Pages 7-18 in Collier, K.J. (Ed), 1994. Restoration of Aquatic Habitats. Selected papers from the second day of the New Zealand Limnological Society 1993 Annual Conference. Department of Consrvation.

ENHANCEMENT OF INVERTEBRATE FOOD SUPPLIES FOR BLACK STILTS BY MANIPULATING WETLAND AND STREAM SUBSTRATA

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ABSTRACT

The black stilt is an endangered species of wetland bird that now breeds only in the Mackenzie Basin, South Canterbury, New Zealand. One major cause of its decline has been the loss of wetland habitat. Attempts in the last decade to create wetlands for black stilts have not been successful, partly because artificial ponds had packed stone and silt substrata that provided few macroinvertebrates as black stilt food. We added up to four substrata (pea straw, small stones, large stones and topsoil) to 1 m^2 quadrats in streams and/or ponds at three sites in an attempt to experimentally enhance invertebrate food supplies. Biomass and densities of macroinvertebrates were quantified 10 and 16 weeks after substrate additions. Invertebrate biomass was up to 18 times greater in quadrats to which pea straw had been added than in control quadrats (no substrate added). Biomass of invertebrates in pea straw, small stone and large stone substrata all exceeded a putative nesting threshold for black stilts of 1 g m^{-2}. *Xanthocnemis zealandica*, *Physa acuta* and Oligochaeta were particularly abundant on pea straw, whereas *Deleatidium* spp. and *Aoteapsyche* sp. were most common on stones. These experiments provide the basis for ongoing research on macroinvertebrate enhancement in wetland areas used by black stilts.

INTRODUCTION

The black stilt (*Himantopus novaezealandiae*) is one of New Zealand's most endangered birds (Williams & Given 1981), and is possibly the world's rarest wading bird (Hayman *et al.* 1986). Black stilts were once widespread in the North and South Islands (Pierce 1984), but are now almost entirely restricted to the Mackenzie Basin, where they inhabit wetlands such as braided riverbeds, lake deltas, ponds, swamps and tarns (Pierce 1982).

The decline of the species was mostly caused by habitat degradation and the spread of introduced mammalian predators following European colonization of New Zealand (Pierce 1982, 1986a). In particular, suitable nesting and feeding habitat has been lost mainly as a direct result of hydro-electric and agricultural development. Entire wetlands and braided river systems have been inundated, diverted, drained or channelised. In addition, much of the remaining habitat is of poor quality because of the combined effects of invasive weeds, mammalian predators, continued grazing and falling water tables.

Increasingly, wildlife managers are adopting a habitat-oriented approach in an effort to conserve rare and endangered specialist species, and the protection of remaining fragments of habitat is a key management objective in this approach. However, some habitats have become so severely degraded that some degree of restoration is required before they become suitable for species or community conservation.

Few attempts have been made to restore wetland habitat for wading birds (see e.g. Hammer 1992). Because of the complex and diverse nature of wetlands, and given the overwhelming focus of enhancement programmes towards riparian, fisheries and waterfowl values, it will be some time before wetland enhancement for waders can be effectively undertaken on a large scale.

In 1991 the Department of Conservation and Electricorp (now ECNZ) signed a compensatory funding agreement called "Project River Recovery" which recognizes the impact of hydro-electric power development on wetland habitats in the Upper Waitaki River catchment. Significantly, the agreement is linked to the rights of ECNZ to use water for power generation (35 year term). It allows for management and enhancement of remaining wetland habitat in reparation for habitat that was lost during the development period (1968 - 1985).

One of Project River Recovery's aims in the first seven years is to enhance wetlands that will be of particular benefit to the endangered black stilt. Previous attempts at creating wetlands for wading birds in the early 1980s (e.g. at Pattersons and Irishman Ponds, adjacent to the Tekapo River) were not successful. These `old' wetlands are steep-sided, over 1 m deep and surrounded by tall vegetation, whereas black stilts require shallow water feeding areas, usually surrounded by flat open spaces (Pierce 1982, Robertson *et al.* 1983). Furthermore, aquatic macroinvertebrates, on which black stilts feed, were present only in very low numbers in samples that we took at several of these old wetlands.

