego, R.; Huang, Y.; Ortiz, L.; Bayona, J.M. 2004: Initial contaminant removal performance factors in horizontal flow reed beds used for treating urban wastewater. *Water Research* 38: 1669-1678.
- Gell, F.R.; Roberts, C.M. 2003: Benefits beyond boundaries: the fishery effects of marine reserves. *Trends in Ecology & Evolution* 18: 448-455.
- Giller, P.S.; Hillebrand, H.; Berninger, U.G.; Gessner, M.O.; Hawkins, S.; Inchausti, P.; Inglis, C.; Leslie, H.; Malmqvist, B.; Monaghan, M.T. 2004: Biodiversity effects on ecosystem functioning: emerging issues and their experimental test in aquatic environments. *Oikos* 104: 423-436.
- Gillingham, A.G.; Thorrold, B.S. 2000: A review of New Zealand research measuring phosphorus in runoff from pasture. *Journal of Environmental Quality* 29: 88-96.
- Gilmour, D.A.; Bonell, M.; Cassells, D.S. 1987: The effects of forestation on soil hydraulic properties in the middle hills of Nepal: a preliminary assessment. *Mountain Research and Development* 7: 239-249.
- Given, B.B. 1945: Tachinid parasites attacking melolonthid larvae in New Zealand. *Transactions of the Royal Society of New Zealand* 75: 321-323.

- Glade, T. 2003: Landslide occurrence as a response to land use change: a review of evidence from New Zealand. *Catena* 51: 297-314.
- Godley, E.J. 1979: Flower biology in New Zealand. *New Zealand Journal of Botany* 17: 441-466.
- Goh, K.M.; Phillips, M.J. 1991: Effects of clearfell logging and clearfell logging and burning of a *Nothofagus* forest on soil nutrient dynamics in South Island, New Zealand—changes in forest floor organic matter and nutrient status. *New Zealand Journal of Botany* 29: 367-384.
- Goldman, R.L.; Thompson, B.H.; Daily, G.C. 2007: Institutional incentives for managing the landscape: inducing cooperation for the production of ecosystem services. *Ecological Economics* 64: 333-343.
- Gomez-Peralta, D.; Oberbauer, S.F.; McClain, M.E.; Philippi, T.E. 2008: Rainfall and cloud-water interception in tropical montane forests in the eastern Andes of Central Peru. *Forest Ecology and Management* 255: 1315-1325.
- Gong, J.; Chen, L.; Fu, B.; Huang, Y.; Huang, Z.; Peng, H. 2006: Effect of land use on soil nutrients in the loess hilly area of the Loess Plateau, China. *Land Degradation & Development* 17: 453-465.
- Goodwin, M. 2004: Introduction and spread of varroa in New Zealand. *Bee World* 85: 26-28.
- Görgens, A.H.M.; van Wilgen, B.W. 2004: Invasive alien plants and water resources: an assessment of current understanding, predictive ability and research challenges. *South African Journal of Science* 100: 27-33.
- Gosselink, J.G.; Shaffer, G.P.; Lee, L.C.; Burdick, D.M.; Childers, D.L.; Leibowitz, N.C.; Hamilton, S.C.; Boumans, R.; Cushman, D.; Fields, S. 1990: Landscape conservation in a forested wetland watershed. *BioScience* 40: 588-600.
- Goulson, D. 2003: Conserving wild bees for crop pollination. *Journal of Food, Agriculture & Environment* 1: 142-144.
- Goulson, D.; Hanley, M.E.; Darvill, B.; Ellis, J.S.; Knight, M.E. 2005: Causes of rarity in bumblebees. *Biological Conservation* 122: 1-8.
- Grant, C.D.; Ward, S.C.; Morley, S.C. 2007: Return of ecosystem function to restored bauxite mines in Western Australia. *Restoration Ecology* 15: S94-S103.
- Grant, P.J. 1989: A hydrologist's contribution to the debate on wild animal management. *New Zealand Journal of Ecology* 12(s): 165-169.
- Gratton, C.; Denno, R.F. 2005: Restoration of arthropod assemblages in a *Spartina* salt marsh following removal of the invasive plant *Phragmites australis*. *Restoration Ecology* 13: 358-372.
- Gratz, N.G. 1999: Emerging and resurging vector-borne diseases. *Annual Review of Entomology* 44: 51-75.
- Gray, J.S. 2002: Biomagnification in marine systems: the perspective of an ecologist. *Marine Pollution Bulletin* 45: 46-52.
- Graynoth, E. 1979: Effects of logging on stream environments and faunas in Nelson. *New Zealand Journal of Marine and Freshwater Research* 13: 79-109.
- Greenleaf, S.S.; Kremen, C. 2006a: Wild bee species increase tomato production and respond differently to surrounding land use in Northern California. *Biological Conservation* 133: 81-87.
- Greenleaf, S.S.; Kremen, C. 2006b: Wild bees enhance honey bees' pollination of hybrid sunflower. *Proceedings of The National Academy of Sciences* 103: 13890-13895.
- Greenway, D.R. 1987: Vegetation and slope stability. Pp. 187-230 in Anderson, M.; Richards, K. (Eds): Slope stability. John Wiley and Sons, Chichester.
- Greenway, M. 2005: The role of constructed wetlands in secondary effluent treatment and water reuse in subtropical and arid Australia. *Ecological Engineering* 25: 501-509.
- Greenwood, K.L.; McKenzie, B.M. 2001: Grazing effects on soil physical properties and the consequences for pastures: a review. *Australian Journal of Experimental Agriculture* 41: 1231-1250.

- Guidetti, P.; Milazzo, M.; Bussotti, S.; Molinari, A.; Murenu, M.; Pais, A.; Spanò, N.; Balzano, R.; Agardy, T.; Boero, F.; Carrada, G.; Cattaneo-Vietti, R.; Cau, A.; Chemello, R.; Greco, S.; Manganaro, A.; Notarbartolo di Sciara, G.; Russo, G.F.; Tunesi, L. 2008: Italian marine reserve effectiveness: does enforcement matter? *Biological Conservation* 141: 699–709.
- Gurr, G.M.; Wratten, S.D.; Barbosa, P. 2000: Success in conservation biological control of arthropods. Pp. 105–132 in Gurr, G.; Wratten, S. (Eds): *Biological control: measures of success*. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Hajabbasi, M.A.; Jalalian, A.; Karimzadeh, H.R. 1997: Deforestation effects on soil physical and chemical properties, Lordegan, Iran. *Plant and Soil* 190: 301–308.
- Hall, R.L.; Calder, I.R. 1993: Drop size modification by forest canopies: measurements using a disdrometer. *Journal of Geophysical Research* 98: 18465–18470.
- Hanchet, S.M. 1990: Effect of land use on the distribution and abundance of native fish in tributaries of the Waikato River in the Hakarimata Range, North Island, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 24: 159–171.
- Hansson, L.A.; Bronmark, C.; Anders Nilsson, P.; Abjornsson, K. 2005: Conflicting demands on wetland ecosystem services: nutrient retention, biodiversity or both? *Freshwater Biology* 50: 705–714.
- Harada, H.; Yamashita, U.; Kurihara, H.; Fukushi, E.; Kawabata, J.; Kamei, Y. 2002: Antitumor activity of palmitic acid found as a selective cytotoxic substance in a marine red alga. *Anticancer Research* 22: 2587–2590.
- Harding, J.S.; Hawke, D.J.; Holdaway, R.N.; Winterbourn, M.J. 2004: Incorporation of marine-derived nutrients from petrel breeding colonies into stream food webs. *Freshwater Biology* 49: 576–586.
- Harding, J.S.; Winterbourn, M.J. 1995: Effects of contrasting land use on physico-chemical conditions and benthic assemblages of streams in a Canterbury (South Island, New Zealand) river system. *New Zealand Journal of Marine and Freshwater Research* 29: 479–492.
- Haubensak, K.A.; D'Antonio, C.M. 2006: Restoration of a coastal California grassland after invasion by nitrogen-fixing shrubs, French broom and Scotch broom. *Ecological Restoration* 24: 93–99.
- Hawke, D.J.; Clark, J.M.; Challies, C.N. 2005: Verification of seabird contributions to Australasian harrier diet at Motunau Island, North Canterbury, using stable isotope analysis. *Notornis* 52: 158–162.
- Hawke, D.J.; Holdaway, R.N. 2005: Avian assimilation and dispersal of carbon and nitrogen brought ashore by breeding Westland petrels (*Procellaria westlandica*): a stable isotope study. *Journal of Zoology* 266: 419–426.
- Hawke, D.J.; Holdaway, R.N.; Causer, J.E.; Ogden, S. 1999: Soil indicators of pre-European seabird breeding in New Zealand at sites identified by predator deposits. *Australian Journal of Soil Research* 37: 103–113.
- Hawke, D.J.; Powell, H.K.J. 1995: Soil solution chemistry at a Westland petrel breeding colony, New Zealand: palaeoecological implications. *Australian Journal of Soil Research* 33: 915–924.
- Hawkes, C.V.; Wren, I.F.; Herman, D.J.; Firestone, M.K. 2005: Plant invasion alters nitrogen cycling by modifying the soil nitrifying community. *Ecology Letters* 8: 976–985.
- Haycock, N.E.; Pinay, G. 1993: Groundwater nitrate dynamics in grass and poplar vegetated riparian buffer strips during the winter. *Journal of Environmental Quality* 22: 273–278.
- Heath, D.J.; Lewis, C.A.; Rowland, S.J. 1997: The use of high temperature gas chromatography to study the biodegradation of high molecular weight hydrocarbons. *Organic Geochemistry* 26: 769–785.
- Hemminga, M.A.; Nieuwenhuize, J. 1990: Seagrass wrack-induced dune formation on a tropical coast (Banc d'Arguin, Mauritania). *Estuarine, Coastal and Shelf Science* 31: 499–502.
- Hesp, P. 2002: Foredunes and blowouts: initiation, geomorphology and dynamics. *Geomorphology* 48: 245–268.

