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Review of the ecological role of Black Swan (*Cygnus atratus*)

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C Howard-Williams

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SUMMARY

This review was carried out under DOC Investigation No. 1869 to improve our understanding of the knowledge relating to Black Swans and their impact on freshwater and estuaries, macrophytes, eutrophication, lake end estuarine littoral zone ecology and land areas at the margins of these habitats. The investigation also had the objective of providing a description of methods of management designed to promote compatability of Black Swans and human use in aquatic habitats.

It is stressed in this report that the information needs to be integrated with the large data set in the Dept. of Conservation. This would best be carried out by Dr. Murray Williams.

There is evidence that Black Swans may have been a feature of some Zew Zealand waterways before the arrival of Europeans. They are now widespread in North and South Islands with large variations in the population numbers, and evidence of a single national mobile population unit. In recent years there have been major declines in population numbers in the Waikato, Cook Straight and mid-Canterbury regions, possibly related to decreased food supply. The large shallow lakes and wetlands of these areas have all undergone major changes in the last few decades.

The feeding habits in large inland lakes is not well known, but where studies exist, exotic waterweeds of the family Hydrocharitaceae make up much of the food. Detailed feeding studies in lowland shallow lakes and coastal lagoons show that swans have a clear preference for submerged plants over wetland and lake edge emergent species. They also graze heavily on the large filamentous algae such as *Enteromorpha* and *Spirogyra*. In estuaries the main food is seagrass (*Zostera*) and sea lettuce (*Ulva* spp.) although further gut content studies from New Zealand are required to asses the relative importance of these items. Both in Australia and New Zealand Black Swan move into pastures to feed when lake food supply is reduced by either high lake levels or macrophyte declines. There are mixed opinions about the influence of swans on pastures with many but not all farmers claiming that swans foul paddocks as well as consuming pasture grasses.

The ecological impacts of swan on natural waters can be assessed from information on rates of aquatic plant consumption, and from rates of nutrient regeneration via faeces. Some of the best studies internationally have been carried out at the University of Otago. The data indicate that a value of 0.25 kg (fresh plant) per kg swan body weight per day can be used as a feeding rate. This rate may be higher in pasture due to lower digestibility of pasture vegetation when compared with aquatic plants. Complex cause/effect relationships exist between Black Swan and eutrophication of water bodies. In some cases swan food has

declined as lakes have become phytoplankton rather than macrophyte dominated due to human induced enrichment. In other cases it is possible that overgrazing by swans and nutrients from swan faeces may have accelerated macrophyte decline. In the few studies where attempts have been made to quantify faecal nutrient loading by Black Swan this was not a significant pathway relative to other nutrient inputs. Black Swan data from New Zealand were found to fit a general nutrient enrichment model for waterfowl. Black Swan faecal production was found to average 52 g dry wt per swan per day with an inorganic nitrogen and phosphorus content of 2.3% and 0.13% of dry wt. respectively.

This report points to gaps in the knowledge, one in particular being the need for more information on the quantitative impact of Black Swan on seagrass beds and on nuisance sea lettuce populations.

1.0 INTRODUCTION

1.1 Background

The Black Swan *Cygnus atratus* (Latham) is one of the most conspicuous waterfowl species in New Zealand. Following its introduction into the country last century it spread rapidly and is now a familiar inhabitant of most lakes, lagoons and estuaries. Introduced both as a gamebird, for which it is still highly valued, and as a means to regulate aquatic plants, it had additional commercial value from the sale of surplus eggs (e.g., Lamb 1964). However, particularly since the late 1960s it has become an agricultural pest in some areas, causing damage to pasture by both grazing and soiling. In addition, there are concerns that it is damaging valuable plant communities in harbours, estuaries and lakes, as well as soiling recreational areas. It has also been reported as a nuisance in some lake-side urban areas.

Management practices have included regular monitoring of the national population and banding studies to determine dispersal, survival and level of exploitation (Williams 1980). Following the destruction of the swan food supply at Lake Ellesmere by the "Wahine" storm of 1968 many birds began grazing on pasture and this led to swan culls (Williams 1979) until the population was reduced to that which could be supported by aquatic plants in the lake. On Farewell Spit, the largest Black Swan moulting site in New Zealand there have been constant calls for swan culls by people concerned at the unknown effects of these birds on eelgrass beds and migrant wader habitat.

1.2 Objectives and report status

A sound understanding of the ecological role of Black Swans in aquatic and riparian habitats is necessary before relevant management can be implemented. Documentation of the effects of Black Swans is fragmented and mostly scattered through unpublished reports and databases. This review was carried out under DOC Investigation No. 1869 with the following objectives:

(1) an understanding of current knowledge relating to Black Swans and their impact on freshwater and estuaries, macrophytes, eutrophication, lake and estuarine littoral zone ecology and land areas at the margins of these habitats; and

(2) a description of methods of management designed to promote compatibility of Black Swans and human use of aquatic habitats.

In preparing this report it became clear that the impact of swans on lake and estuarine littoral zone ecology was linked most closely to swan feeding and to the issue of whether swans enhance the process of eutrophication. These two topics form the bulk of this report in sections 4 (Feeding) and 5 (Eutrophication).

NIWA's expertise is centred on the aquatic ecosystem component of the study but we have included sections on population size and distribution as these are relevant to the magnitude of any swan impacts at a national level. For completeness we have also included a short section on breeding as this may be influenced by food availability.

It is recognised that Dr Murray Williams of DOC is the country's authority on Black Swan. This report has received valuable input from Dr Williams and we recognise that a large unpublished data archive on Black Swan exists in DOC. This report needs to be combined with that archive at some future date.

Although not requested to do so, we have included a short section on gaps in knowledge where these relate to our brief. This could no doubt be expanded by Dr Williams.

1.3 History of introduction

The first Black Swans introduced into New Zealand were five birds received in 1863, from Sydney, by the Nelson Acclimatisation Society (Sowman 1968). These birds were kept in the "Eel Pond" in the present Queen's Gardens, where they bred successfully; by April 1867 there were 23 birds there, but subsequently all dispersed.

Several importations were received in 1864, these birds being released in Canterbury and the North Island (Thomson 1922). By 1870 several releases had been made in Southland, Otago, Canterbury and Auckland. However, Kirk (1895) considered that its simultaneous appearance in many localities between 1865 and 1868 also proved natural immigration had occurred. Further evidence that Black Swans arrived by natural immigration is in the subfossil record of Lake Poukawa, Hawkes Bay, where bones of this species were recovered from Maori midden deposits dating from pre-1840 (McFadgen 1979, Horn 1983). This raises the interesting question as to whether Black Swans should be regarded as an indigenous species. Whatever the source of birds, the Black Swan population increased rapidly, and as early as 1875 it was declared native game in Canterbury and could be shot during the shooting season (Lamb 1964).