Pierce (1982) observed that black stilts only reared chicks at sites where aquatic invertebrate biomass was greater than 1 g dry weight per m^2. He also showed that their feeding rate and choice of feeding site were related to prey availability (Pierce 1986b). Therefore, the development of techniques for increasing aquatic macroinvertebrate production and biomass would create the opportunity to enhance or create wetlands as effective black stilt feeding and breeding habitat.

Creation of the open spaces and shallow, predator-free ponds that are suitable for black stilts would be straightforward. However, it is less clear how to produce and maintain adequate food supplies for black stilts. The sites where we found few aquatic invertebrates had compact cobble substrata, covered by silt. Silted substrata provide poor invertebrate habitat (see Ryan 1991), and it is likely that invertebrate production and biomass at these sites is limited by its presence. Previous studies have shown a relationship between invertebrate abundance and substrate type and size. For example, Quinn and Hickey (1990) and Jowett *et al.* (1991) showed that *Deleatidium* spp. and *Aoteapsyche* sp. were more abundant on large stones and cobbles than on small gravels in streams, whilst in Britain, food supplies for wetland birds inhabiting old gravel pits were dramatically increased (especially snails) by the addition of barley straw (Street 1982). Thus, the aim of the work reported in this paper was to identify substrata that increased the biomass of aquatic invertebrate food supplies for black stilts, and that would be practical to use in large scale habitat enhancement.

METHODS

Study Sites

We conducted substrate addition experiments in both pond and stream habitats at one site ("Aviary Wetland"), and in ponds at two other sites ("Mick's Lagoon" and "Mailbox Inlet") (Fig. 1). These sites are currently used by black stilts, are enclosed within predator-proof electric fences and are likely to be included in future habitat enhancement programs.

Table 1 summarizes physicochemical parameters at the three experimental sites. Temperature ranges were recorded from maximum-minimum thermometers placed under stones at each site for the duration of the experiment. Oxygen concentrations, pH, and conductivities were measured in the early morning and late afternoon at each site on several occasions. Chlorophyll *a* was extracted from stone surfaces using 90% ethanol, and measured spectrophotometrically. Spot water samples were taken within quadrats and in open water, and NO_3-N and PO_4-P concentrations were measured using an auto-analyzer (concentrations < 0.03 mg l^{-1} recorded as trace).

Aviary Wetland is an artificial wetland located on terraces below the Ruataniwha Dam, 3 km from Twizel. Pipes from Lake Ruataniwha supply water to a series of 5 small ponds (generally < 40 cm deep, 10-20 m wide) connected by shallow streams (2-15 cm deep, 1-3 m wide). The substrate in these streams and ponds consists of fine gravel (< 1 cm diameter) embedded in a hard clay-like pan. A layer of glacial silt covers this pan in the ponds and slower sections of the streams. Water in the streams and ponds was often as warm as 29-30°C by late afternoon during the latter stage of our experiment (October-December).

Table 1 Ranges of physicochemical factors recorded during the day at the three experimental sites from October to December 1992. Chlorophyll *a* was measured on surfaces of stones, where these were present. N.D. = Not detectable.

Site	Temp. (°C)	Oxygen conc. (mg l^{-1})	pH	Chlorophyll *a* (µg cm^{-2})	Conductivity (µS cm^{-1})	NO_3-N (mg l^{-1})	PO_4-P (mg l^{-1})
Aviary Wetland ponds	10-29	9.0-12.8	6.4-9.5	0.10-1.5	72	N.D.-0.03	N.D.
Aviary Wetland streams	11-30	10.4-12.5	7.0-9.0	0.15-1.46	73	<0.03	N.D.
Mick's Lagoon	6-18	9.7-12.6	6.2-10.4	-	108	N.D.	0.04-0.09
Mailbox Inlet	5-21	9.8-17.2	6.4-10.3	-	83	0.08-0.26	N.D.