- Hibbert, A.R. 1971: Increases in streamflow after converting chaparral to grass. *Water Resources Research* 7: 71–80.
- Hickey, C.; Quinn, J.; Davies-Colley, R. 1989: Effluent characteristics of dairy shed oxidation ponds and their potential impacts on rivers. *New Zealand Journal of Marine and Freshwater Research* 23: 569–584.
- Hill, A.R. 1996: Nitrate removal in stream riparian zones. *Journal of Environmental Quality* 25: 743–755.
- Hogan, D.M.; Jordan, T.E.; Walbridge, M.R. 2004: Phosphorus retention and soil organic carbon in restored and natural freshwater wetlands. *Wetlands* 24: 573–585.
- Holdaway, R.N. 1996: Arrival of rats in New Zealand. *Nature* 384: 225–226.
- Holdaway, R.N.; Worthy, T.H. 1994: A new fossil species of shearwater *Puffinus* from the Late Quaternary of the South Island, New Zealand, and notes on the biogeography and evolution of the *Puffinus gavia* superspecies. *Emu* 94: 201–215.
- Holdsworth, D.K.; Mark, A.F. 1990: Water and nutrient input: output budgets: effects of plant cover at seven sites in upland snow tussock grasslands of eastern and central Otago, New Zealand. *Journal of the Royal Society of New Zealand* 20: 1–24.
- Holwerda, F.; Burkard, R.; Eugster, W.; Scatena, F.N.; Meesters, A.; Bruijnzeel, L.A. 2006: Estimating fog deposition at a Puerto Rican elfin cloud forest site: comparison of the water budget and eddy covariance methods. *Hydrological Processes* 20: 2669–2692.
- Hooper, D.U.; Chapin Iii, F.S.; Ewel, J.J.; Hector, A.; Inchausti, P.; Lavorel, S.; Lawton, J.H.; Lodge, D.M.; Loreau, M.; Naeem, S. 2005: Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. *Ecological Monographs* 75: 3–35.
- Hooper, D.U.; Vitousek, P.M. 1997: The effects of plant composition and diversity on ecosystem processes. *Science* 277: 1302–1305.
- Hornbeck, J.W.; Adams, M.B.; Corbett, E.S.; Verry, E.S.; Lynch, J.A. 1993: Long-term impacts of forest treatments on water yield: a summary for northeastern USA. *Journal of Hydrology* 150: 323–344.
- Hosetti, B.; Frost, S. 1998: A review of the control of biological waste treatment in stabilization ponds. *Critical Reviews in Environmental Science and Technology* 28: 193–218.
- Houser, C.; Hapke, C.; Hamilton, S. 2008: Controls on coastal dune morphology, shoreline erosion and barrier island response to extreme storms. *Geomorphology* 100: 223–240.
- Hoven, H.M.; Gaudette, H.E.; Short, F.T. 1999: Isotope ratios of ²⁰⁶Pb/²⁰⁷Pb in eelgrass, *Zostera marina*, indicate sources of Pb in an estuary. *Marine Environmental Research* 48: 377–387.
- Howard-Williams, C.; Pickmere, S. 2005: Long-term nutrient and vegetation changes in a retired pasture stream. *Science for Conservation* 257. Department of Conservation, Wellington, NZ. 30 p.
- Howlett, B.G.; Donovan, B.J.; McCallum, J.A.; Newstrom, L.E.; Teulon, D.A.J. 2005: Between and within field variability of New Zealand indigenous flower visitors to onions. *New Zealand Plant Protection* 58: 213–218.
- Howlett, B.G.; McCallum, J.A.; Walker, M.C.; Donovan, B.J.; Newstrom-Lloyd, L.E.; Teulon, D.A.J. n.d. a: Spatial heterogeneity of floral visitor assemblages in commercial onion seed crops in New Zealand. Unpublished report. Crop & Food Research, Christchurch, New Zealand. 43 p.
- Howlett, B.G.; Teulon, D.A.J. n.d.: The distribution of hover flies (Syrphidae) on pak choi and onion seed crops and their effectiveness as pollinators. Unpublished report. Crop & Food Research, Christchurch, New Zealand. 2 p.
- Howlett, B.G.; Walker, M.K. n.d.: The occurrence and requirements of unmanaged crop flower visitors in New Zealand. Unpublished report. Crop & Food Research, Christchurch, New Zealand. 1 p.
- Howlett, B.G.; Witt, T.C.; Fitzjohn, R.; Newstrom-Lloyd, L.E.; Walker, M.C.; Teulon, D.A.J. n.d. b: Flower visitation and pollinator effectiveness of honeybees and alternative pollinators in onion seed crops in New Zealand. Unpublished report. Crop & Food Research, Christchurch, New Zealand. 51 p.

- Huang, M.; Zhang, L.; Gallichand, J. 2003: Runoff responses to afforestation in a watershed of the Loess Plateau, China. *Hydrological Processes* 17: 2599–2609.
- Hughes, R.F.; Kauffman, J.B.; Jaramillo, V.J. 1999: Biomass, carbon, and nutrient dynamics of secondary forests in a humid tropical region of Mexico. *Ecology* 80: 1892–1907.
- Ieno, E.N.; Solan, M.; Batty, P.; Pierce, G.J. 2006: How biodiversity affects ecosystem functioning: roles of infaunal species richness, identity and density in the marine benthos. *Marine Ecology Progress Series* 311: 263–271.
- Igual, J.M.; Forero, M.G.; Gomez, T.; Orueta, J.F.; Oro, D. 2006: Rat control and breeding performance in Cory's shearwater (*Calonectris diomedea*): effects of poisoning effort and habitat features. *Animal Conservation* 9: 59–65.
- Imber, M.J.; West, J.A.; Cooper, W.J. 2003: Cook's petrel (*Pterodroma cooki*): historic distribution, breeding biology and effects of predators. *Notornis* 50: 221–230.
- Ingraham, N.L.; Mark, A.F. 2000: Isotopic assessment of the hydrologic importance of fog deposition on tall snow tussock grass on southern New Zealand uplands. *Austral Ecology* 25: 402–408.
- Irvin, N.A.; Scarratt, S.L.; Wratten, S.D.; Frampton, C.M.; Chapman, R.B.; Tylianakis, J.M. 2006: The effects of floral understoreys on parasitism of leafrollers (Lepidoptera: Tortricidae) on apples in New Zealand. *Agricultural and Forest Entomology* 8: 25–34.
- Irvine, J.; Law, B.E.; Kurpius, M.R.; Anthoni, P.M.; Moore, D.; Schwarz, P.A. 2004: Age-related changes in ecosystem structure and function and effects on water and carbon exchange in ponderosa pine. *Tree Physiology* 24: 753–763.
- Islam, K.R.; Weil, R.R. 2000: Land use effects on soil quality in a tropical forest ecosystem of Bangladesh. *Agriculture, Ecosystems and Environment* 79: 9–16.
- Jackson, R.J. 1987: Hydrology of an acid wetland before and after draining for afforestation, western New Zealand. Pp. 465–474 in: Proceedings, Symposium on Forest Hydrology and Watershed Management, Vancouver, Canada, August 1987. IAHS Publication no. 167.
- Jansson, M.; Andersson, R.; Berggren, H.; Leonardson, L. 1994: Wetlands and lakes as nitrogen traps. *Ambio (Stockholm)* 23: 320–325.
- Jim, C.Y.; Chen, W.Y. 2008: Assessing the ecosystem service of air pollutant removal by urban trees in Guangzhou (China). *Journal of Environmental Management* 88: 665–676.
- Johnson, R. 1998: The forest cycle and low river flows: a review of UK and international studies. *Forest Ecology and Management* 109: 1–7.
- Johnson, S.D.; Bond, W.J. 1997: Evidence for widespread pollen limitation of fruiting success in Cape wildflowers. *Oecologia* 109: 530–534.
- Johnston, C.A. 1991: Sediment and nutrient retention by freshwater wetlands: effects on surface water quality. *Critical Reviews in Environmental Control* 21: 491–565.
- Johnston, C.A. 1993: Material fluxes across wetland ecotones in northern landscapes. *Ecological Applications* 3: 424–440.
- Johnston, C.A.; Detenbeck, N.E.; Niemi, G.J. 1990: The cumulative effect of wetlands on stream water quality and quantity. A landscape approach. *Biogeochemistry* 10: 105–141.
- Jones, H.P.; Tershy, B.R.; Zavaleta, E.S.; Croll, D.A.; Keitt, B.S.; Finkelstein, M.E.; Howald, G.R. 2008: Severity of the effects of invasive rats on seabirds: a global review. *Conservation Biology* 22: 16–26.
- Jones, H.P.; Williamhenry, R.; Howald, G.R.; Tershy, B.R.; Croll, D.A. 2006: Predation of artificial Xantus's murrelet (*Synthliboramphus hypoleucus scrippsii*) nests before and after black rat (*Rattus rattus*) eradication. *Environmental Conservation* 32: 320–325.
- Jowett, I.G.; Richardson, J.; McDowall, R.M. 1996: Relative effects of in-stream habitat and land use on fish distribution and abundance in tributaries of the Grey River, New Zealand. *New Zealand Journal of Marine and Freshwater Research* 30: 463–475.
- Kaiser, B.A. 2006: Economic impacts of non-indigenous species: *Miconia* and the Hawaiian economy. *Euphytica* 148: 135–150.

- Kalin, M.; Wheeler, W.N.; Meinrath, G. 2004: The removal of uranium from mining waste water using algal/microbial biomass. *Journal of Environmental Radioactivity* 78: 151-177.
- Kauffman, J.B.; Cummings, D.L.; Ward, D.E.; Babbitt, R. 1995: Fire in the Brazilian Amazon: 1. Biomass, nutrient pools, and losses in slashed primary forests. *Oecologia* 104: 397-408.
- Kearns, C.A.; Inouye, D.W. 1997: Pollinators, flowering plants, and conservation biology. *BioScience* 47: 297-307.
- Kearns, C.A.; Inouye, D.W.; Waser, N.M. 1998: Endangered mutualisms: the conservation of plant-pollinator interactions. *Annual Reviews in Ecology and Systematics* 29: 83-112.
- Kelly, D.; Brindle, C.; Ladley, J.J.; Robertson, A.W.; Maddigan, F.W.; Butler, J.; Ward-Smith, T.; Murphy, D.J.; Sessions, L.A. 2005: Can stoat (*Mustela erminea*) trapping increase bellbird (*Anthornis melanura*) populations and benefit mistletoe (*Peraxilla tetrapetala*) pollination? *New Zealand Journal of Ecology* 29: 69-82.
- Kelly, D.; Ladley, J.J.; Robertson, A.W. 2004: Is dispersal easier than pollination? Two tests in New Zealand Loranthaceae. *New Zealand Journal of Botany* 42: 89-103.
- Kelly, D.; Robertson, A.W.; Ladley, J.J.; Anderson, S.H.; McKenzie, R.J. 2006: Relative (un) importance of introduced animals as pollinators and dispersers of native plants. Pp. 227-245 in Allen, R.B.; Lee, W.G. (Eds): *Biological invasions in New Zealand*. Springer, Berlin, Germany.
- Kelly, S.; Scott, D.; MacDiarmid, A.B. 2002: The value of a spillover fishery for spiny lobsters around a marine reserve in northern New Zealand. *Coastal Management* 30: 153-166.
- Kelly, S.; Scott, D.; MacDiarmid, A.B.; Babcock, R.C. 2000: Spiny lobster, *Jasus edwardsii*, recovery in New Zealand marine reserves. *Biological Conservation* 92: 359-369.
- Kennard, D.K.; Gholz, H.L. 2001: Effects of high- and low-intensity fires on soil properties and plant growth in a Bolivian dry forest. *Plant and Soil* 234: 119-129.
- Kerr, A.M.; Baird, A.H. 2007: Natural barriers to natural disasters. *BioScience* 57: 102-103.
- Kerr, A.M.; Baird, A.H.; Campbell, S.J. 2006: Comments on 'Coastal mangrove forests mitigated tsunami' by K. Kathiresan and N. Rajendran [Estuar. Coast. Shelf Sci. 65 (2005) 601-606]. *Estuarine, Coastal and Shelf Science* 67: 539-541.
- Kersten, M.; Forstner, U. 1986: Chemical fractionation of heavy metals in anoxic estuarine and coastal sediments. *Water Science and Technology* 18: 121-130.
- Kevan, P.G. 1999: Pollinators as bioindicators of the state of the environment: species, activity and diversity. *Agriculture, Ecosystems and Environment* 74: 373-393.
- Kleijn, D.; van Langevelde, F. 2006: Interacting effects of landscape context and habitat quality on flower visiting insects in agricultural landscapes. *Basic and Applied Ecology* 7: 201-214.
- Klein, A.M. 2003: Fruit set of highland coffee increases with the diversity of pollinating bees. *Proceedings of the Royal Society Series B-Biological Sciences* 270: 955-961.
- Klein, A.M.; Vaissière, B.E.; Cane, J.H.; Steffan-Dewenter, I.; Cunningham, S.A.; Kremen, C.; Tscharntke, T. 2007: Importance of pollinators in changing landscapes for world crops. *Proceedings of the Royal Society Series B-Biological Sciences* 274: 303-313.
- Koch, E.W.; Ackerman, J.D.; Verduin, J.; van Keulen, M. 2006: Fluid dynamics in seagrass ecology—from molecules to ecosystems. Pp. 193-225 in Larkum, A.; Orth, R.; Duarte, C. (Eds): *Seagrasses: biology, ecology and their conservation*. Springer-Verlag, Berlin, Germany.
- Koch, E.W.; Barbier, E.B.; Silliman, B.R.; Reed, D.J.; Perillo, G.M.E.; Hacker, S.D.; Granek, E.F.; Primavera, J.H.; Muthiga, N.; Polasky, S. 2009: Non-linearity in ecosystem services: temporal and spatial variability in coastal protection. *Frontiers in Ecology and the Environment* 7: 29-37.
- Kohler, F.; Verhulst, J.; van Klink, R.; Kleijn, D. 2008: At what spatial scale do high-quality habitats enhance the diversity of forbs and pollinators in intensively farmed landscapes? *Journal of Applied Ecology* 45: 753-762.
- Koskiaho, J. 2003: Flow velocity retardation and sediment retention in two constructed wetland-ponds. *Ecological Engineering* 19: 325-337.