The reasons for the introduction of Black Swans to Canterbury are interesting in the context of this report. In 1864, the North Canterbury Acclimatisation Society received two pairs of Black Swans from Sir George Grey and these were liberated on the Avon River (Lamb 1964). However, the largest liberation that year was made by the Canterbury Provincial Council which had the responsibility of clearing the river of watercress. Watercress was a major problem in the Avon River in the 1860s (Howard-Williams *et al.* 1987). The idea of using swans for this purpose was mooted at a meeting of the Council in August 1864 and a committee was set up to examine the question. After visiting Mrs Deans' farm at Riccarton and seeing the good work performed by a pair of swans in keeping down the watercress there, the committee reported their findings to the Council, which obtained 13 pairs of swans from Sydney and released them on the river. These birds soon dispersed about the country.

2.0 DISTRIBUTION AND POPULATION

Black Swans are endemic to Australia (Marchant and Higgins 1990) and have been introduced to New Zealand (Thomson 1922), although it is likely that some birds arrived naturally (Kirk 1895). Extralimitally, it is a vagrant to southern New Guinea (Beehler 1980).

In New Zealand Black Swans are widespread in both the North Island and South Island, occurring mainly on lakes and ponds in coastal and lowland areas (Bull *et al.* 1985). They reached Chatham Island before 1922 (Thomson 1922).

Williams (1980) provides the most recent comprehensive review of the distribution and size of the Black Swan population in New Zealand. He estimated that in January 1979 the population on the New Zealand mainland was 60 000 birds, of which 5000 were fledged or near-fledged cygnets. The most recent estimate for the Chatham Island was approximately 3000 birds in 1978, although previous estimates were as high as 10 000.

During the 1970s principal breeding concentrations of Black Swans occurred were recorded at (in approximate order of abundance) Lake Ellesmere, Lake Wairarapa, Waikato Lakes, Rotorua Lakes, Lakes Waihola-Waipori, Okarito Lagoon, Lake Ki-Wainono, Waituna Lagoon, Ashburton Lakes, Vernon Lagoon, Manawatu Lakes, Hawkes Bay Lakes, Lake Taupo, Taieri Wetlands and Northland Lakes. In addition, concentrations of non-breeding and/or moulting birds were recorded at Kaipara Harbour, Farewell Spit, Invercargill Estuary-Awarua Bay, Parengarenga Harbour, Tauranga Harbour and Havelock (Pelorus Sound).

Using data from a large-scale study of movements and changes in numbers and distribution Williams (1980) showed that there are several discrete or partially discrete populations of

Black Swans in New Zealand. These populations can be roughly placed into three main subpopulations: an Ellesmere-Southland and Otago group comprising about 22 000 birds in 1979; a Wairarapa, Hawkes Bay, Manawatu, West Coast and Nelson-Marlborough group of about 15 500 birds in 1979; and a Rotorua, Waikato and Northland group of about 25 000 birds in 1979. Some of these populations overlap, sharing a common non-breeding season feeding or moulting area, but there was no evidence of widespread interbreeding or intermingling consistent with the hypothesis of a mobile national population (Williams 1980).

Although widespread and common on mainland New Zealand by 1900, the Black Swan population has varied substantially in recent years. Until 1968 Lake Ellesmere supported the largest concentration of swans in the country with estimates of 40 000 to 80 000 birds during the 1950s and 1960s (Williams 1979). In April 1968 the "Wahine" storm destroyed at least 5000 swans, plus the *Ruppia* beds upon which the swans fed. Subsequently, the diminished food supply resulted in extensive breeding failure, poor cygnet survival, increased adult mortality, and permanent emigration. The swan population decreased rapidly and aerial surveys in January (after the breeding season) gave estimates of 2400 birds in 1969, 18 000 in 1973, 13 000 in 1975, 12 300 in 1976, and 9500 in 1978 (Williams 1979). The population declined further to about 6000 birds by 1984 (O'Donnell 1985) and 3000 birds in 1985 (NCAS 1987). Numbers increased from 1986 and by January 1987 there were an estimated 10 000 birds (NCAS 1987), with 7100 in January 1990 (NCAS 1990).

This is not the first time that reduced food supply has affected the Black Swan population at Lake Ellesmere. In 1947 and 1948 about 21 000 swan eggs were collected by North Canterbury Acclimatisation Society personnel, but about this time the food supply of waterfowl at the lake (*Potamogeton* and *Ruppia*) disappeared and did not begin growing again until 1951, when about 31 000 swan eggs were collected (Lamb 1964).

The subpopulation of swans centred on the Cook Strait region has also declined in recent years. At Lake Wairarapa, the major breeding area for this subpopulation, the swan population declined from 9519 in January 1977 to 2748 swans in January 1983 (Moore *et al.* 1984). Numbers of swans at other areas within the Cook Strait region did not decline during this period. However, the summer population at Farewell Spit, the major area for non-breeding and moulting birds, was about 13 000 during the mid 1970s but declined to around 6500 in the mid 1980s. This decline was attributed to wetland drainage in the Wairarapa (Ward 1990). By 1990 numbers of Black Swans at Farewell Spit had increased to about 12 000.

The small Hawkes Bay population numbered about 800 birds in 1979, but ranged from 1381 (1984) to 3041 (1987) during the 1980s (HBAS 1989, 1986, 1984, 1982). Lowest numbers were counted in 1984 and 1985 (1391 and 1439 respectively) when drought affected the area. During these years weed beds at the margins of lakes were absent and "had obviously been grazed out by swans" (HBAS 1984).

The swan subpopulation of the Rotorua, Waikato and Northland lakes has also decreased substantially in recent years. During the early 1960s there were over 40 000 swans on lakes in the Waikato. However, by 1985 the number had declined to 6000, with 70-80% of the birds on Lake Whangape or, when lake levels were high, on Kawhia and Aotea Harbours (Roxburgh 1985). This dramatic reduction in swan numbers corresponded with the collapse of the aquatic macrophytes in Lakes Waikare, Waahi, Hakamoa and Kimihia (Roxburgh 1985). Roxburgh (1985) also reported that aquatic plants in the southern arm of Lake Whangape, which receives waters discharged from coal mines, had largely disappeared and the numbers of waterfowl, especially Black Swans, using this arm had declined markedly as a result.