Figure 1 Location of study sites in the Mackenzie Basin.

Table 2 Summary of experimental treatments. Substrata that were added to 1 m^2 quadrats (or were present already in the case of controls) are indicated by +.

Site	Control	Topsoil	Large stones	Small stones	Pea straw
Aviary Wetland ponds	+	+	+	+	+
Aviary Wetland streams	+	-	+	+	-
Mick's Lagoon	+	-	-	-	+
Mailbox Inlet	+	-	-	-	+

Juvenile black stilts are reared in three adjacent aviaries before being released to the wild in September. Newly released birds remain near the release point for four to eight weeks following release, and feed at Aviary Wetland and in nearby streams.

Mick's Lagoon and Mailbox Inlet are located on the west side of Lake Tekapo, and are used regularly by black stilts as feeding habitat. Black stilts nested successfully at both sites in the early 1980s (Reed *et al.* 1993). Mick's Lagoon consists of shallow ponds (generally < 40 cm deep) with a soft mud substrate, and is surrounded by *Carex* spp. and pasture. Mailbox Inlet consists of one main pond that has shallow edges and deep (> 1 m) areas. The substrate in the shallows is soft mud or mud and stones. Water chemistry and temperature was similar at both of these sites during October-December 1992. It differed from the Aviary Wetland sites mainly in the lower water temperatures, higher conductivities, and higher NO_3-N and PO_4-P concentrations (Table 1). Very high pH (> 10.0) were recorded on several warm, sunny afternoons.

Experimental Design

Some or all of four types of experimental substrata (pea straw, large stones (screened to 25-60 mm smallest dimension), small stones (screened to < 25 mm smallest dimension) and topsoil) were added to 1 m^2 quadrats at the three sites in September 1992. The type of substrate added to a particular site depended on the suitability of that site, *e.g.* straw and topsoil were not added to streams as they would have been washed away. (Topsoil was added to ponds in Aviary Wetland in a attempt to simulate the apparently highly productive mudflats that occur at many wetlands). Table 2 summarizes substrate additions at each site.

Experimental treatments (types of substrata) were replicated five times at each site. At Aviary Wetland, one replicate of each treatment was placed in a quadrat in each of the five ponds and streams. At Mick's Lagoon and Mailbox Inlet five pea straw and five control quadrats were widely interspersed throughout each site. Black stilts feed in water up to *c.* 18 cm deep (Pierce 1982), therefore, quadrats were situated in water of about that depth (10-20 cm). Undisturbed natural substrata (described above) were used as controls because these represent the types of feeding habitat currently available to black stilts at each site.

One fifth of a bale of pea straw (approx. 5 kg), or 30 shovelfuls of stones or soil (approx. 5 cm depth) were added to each quadrat. Pea straw was held in place by pegging a galvanised wire netting `fence' (40 mm mesh, 50 cm high) around the perimeter of quadrats. The mesh size was large enough to allow small fish (*Gobiomorphus* spp.) to enter quadrats. However, large salmonids (if present) and avian invertebrate predators may have been excluded from straw quadrats by the fence.

Sampling Methods

All quadrats, except one, were sampled 10 weeks (18 Nov. 1992) and 16 weeks (31 Dec. 1992) after substrate additions. The exception was a quadrat at Mick's Lagoon that had dried up after 16 weeks, and could not be sampled a second time. Invertebrates were collected by holding a triangular net (31 cm sides, 0.8 mm mesh) vertically with its base on the substrate and then rapidly sweeping forward 31 cm, thus sampling 0.1 m^2. Samples were taken near the centre of each 1 m^2 quadrat, to minimize possible edge effects. All substrate within the area sampled was collected in the net during this sweep and, in the case of stone and straw samples, was placed immediately in a large plastic bin. Stones were washed in water in the bin, inspected to ensure they were free of invertebrates, and replaced within the quadrat. The contents of the bin were then poured into the net to drain off the water, transferred to plastic bags and preserved in 70% ethylene glycol. Straw was placed in the bin without water. Most straw samples were then halved by thoroughly mixing straw in the bin and discarding half the contents. Straw, topsoil and control samples were transferred directly into plastic bags and preserved in 70% ethylene glycol.