- Koster, R.D.; Suarez, M.J.; Heiser, M. 2000: Variance and predictability of precipitation at seasonal-to-interannual timescales. *Journal of Hydrometeorology* 1: 26–46.
- Kraus, B.; Page Jr, R.E. 1995: Effect of *Varroa jacobsoni* (Mesostigmata: Varroidae) on feral *Apis mellifera* (Hymenoptera: Apidae) in California. *Environmental Entomology* 24: 1473–1480.
- Kremen, C.; Chaplin-Kramer, R. 2007: Insects as providers of ecosystem services: crop pollination and pest control. Pp. 349–382 in Stewart, A.; New, T.; Lewis, O. (Eds): Insect conservation biology: Proceedings of the Royal Entomological Society's 23rd Symposium. CABI Publishing, Wallingford, UK.
- Kremen, C.; Ostfeld, R.S. 2005: A call to ecologists: measuring, analyzing, and managing ecosystem services. *Frontiers in Ecology and the Environment* 3: 540–548.
- Kremen, C.; Williams, N.M.; Bugg, R.L.; Fay, J.P.; Thorp, R.W. 2004: The area requirements of an ecosystem service: crop pollination by native bee communities in California. *Ecology Letters* 7: 1109–1119.
- Kremen, C.; Williams, N.M.; Thorp, R.W. 2002: Crop pollination from native bees at risk from agricultural intensification. *Proceedings of the National Academy of Sciences* 99: 16812–16816.
- Kristensen, E.; Jensen, M.H.; Banta, G.T.; Hansen, K.; Holmer, M.; King, G.M. 1998: Transformation and transport of inorganic nitrogen in sediments of a southeast Asian mangrove forest. *Aquatic Microbial Ecology* 15: 165–175.
- Kruess, A.; Tschamntke, T. 2000: Species richness and parasitism in a fragmented landscape: experiments and field studies with insects on *Vicia sepium*. *Oecologia* 122: 129–137.
- Kutiel, P.; Inbar, M. 1993: Fire impacts on soil nutrients and soil erosion in a mediterranean pine forest plantation. *Catena* 20: 129–139.
- Ladley, J.J.; Kelly, D. 1996: Dispersal, germination and survival of New Zealand mistletoes (Loranthaceae): dependence on birds. *New Zealand Journal of Ecology* 20: 69–79.
- Lal, R. 1994: Soil erosion by wind and water: problems and prospects. Pp. 1–9 in Lal, R. (Ed.): Soil erosion research methods. CRC Press, Boca Raton, Florida, USA.
- Lal, R. 1999: Soil management and restoration for C sequestration to mitigate the accelerated greenhouse effect. *Progress in Environmental Science* 1: 307–326.
- Landis, D.A.; Wratten, S.D.; Gurr, G.M. 2000: Habitat management to conserve natural enemies of arthropod pests in agriculture. *Annual Reviews in Entomology* 45: 175–201.
- Langellotto, G.A.; Denno, R.F. 2004: Responses of invertebrate natural enemies to complex-structured habitats: a meta-analytical synthesis. *Oecologia* 139: 1–10.
- Larned, S.T.; Scarsbrook, M.R.; Snelder, T.H.; Norton, N.J.; Biggs, B.J.F. 2004: Water quality in low-elevation streams and rivers of New Zealand: recent state and trends in contrasting land-cover classes. *New Zealand Journal of Marine and Freshwater Research* 38: 347–366.
- Lawton, R.O.; Nair, U.S.; Pielke, R.A.; Welch, R.M. 2001: Climatic impact of tropical lowland deforestation on nearby montane cloud forests. *Science* 294: 584–587.
- Leamy, M.L.; Blakemore, L.C. 1960: The peat soils of the Auckland Islands. *New Zealand Journal of Agricultural Research* 3: 526–546.
- Leary, J.K.; Hue, N.V.; Singleton, P.W.; Borthakur, D. 2006: The major features of an infestation by the invasive weed legume gorse (*Ulex europaeus*) on volcanic soils in Hawaii. *Biology and Fertility of Soils* 42: 215–223.
- Leibowitz, S.G. 2003: Isolated wetlands and their functions: an ecological perspective. *Wetlands* 23: 517–531.
- Leisnham, P.T.; Lester, P.J.; Slaney, D.P.; Weinstein, P. 2004: Anthropogenic landscape change and vectors in New Zealand: effects of shade and nutrient levels on mosquito productivity. *EcoHealth* 1: 306–316.

- Leisnham, P.T.; Slaney, D.P.; Lester, P.J.; Weinstein, P. 2005: Increased larval mosquito densities from modified landuses in the Kapiti region, New Zealand: vegetation, water quality, and predators as associated environmental factors. *EcoHealth* 2: 313–322.
- Lemenih, M.; Karlun, E.; Olsson, M. 2005: Assessing soil chemical and physical property responses to deforestation and subsequent cultivation in smallholders farming system in Ethiopia. *Agriculture, Ecosystems and Environment* 105: 373–386.
- Le Maitre, D.C.; van Wilgen, B.W.; Gelderblom, C.M.; Bailey, C.; Chapman, R.A.; Nel, J.A. 2002: Invasive alien trees and water resources in South Africa: case studies of the costs and benefits of management. *Forest Ecology and Management* 160: 143–159.
- Lenat, D.R.; Crawford, J.K. 1994: Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. *Hydrobiologia* 294: 185–199.
- Levett, M.P.; Adams, J.A.; Walker, T.W. 1985: Nutrient returns in litterfall in two indigenous and two radiata pine forests, Westland, New Zealand. *New Zealand Journal of Botany* 23: 55–64.
- Levine, J.M.; Vilà, M.; D' Antonio, C.M.; Dukes, J.S.; Grigulis, K.; Lavorel, S. 2003: Mechanisms underlying the impacts of exotic plant invasions. *Proceedings of the Royal Society Series B-Biological Sciences* 270: 775–781.
- Lippincott, C.L. 2000: Effects of *Imperata cylindrica* (L.) Beauv. (cogongrass) invasion on fire regime in Florida Sandhill (USA). *Natural Areas Journal* 20: 140–149.
- Liu, W.; Meng, F.R.; Zhang, Y.; Liu, Y.; Li, H. 2004: Water input from fog drip in the tropical seasonal rain forest of Xishuangbanna, South-West China. *Journal of Tropical Ecology* 20: 517–524.
- Lloyd, D.G. 1985: Progress in understanding the natural history of New Zealand plants. *New Zealand Journal of Botany* 23: 707–722.
- Loch, R.J. 2000: Effects of vegetation cover on runoff and erosion under simulated rain and overland flow on a rehabilitated site on the Meandu Mine, Tarong, Queensland. *Australian Journal of Soil Research* 38: 299–312.
- LoGuidice, K.; Osterfeld, R.S.; Schmidt, K.A.; Keesing, F. 2003: The ecology of infectious disease: effects of host diversity and community composition. *Proceedings of the National Academy of Sciences* 100: 567–571.
- Loope, L.L.; Sanchez, P.G.; Tarr, P.W.; Loope, W.L.; Anderson, R.L. 1988: Biological invasions of arid land nature reserves. *Biological Conservation* 44: 95–118.
- López-Bermúdez, F.; Romero-Díaz, A.; Martínez-Fernandez, J.; Martínez-Fernandez, J. 1998: Vegetation and soil erosion under a semi-arid Mediterranean climate: a case study from Murcia (Spain). *Geomorphology* 24: 51–58.
- Loreau, M.; Naeem, S.; Inchausti, P.; Bengtsson, J.; Grime, J.P.; Hector, A.; Hooper, D.U.; Huston, M.A.; Raffaelli, D.; Schmid, B. 2001: Biodiversity and ecosystem functioning: current knowledge and future challenges. *Science* 294: 804–808.
- Lowrance, R.; Todd, R.; Fail, J.; Hendrickson, O.; Leonard, R.; Asmussen, L. 1984: Riparian forests as nutrient filters in agricultural watersheds. *BioScience* 34: 374–377.
- Luck, G.W.; Harrington, R.; Harrison, P.A.; Kremen, C.; Berry, P.M.; Bugter, R.; Dawson, T.P.; de Bello, F.; Diaz, S.; Feld, C.K. 2009: Quantifying the contribution of organisms to the provision of ecosystem services. *BioScience* 59: 223–235.
- Ludwig, J.A.; Wilcox, B.P.; Breshears, D.D.; Tongway, D.J.; Imeson, A.C. 2005: Vegetation patches and runoff-erosion as interacting ecohydrological processes in semiarid landscapes. *Ecology* 86: 288–297.
- Lumbanraja, J.; Syam, T.; Nishide, H.; Mahi, A.K.; Utomo, M.; Kimura, M. 1998: Deterioration of soil fertility by land use changes in South Sumatra, Indonesia: from 1970 to 1990. *Hydrological Processes* 12: 2003–2113.
- Lüning, K.; Pang, S. 2003: Mass cultivation of seaweeds: current aspects and approaches. *Journal of Applied Phycology* 15: 115–119.
- Lusby, F.E.; Gibbs, M.M.; Cooper, A.B.; Thompson, K. 1998: The fate of groundwater ammonium in a lake edge wetland. *Journal of Environmental Quality* 27: 459–466.

- MA 2005: Millennium ecosystem assessment. Ecosystems and human well-being: current state and trends, Volume 1. Island Press, Washington DC, USA. 917 p.
- Maass, J.M.; Jordan, C.F.; Sarukhan, J. 1988: Soil erosion and nutrient losses in seasonal tropical agroecosystems under various management techniques. *Journal of Applied Ecology* 25: 595-607.
- MacFarlane, G.R.; Pulkownik, A.; Burchett, M.D. 2003: Accumulation and distribution of heavy metals in the grey mangrove, *Avicennia marina* (Forsk.) Vierh.: biological indication potential. *Environmental Pollution* 123: 139-151.
- Macfarlane, R.P.; Ferguson, A.M. 1983: Kiwifruit pollination: a survey of the insect pollinators in New Zealand. Pp. 367-373 in: Proceedings of the Fifth International Symposium on Pollination, 27-30 September, 1983, Versailles, France.
- Mack, M.C.; D' Antonio, C.M.; Ley, R.E. 2001: Alteration of ecosystem nitrogen dynamics by exotic plants: a case study of C4 grasses in Hawaii. *Ecological Applications* 11: 1323-1335.
- Maes, D.; Van Dyck, H. 2001: Butterfly diversity loss in Flanders (north Belgium): Europe's worst case scenario? *Biological Conservation* 99: 263-276.
- Mainville, N.; Webb, J.; Lucotte, M.; Davidson, R.; Betancourt, O.; Cueva, E.; Mergler, D. 2006: Decrease of soil fertility and release of mercury following deforestation in the Andean Amazon, Napo River Valley, Ecuador. *Science of the Total Environment* 368: 88-98.
- Malmqvist, B.; Rundle, S. 2002: Threats to the running water ecosystems of the world. *Environmental Conservation* 29: 134-153.
- Marchante, E.; Kjoller, A.; Struwe, S.; Freitas, H. 2009: Soil recovery after removal of the N₂-fixing invasive *Acacia longifolia*: consequences for ecosystem restoration. *Biological Invasions* 11: 813-823.
- Marden, M.; Rowan, D. 1993: Protective value of vegetation on Tertiary terrain before and during Cyclone Bola, East Coast, North Island, New Zealand. *New Zealand Journal of Forestry Science* 23: 255-263.
- Marden, M.; Rowan, D.; Phillips, C. 2005: Stabilising characteristics of New Zealand indigenous riparian colonising plants. *Plant and Soil* 278: 95-105.
- Marín-Guirao, L.; Atucha, A.M.; Barba, J.L.; López, E.M.; Fernández, A.J.G. 2005: Effects of mining wastes on a seagrass ecosystem: metal accumulation and bioavailability, seagrass dynamics and associated community structure. *Marine Environmental Research* 60: 317-337.
- Mark, A.F.; Dickinson, K.J.M. 2008: Maximizing water yield with indigenous non-forest vegetation: a New Zealand perspective. *Frontiers in Ecology and the Environment* 6: 25-34.
- Mark, A.F.; Holdsworth, D.K. 1979: Yield and macronutrient content of water in relation to plant cover from the snow tussock grassland zone of eastern and central Otago, New Zealand. *Progress in Water Technology* 11: 449-462.
- Mark, A.F.; Rowley, J. 1976: Water yield of low-alpine snow tussock grassland in Central Otago. *Journal of Hydrology (New Zealand)* 15: 59-79.
- Markwell, T.J.; Daugherty, C.H. 2002: Invertebrate and lizard abundance is greater on seabird-inhabited islands than on seabird-free islands in the Marlborough Sounds, New Zealand. *Ecoscience* 9: 293-299.
- Maron, J.L.; Estes, J.A.; Croll, D.A.; Danner, E.M.; Elmendorf, S.C.; Buckelew, S.L. 2006: An introduced predator alters Aleutian Island plant communities by thwarting nutrient subsidies. *Ecological Monographs* 76: 3-24.
- Marrs, R.H.; Lowday, J. 1992: Control of bracken and the restoration of heathland. II. Regeneration of the heathland community. *Journal of Applied Ecology* 29: 204-211.
- Martens, P.; McMichael, A.J.; Patz, J.A. 2000: Globalisation, environmental change and health. *Global Change & Human Health* 1: 4-8.
- Martin, M.R.; Tipping, P.W.; Sickman, J.O. In Press: Invasion by an exotic tree alters above and belowground ecosystem components. *Biological Invasions*: DOI 10.1007/s10530-008-9366-3.