Numbers of swans in the Taupo area declined from about 3600 birds in 1991 and 1992 to 2714 in 1994 (James Holloway, pers. comm.).

3.0 BREEDING

Black Swans may breed in simple pairs solitarily on small water bodies (5 to 20 ha); large water bodies (>20 ha) where non-breeding birds do not remain throughout the breeding season; large water bodies where aquatic macrophytes are distributed as a narrow band around the margins; and areas where the water level is more or less constant throughout winter and spring. By contrast, colonial nesting, where nests may be placed almost within reach of incubating birds, are usually found on large water bodies; water bodies where large number of non-breeders are present throughout the breeding season; water bodies where the water level fluctuates throughout winter and spring; and estuarine areas (Williams 1980). Colonial nesting appears to allow the birds to exploit abundant food resources in areas of fluctuating water levels (Kear 1972).

3.1 Breeding season

Solitary nesting regularly starts in July and continues to October. Colonial nesting is irregular, depending on water levels, usually not starting until water levels fall in September or as late as January. April, May and early June are the only months when eggs or dependent young are least likely to be found (Marchant and Higgins 1990).

3.2 Breeding sites

Black Swans nest over water and on land. Nests over water have been recorded in stands of *Typha* and *Eleocharis*. At Lake Whangape swans have nested below a dense scrub canopy of ponga (*Cyathea*), manuka (*Leptospermum*) and willow (*Salix*). (Marchant and Higgins 1990). They have nested in the open on islands, but prefer barriers of rushes and tussocks at Lake Ellesmere (Miers and Williams 1969).

3.3 Eggs

Mean clutch size from various colonies varied from 4.9 to 5.7, with a range of three to 14 eggs (Miers and Williams 1969). Most clutches with more than eight or nine eggs are almost certainly laid by two females (Marchant and Higgins 1990). An extensive study at Lake Ellesmere in this early 1960s recorded the mean clutch as 5.4 (Miers and Williams 1969). Subsequently, clutch sizes were recorded at Ellesmere from 1975 to 1979 when they declined from 5.0 to 4.0 respectively, reflecting the deteriorating state of the lake as swan habitat (Williams 1979). Eggs are laid at about 24-h intervals and the incubation period averages 36 days (range 32-43 days) (Marchant and Higgins 1990).

3.4 Young

At Lake Ellesmere about a third of cygnets are reared as family broods, the rest join into groups of usually 2-4 broods. Amalgamations are probably induced by patchy distribution of food forcing broods into close contact. Amalgamation of broods has been recorded also at Lake Wairarapa, Okarito Lagoon, and Vernon Lagoon where food is also patchy. It has not been recorded at Lakes Omapere and Whangape where food is well distributed (Marchant and Higgins 1990).

Young weigh about 170 g at hatching and 4000 - 5000 g at 180 days (Marchant and Higgins 1990). At Lake Ellesmere in 1976, 65% of cygnets which remained in family broods fledged, and, overall, 52.2% of the nesting colony survived to independence (Williams 1980).

3.5 Factors affecting breeding success

Lake level fluctuations were one of the most important factors determining breeding success at Lake Ellesmere (Adams 1972), with decreasing levels in winter and spring necessary to stimulate breeding. Grazing of stock, particularly cattle, also affects breeding success by direct disturbance of incubating birds (Meis 1988) and by removal of vegetation suitable for shelter and nesting materials (NCAS 1990). At Lake Ellesmere, an indirect effect of the "Wahine" storm was erosion of prime nesting sites (NCAS 1990). Before the storm *Ruppia* beds used to prevent wave action on the north eastern shoreline, the site of dense concentrations of nesting swans. However, after the storm and removal of the aquatic macrophyte beds, this area was subject to erosion by wave action so that the shoreline moved 42 m by 1989. In addition, nesting material such as native grasses were washed away or buried under silts.

The breeding biology of Black Swans is not well known, with some basic gaps regarding age of first breeding, the cause of large annual variations in the proportion of the population which breeds, annual variations in clutch size, and why pairs may nest solitarily or in colonies (Williams 1980).

4.0 FEEDING

4.1 Introduction

Black Swans are described by Williams (1984) as being more exclusively herbivorous than any other species of waterfowl. A five year study of Black Swan by Frith *et al.* (1969) concluded that while the swans ate mostly plants, 0.1% of the food volume could be attributed to animal material. Small insect larvae and occasional molluscs were probably collected accidentally as the birds grazed the plants. Table 1 gives a known list of plants eaten by Black Swan in New Zealand. This may be expanded later with the additional material in the unpublished archive of Dr Murray Williams (DOC).

TABLE 1. List of known aquatic plants which are eaten by Black Swan in New Zealand. With the exception of *Ceratophyllum emersum*, for which there is evidence that the plant is not eaten, absence from this list of vascular aquatic plants merely indicates that information is not available at present.

Ruppia polycarpa
R. megacarpa
Zostera novazelandica
Potamogeton cheesemanii
P. crispus
P. pectinatus
P. ochreatus
Lagarosiphon major
Elodea canadensis
Egeria densa
Myriophyllum spp.
Polygonum spp.
Eleocharis spp.
Juncus spp.
Ranunculus spp.
Ludwigia spp.
Azolla spp.
Callitriche stagnalis
Lemna minor
Trypha orientalis
Chara spp.
Ulva spp.
Enteromorpha nana
E. intestinalis
Spirogyra sp.
Rhizoclonium sp.
filamentous green algae

4.2 Feeding in lakes and estuaries

4.2.1 Lakes

Little work has been done on the feeding habits of swans in the large inland lakes of New Zealand. Black Swans are common in the Taupo-Rotorua area. Exotic weeds (*Lagarosiphon major, Elodea canadensis)* in Waihi Bay in Lake Taupo support a large Black Swan population (Howard-Williams and Vincent 1983). An investigation of Black Swan feeding at Waihi Bay, Lake Taupo, was carried out in 1983 by DSIR in collaboration with the NZ Wildlife Service. SCUBA dives across Black Swan feeding areas were combined with some underwater photography at the site. Four swans were killed and gut contents identified (C. Howard-Williams, NIWA, unpublished data). It was found that swans were able to graze to a depth of 1 m below the surface (Howard-Williams and Davies 1988), *Lagarosiphon major* and *Elodea canadensis* shoots were bitten off and eaten directly. *Ceratophyllum demersum* was not eaten but the birds tended to pull the shoots up. At nearby Motuoapa Bay extensive areas of native aquatic plants occurred in the shallows and swan feeding resulted in the uprooting of patches of these plants which then floated to shore. No quantitative assessment has been made of this damage to the native plant community but a survey of the bay in 1986 showed that *Potamogeton* spp. were, uncharacteristically, absent. This may well reflect swan grazing (Howard-Williams 1986) as two *Potamogeton* species (*P. cheesmanii, P. ochreatus)* had been recorded there in a survey in 1980 (Howard-Williams, unpub.).