In the laboratory, samples were washed in a 0.8 mm sieve, carefully hand sorted by eye in a white tray, and the detritus was discarded. Invertebrates in each sample were identified (most to family or genus), counted, and dried to constant weight at 60 ± 2 °C. Molluscs, stony-cased caddisflies, and `soft-bodied invertebrates' from each sample were weighed separately. To estimate body weights for molluscs and stony-cased caddisflies (*i.e.* weights excluding shells and cases, which were assumed to have no nutritional value) we multiplied by the following conversion factors: stony-cased caddisflies (*Hudsonema amabilis* and *Pycnocentrodes* sp.), × 0.25; *Potamopyrgus antipodarum* × 0.10; other molluscs (mainly *Lymnaea tomentosa* and *Physa acuta*) × 0.25. Conversion factors were determined by weighing subsamples of animals, except that the value for *P. antipodarum* was taken from Michaelis (1974).

Statistical Analysis

Invertebrate biomass data (body dry weight per 0.1 m^2) from Mick's Lagoon and Mailbox Inlet were analyzed together as a three factor, model I ANOVA, with type of substrate, incubation time and location as factors. Aviary Wetland ponds and Aviary Wetland streams were each analyzed as two factor, model I ANOVAs, with type of substrate and incubation time as factors. Biomass data were normalized (Wilk-Shapiro W'. test, $P > 0.05$) by log transformations, which also reduced variance heterogeneity in Mick's Lagoon and Mailbox Inlet data to non-significant levels (Cochran's Q test $P > 0.05$). Variances of both untransformed and transformed Aviary Wetland data were homogeneous (Cochran's Q test, $P > 0.05$). Tukey's T tests were used for multiple comparisons of means following significant ANOVAs. Invertebrate densities were not compared statistically. For clarity of presentation, untransformed biomass data (including standard error bars) are presented in all figures, although statistical analyses were carried out on log transformed data.

RESULTS

Aviary Wetland Ponds

Type of substrate had a significant effect on invertebrate biomass in Aviary Wetland ponds ($F_{[4,40]} = 30.43$, $P < 0.001$), but incubation time did not ($F_{[1,40]} = 0.01$, $P > 0.05$). However, the effect of substrate was influenced by incubation time (i.e. significant interaction in the ANOVA, $F_{[4,40]} = 4.71$, $P < 0.005$). Therefore, comparisons of mean biomass among substrata were carried out separately for samples taken at 10 weeks and 16 weeks (Table 3). Significant differences are described below. Figure 2a shows mean biomass in Aviary Wetland ponds at 10 and 16 weeks.

Mean (± 1 SE) biomass of invertebrates in pea straw (2.6 ± 0.5 g m^{-2} dry wt.) was significantly higher 10 weeks after addition to ponds than that in control (0.8 ± 0.3 g m^{-2} dry wt.) and topsoil (0.5 ± 0.1 g m^{-2} dry wt.) quadrats. After 16 weeks, mean invertebrate biomass in pea straw had increased dramatically, to 9.1 ± 1.0 g m^{-2} dry wt., and was significantly greater than the biomass on all other substrata. The latter showed little change between 10 and 16 weeks. Mean biomass was similar on both sizes of stones at both times (1.1 ± 0.3 to 1.47 ± 0.2 g m^{-2} dry wt.). Invertebrate biomass was always greater than 1.0 g.m^{-2} dry wt. (putative chick rearing threshold (Pierce 1982)) in stones and pea straw in Aviary Wetland ponds, whereas in topsoil and control quadrats it was always below this level.