- Martin, S.J. 1998: A population dynamic model of the mite *Varroa jacobsoni*. *Ecological Modelling* 109: 267-281.
- Mascarenhas, A.; Jayakumar, S. 2008: An environmental perspective of the post-tsunami scenario along the coast of Tamil Nadu, India: role of sand dunes and forests. *Journal of Environmental Management* 89: 24-34.
- Matheson, F.E.; Nguyen, M.L.; Cooper, A.B.; Burt, T.P. 2003: Short-term nitrogen transformation rates in riparian wetland soil determined with nitrogen-15. *Biology and Fertility of Soils* 38: 129-136.
- Mayer, P.; Reynolds, S.; McCutchen, M.; Canfield, T. 2005: Riparian buffer width, vegetative cover, and nitrogen removal effectiveness: a review of current science and regulations. EPA/600/R-05/118. U.S. Environmental Protection Agency, Cincinnati, OH, USA.
- Mazda, Y.; Magi, M.; Ikeda, Y.; Kurokawa, T.; Asano, T. 2006: Wave reduction in a mangrove forest dominated by *Sonneratia* sp. *Wetlands Ecology and Management* 14: 365-378.
- McClanahan, T.R.; Arthur, R. 2001: The effect of marine reserves and habitat on populations of East African coral reef fishes. *Ecological Applications* 11: 559-569.
- McDonald, M.A.; Healey, J.R. 2000: Nutrient cycling in secondary forests in the Blue Mountains of Jamaica. *Forest Ecology and Management* 139: 257-278.
- McDowell, R.M. 1984: The New Zealand whitebait book. Reed, Wellington. 210 p.
- McDowell, R.M. 1990: New Zealand freshwater fishes: a natural history and guide. Heinemann-Reed, Auckland, NZ. 553 p.
- McGlynn, B.L.; Seibert, J. 2003: Distributed assessment of contributing area and riparian buffering along stream networks. *Water Resources Research* 39: No 4, 1082, doi:10.1029/2002WR001521.
- McGuffie, K.; Henderson-Sellers, A.; Zhang, H.; Durbidge, T.B.; Pitman, A.J. 1995: Global climate sensitivity to tropical deforestation. *Global and Planetary Change* 10: 97-128.
- McGuinness, J.L.; Harrold, L.L. 1971: Reforestation influences on small watershed streamflow. *Water Resources Research* 7: 845-852.
- McIntosh, P.D.; Allen, R.B. 1998: Effect of enclosure on soils, biomass, plant nutrients, and vegetation, on unfertilised steeplands, Upper Waitaki District, South Island, New Zealand. *New Zealand Journal of Ecology* 22: 209-217.
- McIntosh, P.D.; Allen, R.B.; Patterson, R.; Aubrey, B.; McGimpsey, P. 1994: Monitoring the effects of pastoral use on upland and high country soils in South Island, New Zealand. *Proceedings of the New Zealand Grassland Association* 56: 233-237.
- McIntosh, P.D.; Allen, R.B.; Scott, N. 1997: Effects of enclosure and management on biomass and soil nutrient pools in seasonally dry high country, New Zealand. *Journal of Environmental Management* 51: 169-186.
- McIntosh, P.D.; Ogle, G.I.; Patterson, R.; Aubrey, B.; Morris, J.; Giddens, K. 1996: Changes of surface soil nutrients and sustainability of pastoralism on grazed hilly and steep land, South Island, New Zealand. *Journal of Range Management* 49: 361-367.
- McKergow, L.A.; Weaver, D.M.; Prosser, I.P.; Grayson, R.B.; Reed, A.E.G. 2003: Before and after riparian management: sediment and nutrient exports from a small agricultural catchment, Western Australia. *Journal of Hydrology* 270: 253-272.
- McNutt, K.L. 1998: Impacts of reduced bird densities on pollination and dispersal mutualisms in New Zealand forests. Unpublished MSc. thesis, Massey University, New Zealand. 163 p.
- Meeuwig, R.O. 1970: Infiltration and soil erosion as influenced by vegetation and soil in northern Utah. *Journal of Range Management* 23: 185-188.
- Merrill, J.Z.; Cornwell, J. 2000: The role of oligohaline marshes in estuarine nutrient cycling. Pp. 425-441 in Weinstein, M.P.; Kreeger, D.A. (Eds): Concepts and controversies in tidal marsh ecology. Kluwer Academic Publishers, Dordrecht, The Netherlands.
- Merton, J.M. 1980: The interrelationships of *Costelytra zealandica* (White) (Coleoptera: Scarabaeidae) the New Zealand grass grub, and its parasite *Proscissio cana* Hutton (Diptera: Tachinidae). Unpublished MSc. thesis. University of Canterbury, Christchurch, NZ. 111 p.

- Meurk, C.D.; Wratten, S.; Sam, S. 2008: Greening Waipara: a 'grape roots' project to include biodiversity in the wine experience. Unpublished Greening Waipara Research Paper, Landcare Research, Lincoln, NZ.
- Meyer, C.K.; Baer, S.G.; Whiles, M.R. 2008: Ecosystem recovery across a chronosequence of restored wetlands in the Platte River valley. *Ecosystems* 11: 193–208.
- Meziane, T.; Tsuchiya, M. 2002: Organic matter in a subtropical mangrove-estuary subjected to wastewater discharge: origin and utilisation by two macrozoobenthic species. *Journal of Sea Research* 47: 1–11.
- Milchunas, D.G.; Lauenroth, W.K. 1993: Quantitative effects of grazing on vegetation and soils over a global range of environments. *Ecological Monographs* 63: 327–366.
- Ming, J.; Xian-guo, L.; Lin-shu, X.; Li-juan, C.; Shouzheng, T. 2007: Flood mitigation benefit of wetland soil—a case study in Momoge National Nature Reserve in China. *Ecological Economics* 61: 217–223.
- Minns, C.K. 1990: Patterns of distribution and association of freshwater fish in New Zealand. *New Zealand Journal of Marine and Freshwater Research* 24: 31–44.
- Miskelly, C.M.; Taylor, G.A. 2004: Establishment of a colony of Common Diving Petrels (*Pelecanoides urinatrix*) by chick transfers and acoustic attraction. *Emu* 104: 205–211.
- Miskelly, C.M.; Taylor, G.A.; Gummer, H.; Williams, R. In Press: Translocations of eight species of burrow-nesting seabirds (genera *Pterodroma*, *Pelecanoides*, *Pachyptila* and *Puffinus*: Family Procellariidae). *Biological Conservation*: doi:10.1016/j.biocon.2009.03.027.
- Mitchell, C.P. 1994: Whitebait spawning ground management. *Science & Research Series No. 69*. Department of Conservation, Wellington, NZ. 23 p.
- Mitchell, C.P.; Madgewick, H.H.; Strickland, R.R.; Van Boven, R.J. 1992: The use of larval fish as an aid to identifying whitebait spawning grounds, and the role of slugs as predators on whitebait eggs. *New Zealand Freshwater Fisheries Miscellaneous Report* 127. 16 p.
- Mitsch, W.J.; Day Jr, J.W.; Wendell Gilliam, J.; Groffman, P.M.; Hey, D.L.; Randall, G.W.; Wang, N. 2001: Reducing nitrogen loading to the Gulf of Mexico from the Mississippi River Basin: strategies to counter a persistent ecological problem. *BioScience* 51: 373–388.
- Mitsch, W.J.; Gosselink, J.G. 2000: The value of wetlands: importance of scale and landscape setting. *Ecological Economics* 35: 25–33.
- Mizutani, H.; Kabaya, Y.; Moors, P.J.; Speir, T.W.; Lyon, G.L. 1991: Nitrogen isotope ratios identify deserted seabird colonies. *Auk* 108: 960–964.
- Mizutani, H.; Wada, E. 1988: Nitrogen and carbon isotope ratios in seabird rookeries and their ecological implications. *Ecology* 69: 340–349.
- Moll, G. 1996: Using geographic information systems (GIS) to analyse the value of urban ecosystems. In: Urban trees – costing the benefits. Conference proceedings. Chartered Institute of Water and Environmental Management, London, UK.
- Moller, I.; Spencer, T. 2002: Wave dissipation over macro-tidal saltmarshes: effects of marsh edge typology and vegetation change. *Journal of Coastal Research Special Issue* 36: 506–521.
- Molloy, L. 1988: Soils in the New Zealand landscape, the living mantle. New Zealand Society of Soil Science and Mallinson Rendel, Wellington, NZ. 239 p.
- Mols, C.M.M.; Visser, M.E. 2002: Great tits can reduce caterpillar damage in apple orchards. *Journal of Applied Ecology* 39: 888–899.
- Montgomery, B.R.; Kelly, D.; Ladley, J.J. 2001: Pollinator limitation of seed set in *Fuchsia perscandens* (Onagraceae) on Banks Peninsula, South Island, New Zealand. *New Zealand Journal of Botany* 39: 559–565.
- Moody, J.A.; Martin, D.A. 2001a: Initial hydrologic and geomorphic response following a wildfire in the Colorado Front Range. *Earth Surface Processes and Landforms* 26: 1049–1070.
- Moody, J.A.; Martin, D.A. 2001b: Post-fire, rainfall intensity-peak discharge relations for three mountainous watersheds in the western USA. *Hydrological Processes* 15: 2981–2993.