Most studies on the feeding habits of Black Swan in New Zealand have been carried out on lowland shallow lakes.

A clear preference for submerged aquatic macrophytes over wetland plants was demonstrated at Lakes Whangape and Waikare (Williams 1984). For instance, species consumed in Lake Whangape during summer were: *Egeria densa, Elodea canadensis, Potamogeton ochreatus,* and *P. crispus*. When water levels rose in Lake Whangape during winter and *Egeria* was out of reach, swans turned to pasture and a variety of wetland marginal plants, principally the genera: *Myriophyllum, Polygonum, Eleocharis, Juncus, Ranunculus* and *Ludwigia*.

Similar trends were found in a NSW study of a cumbungi *(Typha)* swamp where Black Swan diet depended heavily on the water levels at the time. During periods of flooding (high water) swans grazed almost entirely on pasture plants. During periods of low water the deep water flora became available and swans remained in the deepest and most permanent parts of the swamp. The commonest plant eaten was the alga *Spirogyra*. Swans fed by grazing and uprooting submerged material. Deep water plants of importance were *Potamogeton crispus, P. ochreatus* and *P. pectinatus*. *Chara, Azolla, Lemna,* and *Typha* were also eaten where present (Frith *et al.* 1969). In a separate study waterbirds at four swamps in New South Wales were found to be commonly associated with particular habitats (Briggs 1979) primarily using open meadow and grass swamp.

Analysis of gut contents from swans at Tomahawk Lagoon (Otago), Lake Waipouri and Lake Waihola showed that charophytes were an important constituent of the swans diet (McKinnon 1989). Other plants identified from gut contents were: terrestrial grasses, filamentous algae, seeds, *Elodea canadensis, Myriophyllum* sp., *Lemna* sp., *Callitriche* sp.

and *Potamogeton* sp. At Pukepuke Lagoon swans grazed beds of *Potamogeton* to extinction in preference to marginal pasture grasses and *Veronica* (Potts 1982).

In the "Wahine" storm of 1968 beds of the aquatic macrophytes *Ruppia, Potamogeton* and *Myriophyllum* were stripped from Lake Ellesmere. These macrophytes are highly favoured swan food. Several thousand swans were killed during the storm and the population continued to decline (Williams 1975) as discussed in Section 2 above. Williams (1977) suggested that although quantitative data on food and feeding of swans were not then available, it was possible that the restricted food supply since 1968 could have increased the natural mortality of swans. (Williams 1984) noted that at Lake Ellesmere *Ruppia megacarpa* was preferred over *Myriophyllum* by Black Swans. In 1986 the Black Swan population of Lake Ellesmere was considered to be on the increase again (Meis 1988). It was suggested that if the population continued to increase at a rate in excess of the lakes ability to carry it this would likely lead to swans moving onto farmers paddocks for food (see section 4.3).

A large unpublished data set exists in the personal archives of Dr Murray Williams of DOC. This includes food items from 240 swans shot at Lakes Whangape and Waikare.

4.2.2 Coastal and estuarine areas

Worldwide, several species of swans, including the Black Swan congregate in shallow coastal areas to moult. In New Zealand, 13 000 swans that have over-wintered in large inland lakes and lowland shallow lakes, congregate at Farewell Spit from November to March each year. This area is regarded as the major moulting site for New Zealand populations (Williams 1977).

The largest component of the diet of Black Swans on the intertidal flats of Farewell Spit and Whanganui Inlet was eelgrass (*Zostera novazelandica*) (Byrom and Davidson 1992). Swans cropped only the leaves of eelgrass. They were not observed grubbing for eelgrass roots. Feeding was largely governed by the state of the tide and consequently the depth of water. Swan numbers varied at Farewell Spit and Whanganui Inlet but food was not considered to be limiting at either site.

Mute Swans in a similar habitat on the south eastern coast of Sweden were described by Berglund *et al.* (1963) as being exclusively vegetarian and at the population levels at that time they were considered to have little effect on the vegetation of the area.

Mute Swans gathered for moulting purposes in bays of the Swedish coast shifted sites in relation to food supply (Mathiasson 1973). This was governed to some extent by water levels. Shallow waters less that 1.5 m deep were the main feeding grounds. At high water levels the swans moved towards the coast to shallower sections. The main food was *Zostera* in summer and autumn, while *Ulva* (sea lettuce) was more important in winter. *Ulva* was completely eliminated in certain areas (Mathiasson 1973). The only other food species eaten in the Swedish coastal area was *Zostera marina*. Only parts of *Enteromorpha intestinalis*, and *Ruppia maritima* were eaten.

It is interesting that *E. intestinalis* is eaten by Black Swan in Otago lagoons (Mitchell and Wass, in press). We have observed Black Swan feeding in Tauranga Harbour and Otago Harbour, presumably on *Zostera* beds, but they may also have an impact on *Ulva* in both these locations.

4.3 Feeding in pastures

Swans are selective feeders, preferring aquatic over wetland and terrestrial vegetation. While they prefer aquatic vegetation, when swans are living in an area of reduced natural food supply they may be forced to invade pasture for additional food (Thompson 1981). For example, in Europe the natural food of Bewick's Swans consisted of submerged macrophytes and emergent/ wetland species plus *Zostera* in tidal marshes, but a loss of principal aquatic habitats has caused a shift to arable land in some places (Beekman *et al.* 1991).

Due to declining wetland areas and increased eutrophication of shallow lakes, hence reduced aquatic macrophytes, European studies have more recently focused on swan feeding in agricultural areas. An over-wintering population of Bewick's Swans utilised wetland/flooded pasture in Gloucestershire, Britain, and grazed on flooded pasture (Rees 1990). The swans selected fields according to the quantity of grass available but site usage was more closely correlated with maximum sward length than with total grass biomass. Bewick's Swan was found to prefer young rye grass to clover (*Trifolium repens*) when grazing in pastures. Clover constituted 1% of herbage in the fields, but only 0.01% in the swan faeces (Rees 1989).