Table 3 Multiple comparison (Tukey's T test, 5% level of significance) of mean log invertebrate biomass on experimental substrata, following a significant ANOVA of Aviary Wetland pond data. Substrata for which means did not differ significantly are denoted by the same letter. Means are compared separately for samples taken at 10 and 16 weeks, as the interaction between time and substrate was significant.

Substrate	**10 weeks**		**16 weeks**		
Pea straw	A		A		
Small stones	A	B	B		
Large stones	A	B	B	C	
Control		B		C	D
Topsoil		B			D

Figure 2 Invertebrate biomass (mean ± SE) on four experimental substrata at three sites after 10 weeks (left hand bar of each pair) (n = 5), and 16 weeks (right hand bar) (n = 4-5). The horizontal dotted lines indicate a possible threshold below which black stilts do not rear chicks in that area (Pierce 1982).

Mean densities of invertebrate taxa that were greater than 100 m^{-2} at least once are summarised for all sites in Table 4. Larvae of *Xanthocnemis zealandica*, which are typically found in drowned grasses or floating weeds (Rowe 1987), were particularly abundant (mean ± 1 SE = 464 ± 127 m^{-2}) in pea straw in Aviary Wetland ponds, as were *Physa acuta* (1896 ± 313 m^{-2}) and *Sigara* sp. (816 ± 295 m^{-2}). *Deleatidium* spp. were abundant on large and small stones in Aviary Wetland ponds, whereas *Hudsonema amabilis* was most abundant in control, topsoil and pea straw quadrats. Oligochaeta were present in pea straw (112 ± 75 m^{-2}) but were absent from other substrata in Aviary Wetland ponds.

Aviary Wetland Streams

Type of substrate had a significant effect on invertebrate biomass in Aviary Wetland

Table 4 Mean (SE shown in parentheses) number of invertebrates per m^2 in samples taken from experimental substrata 16 weeks after substrate additions. Only those taxa found at least once at mean densities greater than 100 m^{-2} are shown. C = control, T = topsoil, LS = large stones, SS = small stones, PS = pea straw.

	Aviary Wetland ponds (n = 5)					**Aviary Wetland streams (n = 5)**			**Mick's Lagoon (n = 4)**		**Mailbox Inlet (n = 5)**	
Taxa	**C**	**T**	**LS**	**SS**	**PS**	**C**	**LS**	**SS**	**C**	**PS**	**C**	**PS**
Deleatidium spp.	6 (6)	0 (0)	116 (82)	554 (534)	8 (8)	212 (110)	1116 (378)	898 (369)	0 (0)	0 (0)	0 (0)	0 (0)
Aoteapsyche spp.	0 (0)	0 (0)	4 (2.4)	4 (2.4)	0 (0)	236 (122)	550 (311)	846 (648)	0 (0)	0 (0)	0 (0)	0 (0)
Hudsonema amabilis	446 (90)	318 (137)	82 (40)	24 (24)	264 (62)	56 (22)	102 (29)	40 (11)	0 (0)	0 (0)	0 (0)	0 (0)
Sigara sp.	254 (17)	86 (52)	104 (47)	84 (30)	816 (295)	52 (52)	0 (0)	0 (0)	85 (39)	23 (19)	430 (191)	186 (33)
Berosus sp.	18 (14)	6 (4)	60 (21)	104 (41)	48 (20)	8 (5)	0 (0)	4 (2.4)	5 (2.9)	3 (3)	0 (0)	0 (0)
Xanthocnemis zealandica	4 (4)	4 (4)	14 (9)	58 (23)	464 (127)	0 (0)	8 (8)	0 (0)	5 (5)	13 (13)	4 (2.4)	48 (33)
Lymnaea tomentosa	44 (25)	8 (6)	14 (7)	58 (22)	296 (205)	10 (6)	4 (2)	6 (4)	43 (11)	15 (12)	4 (2)	0 (0)
Gyraulus corinna	0 (0)	2 (2)	4 (4)	2 (2)	80 (44)	0 (0)	0 (0)	2 (2)	0 (0)	3 (3)	94 (60)	124 (72)
Physa acuta	16 (10)	6 (2)	26 (8)	30 (11)	1896 (313)	8 (4)	8 (6)	2 (2)	267 (162)	70 (51)	214 (136)	3200 (2263)
Sphaerium novaezelandiae	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	105 (52)	90 (50)	16 (16)	20 (13)
Chironomidae	42 (31)	18 (16)	38 (11)	36 (29)	152 (61)	32 (17)	32 (15)	30 (13)	0 (0)	0 (0)	4 (4)	0 (0)
Oligochaeta	0 (0)	0 (0)	0 (0)	0 (0)	112 (75)	0 (0)	2 (2)	0 (0)	0 (0)	1500 (1500)	0 (0)	3510 (2300)