- Moors, P.J.; Speir, T.W.; Lyon, G.L. 1988: Soil analyses and $^{13}\text{C}/^{12}\text{C}$ ratios identify sites of deserted rockhopper penguin colonies. *Auk* 105: 796–799.
- Morandin, L.A.; Winston, M.L. 2005: Wild bee abundance and seed production in conventional, organic, and genetically modified canola. *Ecological Applications* 15: 871–881.
- Morin, J.; Van Winkel, J. 1996: The effect of raindrop impact and sheet erosion on infiltration rate and crust formation. *Soil Science Society of America Journal* 60: 1223–1227.
- Morris, S.E.; Moses, T.A. 1987: Forest fire and the natural soil erosion regime in the Colorado Front Range. *Annals of the Association of American Geographers* 77: 245–254.
- Mulder, C.P.; Keall, S.N. 2001: Burrowing seabirds and reptiles: impacts on seeds, seedlings and soils in an island forest in New Zealand. *Oecologia* 127: 350–360.
- Mulder, C.P.H.; Grant-Hoffman, M.N.; Towns, D.R.; Bellingham, P.J.; Wardle, D.A.; Durrett, M.S.; Fukami, T.; Bonner, K.I. in press: Direct and indirect effects of rats: does rat eradication restore ecosystem functioning of New Zealand seabird islands? *Biological Invasions*: 10.1007/s10530-008-9396-x.
- Munro, M.H.G.; Blunt, J.W.; Dumdei, E.J.; Hickford, S.J.H.; Lill, R.E.; Li, S.; Battershill, C.N.; Duckworth, A.R. 1999: The discovery and development of marine compounds with pharmaceutical potential. *Journal of Biotechnology* 70: 15–25.
- Mussen, E. 2007: Colony collapse disorder. *American Bee Journal* 147: 593–594.
- Nabhan, G.P. 1996: Pollinator redbook Vol. 1: global list of threatened vertebrate wildlife species serving as pollinators for crops and wild plants. Unpublished report, Forgotten Pollinators Campaign, Arizona-Sonora Desert Museum, Tucson, AZ, USA. 20 p.
- Nabhan, G.P.; Buchmann, S.L. 1997: Services provided by pollinators. Pp. 133–150 in Daily, G. (Ed.): Nature's services: societal dependence on natural ecosystems. Island Press, Washington DC, USA.
- Naeem, S. 1998: Species redundancy and ecosystem reliability. *Conservation Biology* 12: 39–45.
- Naeem, S.; Thompson, L.J.; Lawler, S.P.; Lawton, J.H.; Woodfin, R.M. 1995: Empirical evidence that declining species diversity may alter the performance of terrestrial ecosystems. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences* 347: 249–262.
- Naiman, R.J.; Decamps, H. 1997: The ecology of interfaces: riparian zones. *Annual Review of Ecology and Systematics* 28: 621–658.
- Neary, D.G.; Klopatek, C.C.; DeBano, L.F.; Ffolliott, P.F. 1999: Fire effects on belowground sustainability: a review and synthesis. *Forest Ecology and Management* 122: 51–71.
- Neary, D.G.; Pearce, A.J.; O'Loughlin, C.L.; Rowe, L.K. 1978: Management impacts on nutrient fluxes in beech-podocarp-hardwood forests. *New Zealand Journal of Ecology* 1: 19–26.
- Neill, W.M. 1983: The tamarisk invasion of desert riparian areas. Educational Bulletin 83–4. Education Foundation of the Desert Protective Council, Inc., Spring Valley, CA, USA. 4 p.
- Nelson, E.; Mendoza, G.; Regetz, J.; Polasky, S.; Tallis, H.; Cameron, D.R.; Chan, K.M.A.; Daily, G.C.; Goldstein, J.; Kareiva, P.M. 2009: Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment* 7: 4–11.
- New Zealand Soil Bureau 1968: Soils of New Zealand. *New Zealand Soil Bureau Bulletin* 26. (3 vols).
- Newman, D.J.; Cragg, G.M.; Snader, K.M. 2000: The influence of natural products upon drug discovery. *Natural Product Reports* 17: 215–234.
- Newstrom, L.; Robertson, A. 2005: Progress in understanding pollination systems in New Zealand. *New Zealand Journal of Botany* 43: 1–59.
- Nguyen, M.L.; Sheath, G.W.; Smith, C.M.; Cooper, A.B. 1998: Impact of cattle treading on hill land: 2. Soil physical properties and contaminant runoff. *New Zealand Journal of Agricultural Research* 41: 279–290.

- Norris, D.E. 2004: Mosquito-borne diseases as a consequence of land use change. *EcoHealth* 1: 19-24.
- Nosetto, M.D.; Jobbagy, E.G.; Paruelo, J.M. 2005: Land-use change and water losses: the case of grassland afforestation across a soil textural gradient in central Argentina. *Global Change Biology* 11: 1101-1117.
- Nowak, D.J. 2006: Institutionalizing urban forestry as a 'biotechnology' to improve environmental quality. *Urban Forestry & Urban Greening* 5: 93-100.
- Nowak, D.J.; Dwyer, J.F. 2000: Understanding the benefits and costs of urban forest ecosystems. Pp. 25-46 in Kuser, J.E. (Ed.): Handbook of urban and community forestry in the northeast. Springer, New York, USA.
- Nye, E.R. 2007: Global warming and possums: contributors in the future to new mosquito-borne human diseases in New Zealand? *The New Zealand Medical Journal* 120: 9-10.
- O'Loughlin, C.L. 1984: Effectiveness of introduced forest vegetation for protection against landslides and erosion in New Zealand steep lands. Pp. 275-280 in O'Loughlin, C.; Pearce, A. (Eds): Proceedings of the Symposium on Effects of Forest Land Use on Erosion and Slope Stability, Honolulu, Hawaii. IUFRO, Vienna, Austria.
- Öckinger, E.; Smith, H.G. 2006: Landscape composition and habitat area affects butterfly species richness in semi-natural grasslands. *Oecologia* 149: 526-534.
- Öckinger, E.; Smith, H.G. 2007: Semi-natural grasslands as population sources for pollinating insects in agricultural landscapes. *Journal of Applied Ecology* 44: 50-59.
- Officer, C.B.; Smayda, T.J.; Mann, R. 1982: Benthic filter feeding: a natural eutrophication control. *Marine Ecology Progress Series* 9: 203-210.
- Ogawa, H.; Male, J.W. 1986: Simulating the flood mitigation role of wetlands. *Journal of Water Resources Planning and Management* 112: 114-128.
- Ogilvie, S.C.; Mitchell, S.F. 1995: A model of mussel filtration in a shallow New Zealand lake, with reference to eutrophication control. *Archiv für Hydrobiologie* 133: 471-482.
- Old, J.M.; Deane, E.M. 2005: Antibodies to the Ross River virus in captive marsupials in urban areas of eastern New South Wales, Australia. *Journal of Wildlife Diseases* 41: 611-614.
- Omernik, J.; Abernathy, A.; Male, L. 1981: Stream nutrient levels and proximity of agricultural and forest land to streams: some relationships. *Journal of Soil and Water Conservation* 36: 227-231.
- Onuf, C.P.; Teal, J.M.; Valiela, I. 1977: Interactions of nutrients, plant growth and herbivory in a mangrove ecosystem. *Ecology* 58: 514-526.
- Pain, C.F.; Stephens, P.R. 1990: Storm damage assessment using digitised aerial photographs: Eltham, New Zealand, 24-25 February 1986. *New Zealand Geographer* 46: 12-25.
- Palmer-Jones, T.; Forster, I.W.; Jeffrey, G.L. 1962: Observations of the role of the honey bee and bumble bee as pollinators of white clover (*Trifolium repens* Linn.) in the Timaru district and Mackenzie country. *New Zealand Journal of Agricultural Research* 5: 318-325.
- Pande, A. 2001: Evaluating biological change in New Zealand marine reserves. Unpublished PhD thesis. Victoria University of Wellington, Wellington, NZ. 196p.
- Parker, F.D.; Batra, S.W.T.; Tepedino, V.J. 1987: New pollinators for our crops. *Agricultural Zoology Reviews* 2: 279-307.
- Parkinson, R.W.; DeLaune, R.D.; White, J.R. 1994: Holocene sea-level rise and the fate of mangrove forests within the wider Caribbean Region. *Journal of Coastal Research* 10: 1077-1086.
- Parkyn, S.M.; Davies-Colley, R.J.; Halliday, N.J.; Costley, K.J.; Croker, G.F. 2003: Planted riparian buffer zones in New Zealand: do they live up to expectations? *Restoration Ecology* 11: 436-447.
- Patrick Jr, W.H. 1994: From wastelands to wetlands. *Journal of Environmental Quality* 23: 892-896.
- Patz, J.A.; Graczyk, T.K.; Geller, N.; Vittor, A.Y. 2000: Effects of environmental change on emerging parasitic diseases. *International Journal for Parasitology* 30: 1395-1405.

- Paul, K.I.; Polglase, P.J.; Nyakuengama, J.G.; Khanna, P.K. 2002: Change in soil carbon following afforestation. *Forest Ecology and Management* 168: 241–257.
- Payne, L.X.; Moore, J.W. 2006: Mobile scavengers create hotspots of freshwater productivity. *Oikos* 115: 69–80.
- Peel, M.C.; McMahon, T.A.; Finlayson, B.L.; Watson, F.G.R. 2001: Identification and explanation of continental differences in the variability of annual runoff. *Journal of Hydrology* 250: 224–240.
- Peltzer, D.A.; Bellingham, P.J.; Kurokawa, H.; Walker, L.R.; Wardle, D.A.; Yeates, G.W. in press: Punching above their weight: low biomass non-native plant species alter soil properties during primary succession. *Oikos*: DOI: 10.1111/j.1600-0706.2009.17244.x.
- Peterjohn, W.T.; Correll, D.L. 1984: Nutrient dynamics in an agricultural watershed: observations on the role of a riparian forest. *Ecology* 65: 1466–1475.
- Pethick, J. 2002: Estuarine and tidal wetland restoration in the United Kingdom: policy versus practice. *Restoration Ecology* 10: 431–437.
- Pfadenhauer, J.; Grootjans, A. 1999: Wetland restoration in central Europe: aims and methods. *Applied Vegetation Science* 2: 95–106.
- Pham, M.; Müller, J.F.; Brasseur, G.P.; Granier, C.; Mégie, G. 1996: A 3D model study of the global sulphur cycle: contributions of anthropogenic and biogenic sources. *Atmospheric Environment* 30: 1815–1822.
- Phillips, C.; Ekanayake, J.; Marden, M.; Watson, A. 2000: Stabilising parameters of vegetation: a critical look down-under. In: Landscape 2000, Proceedings of International Landscape Conference, Peppers Faimont Resort, Leura, NSW, Australia, 16–20 October 2000.
- Pielke, R. 2001: Influence of the spatial distribution of vegetation and soils on the prediction of cumulus convective rainfall. *Reviews of Geophysics* 39: 151–177.
- Pielke Sr, R.A.; Adegoke, J.; Beltrán-Przekurat, A.; Hiemstra, C.A.; Lin, J.; Nair, U.S.; Niyogi, D.; Nobis, T.E. 2007: An overview of regional land-use and land-cover impacts on rainfall. *Tellus* 59B: 587–601.
- Pierce, R.J. 2002: Kiore (*Rattus exulans*) impact on breeding success of Pycroft's petrels and little shearwaters. *DOC Science Internal Series* 39. Department of Conservation, Wellington, NZ. 24p.
- Pimentel, D. 1998: Ecology of soil erosion in ecosystems. *Ecosystems* 1: 416–426.
- Pitman, A.J. 2003: The evolution of, and revolution in, land surface schemes designed for climate models. *International Journal of Climatology* 23: 479–510.
- Post, W.M.; Emanuel, W.R.; Zinke, P.J.; Stangenberger, A.G. 1982: Soil carbon pools and world life zones. *Nature* 298: 156–159.
- Post, W.M.; Kwon, K.C. 2000: Soil carbon sequestration and land-use change: processes and potential. *Global Change Biology* 6: 317–327.
- Potter, C.S. 1999: Terrestrial biomass and the effects of deforestation on the global carbon cycle. *BioScience* 49: 769–780.
- Power, M.E.; Tilman, D.; Estes, J.A.; Menge, B.A.; Bond, W.J.; Mills, L.S.; Daily, G.; Castilla, J.C.; Lubchenco, J.; Paine, R.T. 1996: Challenges in the quest for keystones. *BioScience* 46: 609–620.
- Prinsloo, F.W.; Scott, D.F. 1999: Streamflow responses to the clearing of alien invasive trees from riparian zones at three sites in the Western Cape Province (South Africa). *Southern African Forestry Journal* 185: 1–7.
- Pritchett, W.L.; Fisher, R.F. 1979: Properties and management of forest soils. John Wiley & Sons, New York, USA. 500p.
- Qualls, R.G.; Richardson, C.J. 2000: Phosphorus enrichment affects litter decomposition, immobilization, and soil microbial phosphorus in wetland mesocosms. *Soil Science Society of America Journal* 64: 799–808.