Studies of the feeding activity of Mute Swans (*Cygnus olor*) in Britain described swans feeding on fields of winter wheat and ley grass where they spent 67% of the daytime actively grazing. Those feeding on a lake fed for 46% of the daytime on filamentous algae. Bread was the preferred food when proffered by members of the public (Sears 1989). Scott and Birkhead (1983) found that Mute Swans had larger clutches in areas with a high potential bread supply. Females laid earlier and larger clutches in area with abundant aquatic vegetation and females were heavier on territories with a high diversity of aquatic vegetation.

Large numbers of Bewick's Swans used wetlands and agricultural areas in winter in the Netherlands. When the swans arrived in the area in winter they had a clear preference for pondweed (*Potamogeton pectinatus, P. perfoliatus)* tubers. After depleting these the swans switched to field feeding, consuming crop wastes of root crops which, like tubers, are carbohydrate high, energy foods (Beekman *et al.* 1991), and winter wheat and grasses (relatively high protein foods) (Dirksen *et al.* 1991).

Both in Australia (Frith *et al.* 1969) and in New Zealand, swan feeding on pasture grasses and other wetland marginal plants occurs only when aquatic macrophytes are unavailable (Williams 1984). Pasture feeding by Black Swan is a very common phenomenon around all major New Zealand lowland lakes (Dr M. Williams, DOC, pers. comm.). Large concentrations of swans in traditional nesting areas such as Lake Ellesmere have in the past caused damage to lakeside pastures. This is more likely to be a problem when natural sources of food are destroyed (such as in the "Wahine" storm) or over winter when lake levels are high. A reduction in available wetlands around many breeding areas in New Zealand has forced swans and many other waterfowl to find alternative sources of food on agricultural land.

High lake levels have been shown to prevent access to food and at such times Black Swan will shift to feeding in pasture. Examples were at Lake Ellesmere in the 1980s when the outlet was blocked and the then *Ruppia* beds became too deep for swan feeding. The same situation occurred at Lakes Whangape and Waihi (Waikato), Hautuna (Hawkes Bay) and Omapere (Northland) (Dr M Williams, DOC, pers. comm.) where pasture feeding was initiated by a temporary denial of access to the aquatic macrophytes. Over the last two decades in many of these lakes the macrophyte populations have declined markedly for varying reasons. Resident Black Swans have, in almost all cases, sustained themselves by pasture feeding on a permanent basis (Dr M Williams, DOC, pers. comm.).

In many areas of New Zealand lakeside farmers have an antipathy towards Black Swans claiming that swans eat a lot of pasture and that their droppings foul pastures to the extent that livestock avoid the areas.

After interviewing farmers in the Central Otago area (Thompson 1981) found that not all farmers considered swans to be problematic. Those who did suggested that damage included pasture and crop depredations and fouling and trampling of land near rivers. Swans did not cause pasture damage regularly from year to year but damage incurred by a young grass paddock could be severe at times. Sheep preferred to graze on grass unfouled by swans with the main repelling factor appearing to be chemical in nature. In a paddock where swans had been grazing, the average grass length was 27% shorter than in ungrazed areas (Thompson 1981).

At Rotorua, swans feed in gardens on the lake edge and have proved a particular nuisance in the lake front reserve in the city. (There is an unconfirmed report of them eating the roses from the lake edge gardens.) Without more information it is not known whether these problems have followed the aquatic weed spraying operations which have been very effective in killing off the aquatic weedbeds, and hence the swan food source, opposite Rotorua City over the years.

4.4 Rates of food consumption

The literature shows up a consistent gap in information referred to in studies of several swan species; that of food consumption rates. We have found only five studies in the literature data base which report measurements of food intake (Table 2).

TABLE 2 Food consumption of swan species

Species	Black Swan	Mute Swan	Trumpeter Swan	Bewick's Swan
Reference	Mitchell & Wass (in press)	Mathiasson 1973	Owen & Kear 1972 Benedict & Fox 1927	Beekman *et al.* 1989
Species eaten	*Enteromorpha intestinalis* *Spirogyra* sp. *Rhizoclonium* sp.	*Zostera marina*, *Ulva lactuca*		
Food consumed:				
kg (fresh) kg^{-1} body wt day^{-1}	0.25	0.49 - 0.54	0.35	
kg (dry) kg^{-1} body wt day^{-1}	0.018	0.077 - 0.183		0.054
Energy intake (W kg^{-1})	2.0		2.3	

Mitchell and Wass (in press) used the amounts and cellulose composition of the faeces to estimate food intake. From this they estimated that on average a Black Swan would consume 104 g dry weight of plants per day. The assimilation efficiency (food ingested minus food excreted/food ingested) was 50%. Grazing by Black Swans in Tomahawk Lagoon was calculated to have removed about 15-25% of the production of macrophytes during the growing season (20-50% per annum) (Mitchell 1989).

Densities of swans in good feeding areas (e.g., Tomahawk Lagoon, Otago, and Waihi Bay, Lake Taupo) were from 10 to 20 birds ha^{-1}. For example, in Hawkesbury Lagoon in 1990-91 counts ranged from 3.15 to 13.19 swans ha^{-1} (Wass 1991).

Using the range of 10 and 20 birds per hectare and a consumption rate of 104 g dry weight day^{-1}, the biomass removal would be 1.04 and 2.08 kg ha^{-1} day^{-1} respectively. The growth rate of vascular aquatic plants in good conditions may be 0.02 g g^{-1} (dry weight) day^{-1} (2% of biomass per day). Thus a biomass of 52 and 104 kg ha^{-1} would be required to support the removal rate listed above. It should be noted that growth rates of filamentous green algae will be very much higher than 0.02 day^{-1}, values as high as 0.1 - 0.2 day^{-1} have been recorded in the literature (e.g. Gordon *et al.* 1981). Actual biomass values for productive beds of aquatic plants in New Zealand are 500 - 5000 kg ha^{-1}. Indeed, in Hawkesbury Lagoon no clear relationship between Black Swan density and macrophyte biomass was concluded. Macrophytes were able to increase in biomass in spite of grazing pressure from 10-20 swans ha^{-1} (Wass 1991).