- Quartel, S.; Kroon, A.; Augustinus, P.; Van Santen, P.; Tri, N.H. 2007: Wave attenuation in coastal mangroves in the Red River Delta, Vietnam. *Journal of Asian Earth Sciences* 29: 576-584.
- Quinn, J.M. 2000: Effects of pastoral development. Pp. 208-229 in Collier, K.; Winterbourn, M. (Eds): *New Zealand stream invertebrates: ecology and implications for management*. Caxton, Christchurch, NZ.
- Quinn, J.M.; Cooper, A.B.; Davies-Colley, R.J.; Rutherford, J.C.; Williamson, R.B. 1997: Land use effects on habitat, water quality, periphyton, and benthic invertebrates in Waikato, New Zealand, hill-country streams. *New Zealand Journal of Marine and Freshwater Research* 31: 579-597.
- Quinn, J.M.; Stroud, M.J. 2002: Water quality and sediment and nutrient export from New Zealand hill-land catchments of contrasting land use. *New Zealand Journal of Marine and Freshwater Research* 36: 409-429.
- Quinn, P. 1984: Survey of native bees (Hymenoptera: Colletidae and Halictidae) in the Mackenzie Basin. *New Zealand Entomologist* 8: 41-44.
- Rasmussen, L. 1998: Effects of afforestation and deforestation on the deposition, cycling and leaching of elements. *Agriculture, Ecosystems and Environment* 67: 153-159.
- Rathcke, B.J.; Jules, E.S. 1993: Habitat fragmentation and plant-pollinator interactions. *Current Science* 65: 273-277.
- Ray, D.K.; Nair, U.S.; Lawton, R.O.; Welch, R.M.; Pielke Sr, R.A. 2006: Impact of land use on Costa Rican tropical montane cloud forests: sensitivity of orographic cloud formation to deforestation in the plains. *Journal of Geophysical Research* 111, D02108, doi:02110.01029/02005JD006096.
- Raya, A.M.; Zuazo, V.H.D.; Martinez, J.R.F. 2006: Soil erosion and runoff response to plant-cover strips on semiarid slopes (SE Spain). *Land Degradation & Development* 17: 1-11.
- Resh, S.C.; Binkley, D.; Parrotta, J.A. 2002: Greater soil carbon sequestration under nitrogen-fixing trees compared with *Eucalyptus* species. *Ecosystems* 5: 217-231.
- Rey, F. 2003: Influence of vegetation distribution on sediment yield in forested marly gullies. *Catena* 50: 549-562.
- Richardson, J. 2002: Is stream cover important for inanga? *Water & Atmosphere* 10: 14-15.
- Richardson, J.; Rowe, D.K.; Smith, J.P. 2001: Effects of turbidity on the migration of juvenile banded kokopu (*Galaxias fasciatus*) in a natural stream. *New Zealand Journal of Marine and Freshwater Research* 35: 191-196.
- Ricketts, T.H. 2004: Tropical forest fragments enhance pollinator activity in nearby coffee crops. *Conservation Biology* 18: 1262-1271.
- Ricketts, T.H.; Regetz, J.; Steffan-Dewenter, I.; Cunningham, S.A.; Kremen, C.; Bogdanski, A.; Gemmill-Herren, B.; Greenleaf, S.S.; Klein, A.M.; Mayfield, M.M. 2008: Landscape effects on crop pollination services: are there general patterns? *Ecology Letters* 11: 499-515.
- Rivera-Monroy, V.H.; Twilley, R.R. 1996: The relative role of denitrification and immobilization in the fate of inorganic nitrogen in mangrove sediments (Terminos Lagoon, Mexico). *Limnology and Oceanography* 41: 284-296.
- Roberts, C.M.; Bohnsack, J.A.; Gell, F.; Hawkins, J.P.; Goodridge, R. 2001: Effects of marine reserves on adjacent fisheries. *Science* 294: 1920-1923.
- Roberts, C.M.; Hawkins, J.P.; Gell, F.R. 2005: The role of marine reserves in achieving sustainable fisheries. *Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences* 360: 123-132.
- Robertson, A.W.; Kelly, D.; Ladley, J.J.; Sparrow, A.D. 1999: Effects of pollinator loss on endemic New Zealand mistletoes (Loranthaceae). *Conservation Biology* 13: 499-508.
- Robichaud, P.R. 2000: Fire effects on infiltration rates after prescribed fire in Northern Rocky Mountain forests, USA. *Journal of Hydrology* 231: 220-229.
- Rodenhouse, N.L.; Barrett, G.W.; Zimmerman, D.M.; Kemp, J.C. 1992: Effects of uncultivated corridors on arthropod abundances and crop yields in soybean agroecosystems. *Agriculture, Ecosystems and Environment* 38: 179-191.

- Roling, W.F.M.; Milner, M.G.; Jones, D.M.; Lee, K.; Daniel, F.; Swannell, R.J.P.; Head, I.M. 2002: Robust hydrocarbon degradation and dynamics of bacterial communities during nutrient-enhanced oil spill bioremediation. *Applied and Environmental Microbiology* 68: 5537-5548.
- Ross, D.J.; Tate, K.R.; Scott, N.A.; Feltham, C.W. 1999: Land-use change: effects on soil carbon, nitrogen and phosphorus pools and fluxes in three adjacent ecosystems. *Soil Biology and Biochemistry* 31: 803-813.
- Rowe, D.; Hicks, M.; Richardson, J. 2000: Reduced abundance of banded kokopu (*Galaxias fasciatus*) and other native fish in turbid rivers of the North Island of New Zealand. *New Zealand Journal of Marine and Freshwater Research* 34: 547-558.
- Rowe, D.K.; Chisnall, B.L.; Dean, T.L.; Richardson, J. 1999: Effects of land use on native fish communities in east coast streams of the North Island of New Zealand. *New Zealand Journal of Marine and Freshwater Research* 33: 141-151.
- Rowe, D.K.; Dean, T.L. 1998: Effects of turbidity on the feeding ability of the juvenile migrant stage of six New Zealand freshwater fish species. *New Zealand Journal of Marine and Freshwater Research* 32: 21-29.
- Rowe, D.K.; Smith, J.; Quinn, J.; Boothroyd, I. 2002a: Effects of logging with and without riparian strips on fish species abundance, mean size, and the structure of native fish assemblages in Coromandel, New Zealand, streams. *New Zealand Journal of Marine and Freshwater Research* 36: 67-79.
- Rowe, L.K.; Jackson, R.; Fahey, B. 2002b: Land use and water resources: hydrological effects of different vegetation covers. SMF2167 Report No. 5, prepared for the Ministry for the Environment, Wellington, NZ. Landcare Research Report LC0203/027. 142 p.
- Ruprecht, J.K.; Schofield, N.J. 1989: Analysis of streamflow generation following deforestation in southwest Western Australia. *Journal of Hydrology* 105: 1-17.
- Russ, G.R.; Alcala, A.C.; Maypa, A.P.; Calumpang, H.P.; White, A.T. 2004: Marine reserve benefits local fisheries. *Ecological Applications* 14: 597-606.
- Ryan, P.A. 1991: Environmental effects of sediment on New Zealand streams: a review. *New Zealand Journal of Marine and Freshwater Research* 25: 207-221.
- Sahani, U.; Behera, N. 2001: Impact of deforestation on soil physicochemical characteristics, microbial biomass and microbial activity of tropical soil. *Land Degradation & Development* 12: 93-105.
- Sahin, V.; Hall, M.J. 1996: The effects of afforestation and deforestation on water yields. *Journal of Hydrology* 178: 293-309.
- Salati, E.; Nobre, C.A. 1991: Possible climatic impacts of tropical deforestation. *Climatic Change* 19: 177-196.
- Sánchez, L.A.; Ataroff, M.; López, R. 2002: Soil erosion under different vegetation covers in the Venezuelan Andes. *The Environmentalist* 22: 161-172.
- Saunders, D.L.; Kalff, J. 2001: Nitrogen retention in wetlands, lakes and rivers. *Hydrobiologia* 443: 205-212.
- Saviozzi, A.; Levi-Minzi, R.; Cardelli, R.; Riffaldi, R. 2001: A comparison of soil quality in adjacent cultivated, forest and native grassland soils. *Plant and Soil* 233: 251-259.
- Scheffer, M.; Carpenter, S.; Foley, J.A.; Folke, C.; Walker, B. 2001: Catastrophic shifts in ecosystems. *Nature* 413: 591-596.
- Schimel, D.S. 1995: Terrestrial ecosystems and the carbon cycle. *Global Change Biology* 1: 77-91.
- Schroeter, S.C.; Reed, D.C.; Kushner, D.J.; Estes, J.A.; Ono, D.S. 2001: The use of marine reserves in evaluating the dive fishery for the warty sea cucumber (*Parastichopus parvimensis*) in California, U.S.A. *Canadian Journal of Fisheries and Aquatic Sciences* 58: 1773-1781.
- Schwartz, M.W.; Brigham, C.A.; Hoeksema, J.D.; Lyons, K.G.; Mills, M.H.; van Mantgem, P.J. 2000: Linking biodiversity to ecosystem function: implications for conservation ecology. *Oecologia* 122: 297-305.

- Scoffin, T.P. 1970: The trapping and binding of subtidal carbonate sediments by marine vegetation in Bimini lagoon, Bahamas. *Journal of Sedimentary Research* 40: 249–273.
- Scott, D.F. 1993: Hydrological effects of fire in South-African mountain catchments. *Journal of Hydrology* 150: 409–432.
- Scott, D.F.; Lesch, W. 1997: Streamflow responses to afforestation with *Eucalyptus grandis* and *Pinus patula* and to felling in the Mokobulaan experimental catchments, South Africa. *Journal of Hydrology* 199: 360–377.
- Scott-Dupree, C.D.; Winston, M.L. 1987: Wild bee diversity and abundance in orchard and uncultivated habitats in the Okanagan Valley. *British Columbia. Canadian Entomologist* 119: 735–745.
- Scott Schneider, S.; DeGrandi-Hoffman, G.; Smith, D.R. 2004: The African honey bee: factors contributing to a successful biological invasion. *Annual Reviews in Entomology* 49: 351–376.
- Şekercioğlu, C.H.; Daily, G.C.; Ehrlich, P.R. 2004: Ecosystem consequences of bird declines. *PNAS* 101: 18042–18047.
- Shafroth, P.B.; Cleverly, J.R.; Dudley, T.L.; Taylor, J.P.; Van Riper, C.; Weeks, E.P.; Stuart, J.N. 2005: Control of *Tamarix* in the western United States: implications for water salvage, wildlife use, and riparian restoration. *Environmental Management* 35: 231–246.
- Shakesby, R.A.; Coelho, C.O.A.; Ferreira, A.D.; Terry, J.P.; Walsh, R.P.D. 1993: Wildfire impacts on soil erosion and hydrology in wet mediterranean forest, Portugal. *International Journal of Wildland Fire* 3: 95–110.
- Shears, N.T.; Babcock, R.C. 2003: Continuing trophic cascade effects after 25 years of no-take marine reserve protection. *Marine Ecology Progress Series* 246: 1–16.
- Shears, N.T.; Usmar, N.R. 2006a: Response of reef fish to partial and no-take protection at Mayor Island (Tuhua). *Department of Conservation Research and Development Series* 243. Department of Conservation, Wellington, NZ. 31 p.
- Shears, N.T.; Usmar, N.R. 2006b: The role of the Hauraki Gulf Cable Protection Zone in protecting exploited fish species: de facto marine reserve? *DOC Research and Development Series* 253. Department of Conservation, Wellington, NZ. 27 p.
- Shukla, J.; Nobre, C.; Sellers, P. 1990: Amazon deforestation and climate change. *Science* 247: 1322–1325.
- Sidle, R.C.; Ziegler, A.D.; Negishi, J.N.; Nik, A.R.; Siew, R.; Turkelboom, F. 2006: Erosion processes in steep terrain—truths, myths, and uncertainties related to forest management in Southeast Asia. *Forest Ecology and Management* 224: 199–225.
- Silva Dias, M.A.F.; Rutledge, S.; Kabat, P.; Dias, P.L.S.; Nobre, C.; Fisch, G.; Dolman, A.J.; Zipser, E.; Garstang, M.; Manzi, A. 2002: Cloud and rain processes in a biosphere-atmosphere interaction context in the Amazon region. *Journal of Geophysical Research* 107, (D20), 8072, doi:8010.1029/2001JD000335.
- Silver, W.L.; Kueppers, L.M.; Lugo, A.E.; Ostertag, R.; Matzek, V. 2004: Carbon sequestration and plant community dynamics following reforestation of tropical pasture. *Ecological Applications* 14: 1115–1127.
- Silver, W.L.; Ostertag, R.; Lugo, A.E. 2000: The potential for carbon sequestration through reforestation of abandoned tropical agricultural and pasture lands. *Restoration Ecology* 8: 394–407.
- Singer, F.J.; Swank, W.T.; Clebsch, E.E.C. 1984: Effects of wild pig rooting in a deciduous forest. *The Journal of Wildlife Management* 48: 464–473.
- Sliva, L.; Dudley Williams, D. 2001: Buffer zone versus whole catchment approaches to studying land use impact on river water quality. *Water Research* 35: 3462–3472.
- Smil, V. 2000: Phosphorus in the environment: natural flows and human interferences. *Annual Reviews of Energy and the Environment* 25: 53–88.
- Smith, C.M. 1989: Riparian pasture retirement effects on sediment, phosphorus, and nitrogen in channelised surface run-off from pastures. *New Zealand Journal of Marine and Freshwater Research* 23: 139–146.

- Smith, C.M. 1992: Riparian afforestation effects on water yields and water quality in pasture catchments. *Journal of Environmental Quality* 21: 237-245.
- Smith, C.M.; Wilcock, R.J.; Vant, W.N.; Smith, D.G.; Cooper, A.B. 1993: Towards sustainable agriculture: freshwater quality in New Zealand and the influence of agriculture. Ministry of Agriculture and Fisheries Policy Technical Paper 93/10.
- Snyder, R.A.; Boss, C.L. 2002: Recovery and stability in barrier island plant communities. *Journal of Coastal Research* 18: 530-536.
- Soetaert, K.; Middelburg, J.J.; Heip, C.; Meire, P.; Van Damme, S.; Maris, T. 2006: Long-term change in dissolved inorganic nutrients in the heterotrophic Scheldt estuary (Belgium, The Netherlands). *Limnology and Oceanography* 51: 409-423.
- Sparling, G.P. 1997: Soil microbial biomass, activity and nutrient cycling as indicators of soil health. Pp. 97-119 in Pankhurst, C.; Doube, B.M.; Gupta, V.V.S.R. (Eds): Biological indicators of soil health. CAB International, New York, USA.
- Spitsyna, N.T.; Skripal'shchikova, L.N. 1991: Phytomass and dust accumulation of Birch forests near open-pit mines. *Soviet Journal of Ecology* 22: 354-359.
- Steffan-Dewenter, I.; Munzenberg, U.; Burger, C.; Thies, C.; Tscharntke, T. 2002: Scale-dependent effects of landscape context on three pollinator guilds. *Ecology* 83: 1421-1432.
- Steffan-Dewenter, I.; Tscharntke, T. 1999: Effects of habitat isolation on pollinator communities and seed set. *Oecologia* 121: 432-440.
- Stewart, M.K.; Mehlhorn, J.; Elliott, S. 2007: Hydrometric and natural tracer (oxygen-18, silica, tritium and sulphur hexafluoride) evidence for a dominant groundwater contribution to Pukemanga Stream, New Zealand. *Hydrological Processes* 21: 3340-3356.
- Stokstad, E. 2007: The case of the empty hives. *Science* 316: 970-972.
- Stromgaard, P. 1984: The immediate effect of burning and ash-fertilization. *Plant and Soil* 80: 307-320.
- Sukias, J.; Tanner, C. 2004: Evaluation of the performance of constructed wetlands treating domestic wastewater in the Waikato region. Environment Waikato Technical Report 2004/15. Environment Waikato, Hamilton, NZ. 11 p.
- Sumner, D.A.; Boriss, H. 2006: Bee-economics and the leap in pollination fees. *Agricultural and Resource Economics Update* 9: 9-11.
- Sundaravadeivel, M.; Vigneswaran, S. 2001: Constructed wetlands for wastewater treatment. *Critical Reviews in Environmental Science and Technology* 31: 351-409.
- Swales, S.; West, D.W. 1991: Distribution, abundance and conservation status of native fish in some Waikato streams in the North Island of New Zealand. *Journal of the Royal Society of New Zealand* 21: 281-296.
- Taha, H. 1996: Modeling impacts of increased urban vegetation on ozone air quality in the South Coast Air Basin. *Atmospheric Environment* 30: 3423-3430.
- Takamatsu, S.; Hodges, T.W.; Rajbhandari, I.; Gerwick, W.H.; Hamann, M.T.; Nagle, D.G. 2003: Marine natural products as novel antioxidant prototypes. *Journal of Natural Products* 66: 605-608.
- Takar, A.A.; Dobrowolski, J.P.; Thurow, T.L. 1990: Influence of grazing, vegetation, life-form and soil type on infiltration rates and interrill erosion on a Somalian rangeland. *Journal of Range Management* 43: 486-490.
- Tam, N.F.Y.; Wong, Y.S. 1993: Retention of nutrients and heavy metals in mangrove sediment receiving wastewater of different strengths. *Environmental Technology* 14: 719-729.
- Tanner, C.C.; Nguyen, M.L.; Sukias, J.P.S. 2005: Nutrient removal by a constructed wetland treating subsurface drainage from grazed dairy pasture. *Agriculture, Ecosystems and Environment* 105: 145-162.
- Tappin, A.D. 2002: An examination of the fluxes of nitrogen and phosphorus in temperate and tropical estuaries: current estimates and uncertainties. *Estuarine, Coastal and Shelf Science* 55: 885-901.

- Taylor, L.H.; Latham, S.M.; Woolhouse, M.E.J. 2001: Risk factors for human disease emergence. *Philosophical Transactions of the Royal Society of London Series B-Biological Sciences* 356: 983-990.
- Templer, P.; Findlay, S.; Wigand, C. 1998: Sediment chemistry associated with native and non-native emergent macrophytes of a Hudson River marsh ecosystem. *Wetlands* 18: 70-78.
- Terrados, J.; Duarte, C.M. 2000: Experimental evidence of reduced particle resuspension within a seagrass (*Posidonia oceanica* L.) meadow. *Journal of Experimental Marine Biology and Ecology* 243: 45-53.
- Tewksbury, J.J.; Levey, D.J.; Haddad, N.M.; Sargent, S.; Orrock, J.L.; Weldon, A.; Danielson, B.J.; Brinkerhoff, J.; Damschen, E.I.; Townsend, P. 2002: Corridors affect plants, animals, and their interactions in fragmented landscapes. *Proceedings of the National Academy of Sciences* 99: 12923-12926.
- Thibodeau, F.R.; Ostro, B.D. 1981: An economic analysis of wetland protection. *Journal of Environmental Management* 12: 19-30.
- Thiele, H.U. 1964: Ökologische Untersuchungen an bodenbewohnenden Coleopteren einer Heckenlandschaft. *Zeitschrift für Morphologie und Ökologie der Tiere* 53: 537-586.
- Thies, C.; Roschewitz, I.; Tschardtke, T. 2005: The landscape context of cereal aphid-parasitoid interactions. *Proceedings of the Royal Society Series B-Biological Sciences* 272: 203-210.
- Thies, C.; Tschardtke, T. 1999: Landscape structure and biological control in agroecosystems. *Science* 285: 893-895.
- Thomas, C.D.; Abery, J.C.G. 1995: Estimating rates of butterfly decline from distribution maps: the effect of scale. *Biological Conservation* 73: 59-65.
- Thomas, J.A.; Telfer, M.G.; Roy, D.B.; Preston, C.D.; Greenwood, J.J.D.; Asher, J.; Fox, R.; Clarke, R.T.; Lawton, J.H. 2004: Comparative losses of British butterflies, birds, and plants and the global extinction crisis. *Science* 303: 1879-1881.
- Thomas, W.P. 1963: A natural enemy of the common grass grub, *Costelytra zealandica* White. *New Zealand Entomologist* 3: 15-18.
- Thompson, R.; Starzomski, B.M. 2007: What does biodiversity actually do? A review for managers and policy makers. *Biodiversity and Conservation* 16: 1359-1378.
- Tilman, D. 1997: The influence of functional diversity and composition on ecosystem processes. *Science* 277: 1300-1302.
- Tilman, D.; Reich, P.B.; Knops, J.; Wedin, D.; Mielke, T.; Lehman, C. 2001: Diversity and productivity in a long-term grassland experiment. *Science* 294: 843-845.
- Toky, O.P.; Ramakrishnan, P.S. 1983: Secondary succession following slash and burn agriculture in north-eastern India. II. Nutrient cycling. *Journal of Ecology* 71: 747-757.
- Towns, D.R.; Wardle, D.A.; Mulder, C.P.H.; Yeates, G.W.; Fitzgerald, B.M.; Parrish, G.R.; Bellingham, P.J.; Bonner, K.I. 2009: Predation of seabirds by invasive rats: multiple indirect consequences for invertebrate communities. *Oikos* 118: 420-430.
- Townsend, C.R.; Crowl, T.A. 1991: Fragmented population structure in a native New Zealand fish: an effect of introduced brown trout? *Oikos* 61: 347-354.
- Townsend, P.A.; Levey, D.J. 2005: An experimental test of whether habitat corridors affect pollen transfer. *Ecology* 86: 466-475.
- Troell, M.; Rönnbäck, P.; Halling, C.; Kautsky, N.; Buschmann, A. 1999: Ecological engineering in aquaculture: use of seaweeds for removing nutrients from intensive mariculture. *Journal of Applied Phycology* 11: 89-97.
- Trustrum, N.A.; Page, M.J. 1992: The long term erosion history of Lake Tutira watershed: implications of sustainable land use management. Pp. 212-215 in Henriques, P. (Ed.): Proceedings of International Conference on Sustainable Land Management. Napier, New Zealand.
- Turner, R.E.; Lewis, R.R. 1997: Hydrologic restoration of coastal wetlands. *Wetlands Ecology and Management* 4: 65-72.

- Turner, R.K.; van den Bergh, J.; Söderqvist, T.; Barendregt, A.; van der Straaten, J.; Maltby, E.; van Ierland, E.C. 2000: Ecological-economic analysis of wetlands: scientific integration for management and policy. *Ecological Economics* 35: 7-23.
- Turner, S.; Schwarz, A. 2006: Management and conservation of seagrass in New Zealand: an introduction. *Science for Conservation* 264. Department of Conservation, Wellington, NZ. 90p.
- Tylianakis, J.M.; Didham, R.K.; Wratten, S.D. 2004: Improved fitness of aphid parasitoids receiving resource subsidies. *Ecology* 85: 658-666.
- Umemura, K.; Yanase, K.; Suzuki, M.; Okutani, K.; Yamori, T.; Andoh, T. 2003: Inhibition of DNA topoisomerases I and II, and growth inhibition of human cancer cell lines by a marine microalgal polysaccharide. *Biochemical Pharmacology* 66: 481-487.
- Vanacker, V.; von Blanckenburg, F.; Govers, G.; Molina, A.; Poesen, J.; Deckers, J.; Kubik, P. 2007: Restoring dense vegetation can slow mountain erosion to near natural benchmark levels. *Geology* 35: 303-306.
- Van der Putten, W.H.; Klironomos, J.N.; Wardle, D.A. 2007: Microbial ecology of biological invasions. *The ISME Journal* 1: 28-37.
- van Emden, H.F. 1965: The role of uncultivated land in the biology of crop pests and beneficial insects. *Scientific Horticulture* 17: 121-136.
- van Straalen, N.M.; Ernst, W.H.O. 1991: Metal biomagnification may endanger species in critical pathways. *Oikos* 62: 255-256.
- Vant, W.N. 2001: New challenges for the management of plant nutrients and pathogens in the Waikato River, New Zealand. *Water Science Technology* 43: 137-144.
- Verhoeven, J.T.A.; Arheimer, B.; Yin, C.; Hefting, M.M. 2006: Regional and global concerns over wetlands and water quality. *Trends in Ecology & Evolution* 21: 96-103.
- Vermaat, J.E.; Thampanya, U. 2006: Mangroves mitigate tsunami damage: a further response. *Estuarine, Coastal and Shelf Science* 69: 1-3.
- Vertessy, R.A.; Watson, F.G.R.; O'Sullivan, S.K. 2001: Factors determining relations between stand age and catchment water balance in mountain ash forests. *Forest Ecology and Management* 143: 13-26.
- Vesterdal, L.; Ritter, E.; Gundersen, P. 2002: Change in soil organic carbon following afforestation of former arable land. *Forest Ecology and Management* 169: 137-147.
- Victor, S.; Golbuu, Y.; Wolanski, E.; Richmond, R.H. 2004: Fine sediment trapping in two mangrove-fringed estuaries exposed to contrasting land-use intensity, Palau, Micronesia. *Wetlands Ecology and Management* 12: 277-283.
- Villamil, M.B.; Amiotti, N.M.; Peinemann, N. 2001: Soil degradation related to overgrazing in the semi-arid Southern Caldenal area of Argentina. *Soil Science* 166: 441-452.
- Villegas, J.C.; Tobon, C.; Breshears, D.D. 2008: Fog interception by non-vascular epiphytes in tropical montane cloud forests: dependencies on gauge type and meteorological conditions. *Hydrological Processes* 22: 2484-2492.
- Vincent, W.F.; Downes, M.T. 1980: Variation in nutrient removal from a stream by watercress (*Nasturtium officinale* R. Br.). *Aquatic Botany* 9: 221-235.
- Vitousek, P.M. 1983: The effects of deforestation on air, soil, and water. Pp. 223-245 in Bolin, B.; Cook, R.B. (Eds): The major biogeochemical cycles and their interactions. SCOPE 21. John Wiley & Sons, Chichester, UK.
- Vitousek, P.M. 1992: Effects of alien plants on native ecosystems. Pp. 29-41 in Stone, C.P.; Smith, C.W.; Tunison, J.T. (Eds): Alien plant invasions in native ecosystems of Hawaii: management and research. University of Hawaii Cooperative National Park Resources Studies Unit, Honolulu, USA.
- Vitousek, P.M.; Aber, J.D.; Howarth, R.W.; Likens, G.E.; Matson, P.A.; Schindler, D.W.; Schlesinger, W.H.; Tilman, D.G. 1997a: Human alteration of the global nitrogen cycle: sources and consequences. *Ecological Applications* 7: 737-750.