The daily fresh weight consumption by moulting Mute Swans in Swedish coastal waters was found to be 3.66 kg of *Zostera* or 4.03 kg of *Ulva* (Mathiasson 1973). This was equivalent to 570 g and 1365 g dry weight of *Zostera* and *Ulva* respectively. In order to compare with Black Swan the numbers need to be normalised to unit of body weight (Table 2). Values for Mute Swan were 0.49 kg *Zostera* or 0.54 kg of *Ulva* per kg swan on a wet weight basis.This is considerably higher than the values of Mitchell and Wass (in press) cited above who estimated 0.25 kg kg^{-1} body wt day^{-1} for Black Swan.

Swan densities at Farewell Spit were always less than 10 birds ha^{-1} (Byron and Davidson) and biomass removal of seagrasses would be less than 1.04 kg day^{-1}. Seagrass biomass is reported as 450-4000 kg ha^{-1} (Long *et al.* 1994) and with the growth rates for vascular plants as reported above it is likely that seagrasses are also able to increase in biomass in spite of grazing pressure from swans at the density reported above.

Sears (1989) suggested that when Mute Swans are feeding in pasture the average daily consumption is likely to be considerably higher that the 4 kg (wet weight) of aquatic vegetation per day estimated by Mathiasson (1973). Differences in the digestibility (food quality) of submerged aquatic plants *versus* pasture plants may account for the fact that both Black and Mute Swan have a lower food intake per unit of body weight than pasture eating geese species (see references in Mitchell and Wass in press). In addition, Sears (1989) records that swans feeding in pastures drop a large proportion of the material they have cropped because they are unable to swallow it all at once.

5.0 RELATIONSHIP OF SWANS AND EUTROPHICATION

5.1 Species effects

Eutrophication in the Netherlands, at least partly caused by fertilizer used in agriculture, and consequent algal blooms have caused pondweeds to disappear in some areas. In these areas feeding of swans on protein rich grass species is common. While eutrophication has caused pondweeds to disappear the same fertilizers have improved the quality and protein content of adjacent grasslands. Dirksen *et al.* (1991) questioned which choice Bewick's Swans would make in spring if they could still choose between pondweed tubers and protein rich grass species.

In other areas, eutrophication can lead to improvements in such habitat. Eutrophication of Lake Constance in central Europe has resulted in the replacement of Characean communities with dense beds of *Potamogeton pectinatus* (Laing 1981). This has had the effect of greatly increasing swan (*Cygnus cygnus*) numbers on the lake as the tubers of *P. pectinatus* are an important swan food (Schneider-Jacoby *et al.* 1989) in the lake. Other species of waterfowl, particularly diving ducks and coots, have benefited from the Whooper Swans by feeding around them ("commensalism" Jacoby *et al.* 1970).

In Loch Levin in Scotland Mute Swan (*Cygnus olor*) numbers fluctuated in parallel with the decline and recovery of macrophytes (*Potamogeton* sp.) from 1966 to 1971 (Jupp and Spence 1977).

The interrelationship between swan numbers and macrophyte biomass is an issue which has been of particular interest to researchers over the last decade. At Farewell Spit and Whanganui Inlet the calculation of daily consumption of eelgrass by Black Swans is suggested as the next step toward understanding the swans impact on the environment. Large numbers of Black Swans recovering from moulting could either deplete the eelgrass, or, through their droppings, increase the growth and productivity of the beds, although the evidence suggested in section 4.3 suggests that this is not a problem at current swan densities (10 ha^{-1}).

Quantification of interactions between wildfowl and macrophytes is complicated due to difficulties in estimating factors such as consumption rates, in situ macrophyte production and impacts of grazing on macrophyte production (Køirboe 1980). In a study of Pukepuke Lagoon, where macrophyte collapses have been recorded, Potts (1982) raised the possibility that swan grazing may have been sufficiently heavy to tip the balance between macrophytes and phytoplankton in favour of the latter. In the mid 1980s macrophyte collapses in Waikato lakes began to raise similar questions, but in this case concern was expressed that a drastic reduction in swan numbers may have been the result of the collapse of aquatic macrophytes in several of the lakes.

By 1985 concern was being expressed at an apparent trend of deteriorating water quality and declining abundance and health of the macrophytes in Lake Whangape which supported 70-80% of the North Island Black Swan population. Between 1979 and 1983 *Egeria* failed to grow in the southern half of the southwest arm of the lake and from late 1985 to mid 1987 it virtually disappeared throughout the whole lake. *Ceratophyllum* increased in biomass as *Egeria* declined, but it had also declined to negligible biomass by the latter half of 1987.

Part of a study on the lake during the macrophyte decline (Wells and Clayton 1989) focused on the interaction between Black Swans and the macrophytes. Swan exclusion cages were placed over the macrophytes at various sites around the lake. Wells and Clayton (1989) concluded from this study that the main effect of swan browsing was to prevent all palatable species (*Egeria densa, Elodea canadensis*) from growing within 0.5 m of the water surface. Results suggested that a lack of light, not swan browsing, was preventing regeneration of the macrophyte beds. It is relevant to note that swans have been numerous in Lake Whangape for many years with considerably larger numbers in the 1960s compared to the 1980s and *Egeria* was able to withstand grazing for a number of years. However, more recently there may have been a synegistic effect between increasing water turbidity and swan grazing, resulting in the decline of *Egeria*.

McKinnon (1989) suggested that Black Swans are susceptible to lake eutrophication through the shading of macrophytes, their major food source by increasing phytoplankton density. In Tomahawk Lagoon No. 2 Mitchell *et al.* (1988) found that both macrophyte biomass and swans were suppressed when the lake was in its eutrophic, phytoplankton dominated phase. A positive correlation was found between Black Swan populations and submerged macrophyte biomass in winter and a negative correlation between winter Black Swan populations and phytoplankton production of the previous summer. McKinnon and Mitchell (1992) presented simple regression equations relating Black Swan populations to trophic status and to macrophytes which may have predictive value for Black Swan populations elsewhere. The weighted linear regression relationship derived for eleven lakes was:

$$Y = 0.62 + 0.045X \ (p < 0.05) \qquad \text{Equation 1:}$$

where Y = winter swan population (No. ha^{-1}), and X = macrophyte dry weight ($g\ m^{-2}$).

The generality of these relationships was tested by McKinnon (1989) and McKinnon and Mitchell (1992) and found to hold for five New Zealand lakes (Table 3). In lakes which had lower swan numbers than predicted, sediments were predominantly sand or fine clay and macrophyte biomass may have been constrained by the nature of the sediment rather than effects by swans (McKinnon and Mitchell 1992).

TABLE 3. Lakes for which Equation 1 was found to hold (McKinnon and Mitchell 1992).

Tomahawk Lagoon No. 2
Tomahawk Lagoon No. 1
Waipori
Waihola
Tuakitoto

5.2 Nutrient loading

A further aspect of the relationship between swans and eutrophication concerns the faecal input from swan populations to the littoral zone of lakes. A study of food consumption and faecal deposition of Black Swans in Hawksbury Lagoon was discussed in relation to other studies by (Mitchell and Wass in press). Faecal contributions of N and P were only a minor component of fluctuations observed in the lake and were also small in relation to the total nutrient pool in the water and benthic algae.

Black Swan faecal production was found to average 52 g dry weight per bird per day (Mitchell and Wass in press). The nitrogen content of the faeces is 2.3% of dry weight (Table 4) with 5% of this (0.13% of dry weight) being as dissolved inorganic N (NH4-N). The dissolved reactive phosphorus (DRP) content of the faeces was also 0.13% of dry weight (Table 4). These figures equate to 0.07 g of inorganic N or P per bird per day. Mitchell and Wass (in press) found that nutrient loading on eutrophic Hawkesbury Lagoon from Black Swans was not a significant amount relative to the loading from other sources.

We have used these data to estimate *N* and *P* loadings by swans to Waihi Bay in oligotrophic Lake Taupo and eutrophic Lake Ellesmere as examples of calculations that could be done for other areas. The area of aquatic plants in the bay where swans feed in Lake Taupo is *ca.* 90 ha. Swan numbers have been *ca.* 400 in the early 1980s (Bull 1983), but in the period 1991-1994 numbers ranged between 1155 and 1883 (James Holloway, pers. comm.). Using the highest number (1883 birds) the dissolved inorganic N (DIN) and DRP input from faeces would be 0.132 kg day^{-1}. The Tokaanu tail-race provides the major inflow source of nutrients to the bay, calculated as 24 kg DRP and 57 kg DIN per day. While much of this water may not circulate directly into all the aquatic plant areas the difference between the swan loading and the river loading is large enough to assume that swan derived nutrients will not be important at that site though the swan loading will be localised to the growing tips of the weed beds, rather then distributed through the bay.

TABLE 4 Adapted from Mitchell and Wass (in press). Chemical composition of swan food (filamentous algae) and faeces in Tomahawk Lagoon, Otago. Data as % of dry weight. Also shown are calculated daily outputs per swan and annual inputs to Tomahawk Lagoon by a population of 9.7 swans ha^{-1}. *, DW (dry weight) for food and faeces = % of fresh weight.

		DW	Carbon	TN	NH_4-N	TP	DRP
Food	Mean	7.1*	31.4	1.16		0.33	
(% of DW)	SE	0.36	0.23	0.04		0.05	
	n	30	12	12		6	
Faeces	Mean	13.6*	37.2	2.30	0.13	0.44	0.13
(% of DW)	SE	0.58	0.35	0.33	0.01	0.04	0.002
	n	39	12	6	21	6	21
Output	Mean	52.0	19.4	1.20	0.07	0.23	0.07
(g swan^{-1} day^{-1})	SE	0.35	0.22	0.17		0.02	
	n	3					
Input to lake	Mean	18.5	6.9	0.42	0.02	0.08	0.024
(g m^{-2} y^{-1})	SE	0.12	0.08	0.06		0.007	

On the basis of data in Table 4 the total phosphorus and total nitrogen inputs from swan faeces would therefore be 840 and 4380 kg/year respectively into Lake Ellesmere, based on a resident swan population of 10 000 birds. This closely fits a model developed by Manny *et al.* (1994) (Fig 1). The total phosphorus load to the lake from catchment rivers and streams is approximately 94 tonnes per year and the inorganic nitrogen load approximately 6400 tonnes per year. The contribution by swans to the nutrient loading of Lake Ellesmere is less than 1% of the annual inputs to the lake.

The impact of swans may be greater in small water bodies with low nutrient inflow rates and such calculations should be done on a case by case basis. For instance waterfowl have been