- Vitousek, P.M.; Mooney, H.A.; Lubchenco, J.; Melillo, J.M. 1997b: Human domination of earth's ecosystems. *Science* 277: 494-499.
- Vogelmann, H.W. 1973: Fog precipitation in the cloud forests of Eastern Mexico. *BioScience* 23: 96-100.
- Wagenius, S. 2006: Scale dependence of reproductive failure in fragmented *Echinacea* populations. *Ecology* 87: 931-941.
- Walbridge, M.R. 1993: Functions and values of forested wetlands in the southern United States. *Journal of Forestry* 91: 15-19.
- Walker, M.C.; Howlett, B.G.; Butler, R. n.d.: The influence of landscape features on pollinator distribution in Canterbury agro-ecosystems. Unpublished report, Crop & Food Research, Christchurch, NZ. 1 p.
- Wall, D.H.; Virginia, R.A. 2000: The world beneath our feet: soil biodiversity and ecosystem functioning. Pp. 225-241 in Raven, P.H. (Ed.): Nature and human society: the quest for a sustainable world. Proceedings of the 1997 Forum on Biodiversity. National Academy Press, Washington DC, USA.
- Wan, S.; Hui, D.; Luo, Y. 2001: Fire effects on nitrogen pools and dynamics in terrestrial ecosystems: a meta-analysis. *Ecological Applications* 11: 1349-1365.
- Wang, W.X.; Stupakoff, I.; Fisher, N.S. 1999: Bioavailability of dissolved and sediment-bound metals to a marine deposit-feeding polychaete. *Marine Ecology Progress Series* 178: 281-293.
- Wantiez, L.; Thollot, P.; Kulbicki, M. 1997: Effects of marine reserves on coral reef fish communities from five islands in New Caledonia. *Coral Reefs* 16: 215-224.
- Ward, T.J. 1987: Temporal variation of metals in the seagrass *Posidonia australis* and its potential as a sentinel accumulator near a lead smelter. *Marine Biology* 95: 315-321.
- Ward, T.J.; Correll, R.L.; Anderson, R.B. 1986: Distribution of cadmium, lead and zinc amongst the marine sediments, seagrasses and fauna, and the selection of sentinel accumulators, near a lead smelter in South Australia. *Australian Journal of Marine and Freshwater Research* 37: 567-585.
- Wardle, D.A.; Barker, G.M.; Yeates, G.W.; Bonner, K.I.; Ghani, A. 2001: Introduced browsing mammals in New Zealand natural forests: aboveground and belowground consequences. *Ecological Monographs* 71: 587-614.
- Waser, N.M.; Chittka, L.; Price, M.V.; Williams, N.M.; Ollerton, J. 1996: Generalization in pollination systems, and why it matters. *Ecology* 77: 1043-1060.
- Watanabe, M.E. 1994: Pollination worries rise as honey bees decline. *Science* 265: 1170-1170.
- Watson, A.; Phillips, C.; Marden, M. 1999: Root strength, growth, and rates of decay: root reinforcement changes of two tree species and their contribution to slope stability. *Plant and Soil* 217: 39-47.
- Watts, C.H.; Clarkson, B.R.; Didham, R.K. 2008: Rapid beetle community convergence following experimental habitat restoration in a mined peat bog. *Biological Conservation* 141: 568-579.
- Waugh, J. 2007: Report on the Whangamarino Wetland and its role in flood storage on the lower Waikato River. Unpublished report to the Department of Conservation, NZ.
- Westphal, C.; Steffan-Dewenter, I.; Tschardt, T. 2003: Mass flowering crops enhance pollinator densities at a landscape scale. *Ecology Letters* 6: 961-965.
- Westrich, P.; Matheson, A.; Buchmann, S.L.; O'Toole, C.; Westrich, P.; Williams, I.H. (Eds) 1996: The conservation of bees. Academic Press, London, UK. 254 p.
- Wheat, C.G.; Feely, R.A.; Mottl, M.J. 1996: Phosphate removal by oceanic hydrothermal processes: An update of the phosphorus budget in the oceans. *Geochimica et Cosmochimica Acta* 60: 3593-3608.
- Whigham, D.F.; Chitterling, C.; Palmer, B. 1988: Impacts of freshwater wetlands on water quality: a landscape perspective. *Environmental Management* 12: 663-671.

- Whitworth, D.L.; Carter, H.R.; Young, R.J.; Koepke, J.S.; Gress, F.; Fangman, S. 2005: Initial recovery of Xantus's Murrelets following rat eradication on Anacapa Island, California. *Marine Ornithology* 33: 131-137.
- Wiersum, K.F. 1984: Surface erosion under various tropical agroforestry systems. Pp. 231-239 in: Proceedings of symposium on effects of forest land use on erosion and slope stability. International Union of Forestry Research Organization, Vienna, and East-West Centre, Hawaii, USA.
- Wijetunge, J.J. 2006: Tsunami on 26 December 2004: spatial distribution of tsunami height and the extent of inundation in Sri Lanka. *Science of Tsunami Hazards* 24: 225-239.
- Wilcox, B.P.; Thurow, T.L. 2006: Emerging issues in rangeland ecohydrology: vegetation change and the water cycle. *Rangeland Ecology & Management* 59: 220-224.
- Williams, C.E. 2001: Biological invasions and global change: what might the future bring? *Ecology* 82: 1498-1499.
- Williams, M.R.; Fisher, T.R.; Melack, J.M. 1997: Solute dynamics in soil water and groundwater in a central Amazon catchment undergoing deforestation. *Biogeochemistry* 38: 303-335.
- Williams, P.A.; Karl, B.J. 2002: Birds and small mammals in kanuka (*Kunzea ericoides*) and gorse (*Ulex europaeus*) scrub and the resulting seed rain and seedling dynamics. *New Zealand Journal of Ecology* 26: 31-41.
- Williams, P.H.; Haynes, R.J. 1990: Influence of improved pastures and grazing animals on nutrient cycling within New Zealand soils. *New Zealand Journal of Ecology* 14: 49-57.
- Williamson, R.B.; Smith, C.M.; Cooper, A.B. 1996: Watershed riparian management and its benefits to a eutrophic lake. *Journal of Water Resources Planning and Management* 122: 24-32.
- Willis, T.J.; Millar, R.B.; Babcock, R.C. 2003a: Protection of exploited fish in temperate regions: high density and biomass of snapper *Pagrus auratus* (Sparidae) in northern New Zealand marine reserves. *Journal of Applied Ecology* 40: 214-227.
- Willis, T.J.; Millar, R.B.; Babcock, R.C.; Tolimieri, N. 2003b: Burdens of evidence and the benefits of marine reserves: putting Descartes before des horse? *Environmental Conservation* 30: 97-103.
- Winfree, R.; Griswold, T.; Kremen, C. 2007a: Effect of human disturbance on bee communities in a forested ecosystem. *Conservation Biology* 21: 213-223.
- Winfree, R.; Williams, N.M.; Dushoff, J.; Kremen, C. 2007b: Native bees provide insurance against ongoing honey bee losses. *Ecology Letters* 10: 1105-1113.
- Winfree, R.; Williams, N.M.; Gaines, H.; Ascher, J.S.; Kremen, C. 2008: Wild bee pollinators provide the majority of crop visitation across land-use gradients in New Jersey and Pennsylvania, USA. *Journal of Applied Ecology* 45: 793-802.
- Wondzell, S.M.; King, J.G. 2003: Postfire erosional processes in the Pacific Northwest and Rocky Mountain regions. *Forest Ecology and Management* 178: 75-87.
- Wong, Y.S.; Tam, N.F.Y.; Lan, C.Y. 1997: Mangrove wetlands as wastewater treatment facility: a field trial. *Hydrobiologia* 352: 49-59.
- Woodward, F.I. 1993: How many species are required for a functional ecosystem? Pp. 271-291 in Schulze, E.-D.; Mooney, H.A. (Eds): Biodiversity and ecosystem function. Springer Verlag, Berlin, Germany.
- Worm, B.; Barbier, E.B.; Beaumont, N.; Duffy, J.E.; Folke, C.; Halpern, B.S.; Jackson, J.B.C.; Lotze, H.K.; Micheli, F.; Palumbi, S.R. 2006: Impacts of biodiversity loss on ocean ecosystem services. *Science* 314: 787-790.
- Worthy, T.H. 1998: Fossils indicate *Pelecanoides georgicus* had large colonies at Mason Bay, Stewart Island, New Zealand. *Notornis* 45: 229-246.
- Yang, B.; Lan, C.Y.; Yang, C.S.; Liao, W.B.; Chang, H.; Shu, W.S. 2006: Long-term efficiency and stability of wetlands for treating wastewater of a lead/zinc mine and the concurrent ecosystem development. *Environmental Pollution* 143: 499-512.

- Yang, J.; McBride, J.; Zhou, J.; Sun, Z. 2005: The urban forest in Beijing and its role in air pollution reduction. *Urban Forestry & Urban Greening* 3: 65-78.
- Yelenik, S.G.; Stock, W.D.; Richardson, D.M. 2004: Ecosystem level impacts of invasive *Acacia saligna* in the South African fynbos. *Restoration Ecology* 12: 44-51.
- Yong-Zhong, S.; Yu-Lin, L.; Jian-Yuan, C.; Wen-Zhi, Z. 2005: Influences of continuous grazing and livestock exclusion on soil properties in a degraded sandy grassland, Inner Mongolia, northern China. *Catena* 59: 267-278.
- Yu, K.C.; Tsai, L.J.; Chen, S.H.; Ho, S.T. 2001: Chemical binding of heavy metals in anoxic river sediments. *Water Research* 35: 4086-4094.
- Zabel, J.; Tschamtkke, T. 1998: Does fragmentation of *Urtica* habitats affect phytophagous and predatory insects differentially? *Oecologia* 116: 419-425.
- Zaman, M.; Nguyen, M.L.; Gold, A.J.; Groffman, P.M.; Kellogg, D.Q.; Wilcock, R.J. 2008: Nitrous oxide generation, denitrification, and nitrate removal in a seepage wetland intercepting surface and subsurface flows from a grazed dairy catchment. *Australian Journal of Soil Research* 46: 565-577.
- Zedler, J.B. 2003: Wetlands at your service: reducing impacts of agriculture at the watershed scale. *Frontiers in Ecology and the Environment* 1: 65-72.