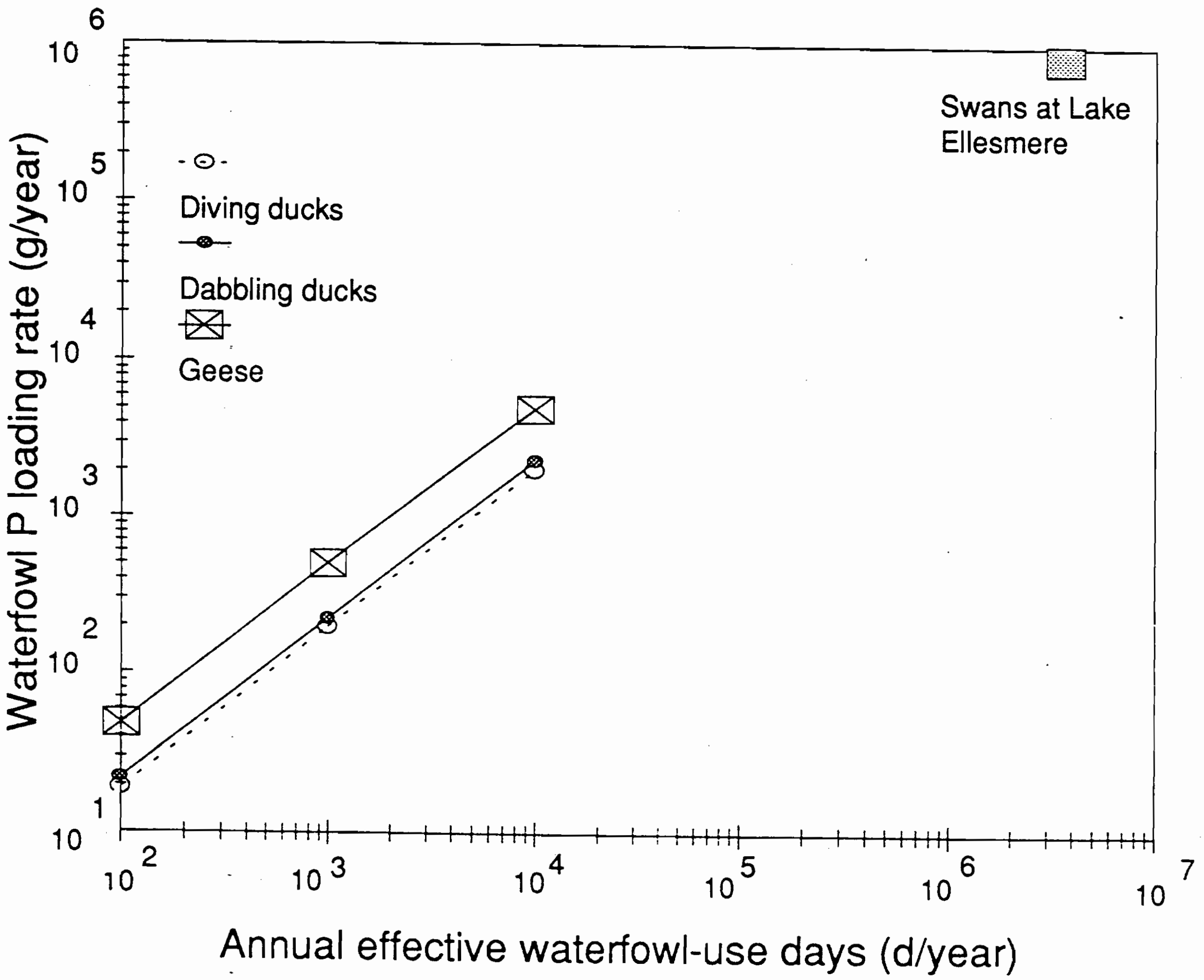

Figure 1: Relation between annual, effective, goose-use and duck-use days and the annual phosphorus loading rate by three kinds of waterfowl (after Manny *et al.* 1994). Data for Black Swan at Lake Ellesmere, shown as a solid square assuming 10 000 resident birds (see text). A Total nitrogen:Total phosphorus ratio of 5:1 (see Table 4) can be used to calculate the N loading.

shown to provide 70% of all the phosphorus entering Wintergreen Lake in the USA (Manny *et al.* 1994).

6.0 GAPS IN KNOWLEDGE

1 Historical introductions

The question of naturalised status of Black Swan in New Zealand needs to be further clarified by work on documenting the evidence of the bird in Maori middens. The few existing data point to the species being present before European arrival.

2 Breeding sites

There is a requirement for data which relates breeding success to habitat. This will be of value in the management of swan populations. Nothing seems to be known of the age of first breeding.

3 Demography

The reasons for the very low and variable proportion of the New Zealand population which breeds needs research, again as background information for population management.

A knowledge of what triggers solitary *vs* colonial breeding is needed.

Is breeding success related to food supply? One model of Mute Swan population dynamics (Bacon and Beekman 1991) relates breeding to nutrition.

4 Feeding

Swan feeding in inland lakes is little studied. Does swan grazing in dense weedbeds encourage *Ceratophyllum* dominance? By selectively grazing other species the birds may be encouraging a species shift to *Ceratophyllum*. Such a change would be detrimental to the swans.

Further information on feeding rates and selectivity of freshwater aquatic plants is needed.

5 Impacts

Does Black Swan have an impact on the nuisance sea lettuce (*Ulva*) beds in Tauranga and other harbours?

Better calculations of the impacts of Black Swan on eelgrass beds could be made if quantitative data on *Zostera* biomass and growth rates were available for New Zealand conditions.

Assessment of the economic impact of Black Swan in pastures. This could be done in the same way as that for Canada Goose in the Canterbury high country.

7.0 MANAGEMENT

Issues relating to the management of Black Swan fall into the following categories:

- the exploitable resource
- the impact on lakeside pastures
- the potential impact on aquatic ecosystems
- urban impacts.

Of direct philosophical relevance to the perception of all these issues is the unresolved question of the native or introduced status of the bird. A <u>perceived</u> adverse impact may in fact be part of a natural system.

7.1 The exploitable resource

This is the concern of the Fish and Game Councils, some of which (e.g. Eastern Region) maintain excellent and easily accessible data sets on swan numbers and distribution.

7.2 Pasture impacts

This was covered in section 4.2.4 and there appears to be conflicting opinions over the "damage" done to pastures. Dr Murray Williams (pers. comm.) provided the following list of techniques used to control swans in lakeside pastures.

7.2.1 Harassment

This includes daily hunting, bangers, scarecrows, balloons.

7.2.2 Cropping areas

Setting aside areas where swans are encouraged to congregate. These can be enhanced by decoys or models (see e.g. Montague 1986).

7.2.3 Lake level management

Reducing lake levels to allow access to aquatic macrophytes may be feasible at some places.

7.3 Impacts in aquatic ecosystems

Any effects of Black Swan on aquatic ecosystems fall into the following categories:

- nutrient enrichment
- overgrazing to remove aquatic plants
- selective grazing to change species composition of the aquatic vegetation
- interactions with other species.

7.3.1 Nutrient enrichment

The amounts of nitrogen and phosphorus enrichment for a particular water body can be calculated from the data in Table 4 or Figure 1 if swan numbers are known. These need to be compared with the other inputs and consideration should be given to whether the birds are importing nutrients to the water body or merely recycling them. The evidence for large lakes (Taupo, Ellesmere) is that the contribution by swans is very small.

7.3.2 Overgrazing on aquatic communities

Food consumption can be calculated from Table 4 and if the food biomass and yield are known it is possible to assess whether the swan population is too large. Alternatively, for lakes, the equation of McKinnon and Mitchell (1992) (see Section 5.1) can be used, where a knowledge of winter food biomass is required. Calculations for Farewell Spit do not suggest an overgrazing problem for the whole area, although there may be local sites where this does occur. There is not sufficient evidence to recommend a specific swan management programme to counter "overgrazing".

7.3.3 Changing species composition

Where aquatic ecosystems are invaded by exotic aquatic weeds, swans may exacerbate the problem by selective feeding. For instance, the nuisance species *Ceratophyllum demersum* may be encouraged at the expense of others as it does not appear to be eaten by Black San.

Dense beds of exotic macrophytes may encourage larger numbers of swans than could be supported by native macrophytes. In Lake Taupo, evidence of a decline in some native species may be due to the very high swan numbers attracted to the beds of *Lagarosiphon major*.

7.3.4 Species interactions

This covers the concept that high swan numbers in some areas may "threaten" other species. An example could be wading birds at a restricted habitat along an estuary shore. The question as to the native or introduced status of Black Swan is particularly relevant in such considerations.

7.4 Urban impacts

The Department of Conservation receives many calls asking how swans can be prevented from threatening people in parks. According to Dr Murray Williams (pers. comm.) it was due to solitary swan pairs at lake-shore parks, when the cob was in territory defense mode. The best "management" approach would be signs asking people to avoid the swans.

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