streams ($F_{[2,24]} = 3.70$, $P < 0.05$). Incubation time did not affect invertebrate biomass at these sites ($F_{[1,24]} = 1.48$, $P > 0.05$), nor did it interact with the effect of substrate ($F_{[2,24]} = 0.27$, $P > 0.05$). Mean biomass was greater on large and small stones than in control quadrats (Figure 2b), although these differences were not significant in multiple comparisons of means (Tukey's T test, $P > 0.05$). Mean invertebrate biomass on large and small stones ranged from 1.5 ± 0.5 to 2.8 ± 0.9 g m^{-2} dry wt., and was therefore greater than the possible chick rearing threshold. In contrast, mean biomass in control quadrats was closer to 1.0 g m^{-2} dry wt. Mean biomass in control and stone-filled quadrats was about 0.5 g m^{-2} dry wt. greater in streams than ponds at Aviary Wetland.

Aviary Wetland streams were dominated numerically by *Deleatidium* spp., *Aoteapsyche* sp., *H. amabilis* and Chironomidae, in that order (Table 4). Densities of *Deleatidium* spp. and *Aoteapsyche* sp. were highly variable but, on average, were higher on stones than in control quadrats. *H. amabilis* was present at similar densities on small stones (40 ± 11 m^{-2}) and in control quadrats (56 ± 22 m^{-2}), but was twice as abundant on large stones (102 ± 29 m^{-2}). *Sigara* sp. was absent from stones, and other taxa occurred only in low numbers.

Mick's Lagoon and Mailbox Inlet

Type of substrate ($F_{[1,30]} = 25.67$, $P < 0.001$) and location ($F_{[1,30]} = 9.26$, $P < 0.005$) significantly affected invertebrate biomass at Mick's Lagoon and Mailbox Inlet; mean biomass was greater in pea straw quadrats than control quadrats at both sites, and was greater at Mailbox Inlet than at Mick's Lagoon (Fig. 2c). Neither incubation time ($F_{[1,30]} = 0.03$, $P > 0.05$), nor any interaction terms in the ANOVA were significant ($P > 0.05$ for all interaction terms).

The invertebrate faunas at Mick's Lagoon and Mailbox Inlet were dominated numerically by Oligochaeta, *P. acuta*, and *Sigara* sp. (Table 4). At Mailbox Inlet, *P. acuta* was much more abundant on pea straw than in control quadrats but at Mick's Lagoon, where numbers were lower, the reverse was found. *Sigara* sp. was more abundant at Mailbox Inlet than Mick's Lagoon, and was about twice as abundant in pea straw as in control quadrats at both sites. At both sites, as in Aviary Wetland, *X. zealandica* was more abundant on pea straw than in control quadrats. However, *X. zealandica* was much less abundant at these sites than in Aviary Wetland ponds. Oligochaeta were abundant in pea straw and absent from control quadrats at both sites.

DISCUSSION

We investigated the effect of substrate additions on aquatic invertebrate biomass and taxonomic composition, in three wetlands. This initial, small-scale research was motivated by a need to develop practical techniques for the enhancement of food supplies for black stilts in future, large-scale wetland enhancement projects.

We found that mean invertebrate biomass in samples taken from quadrats to which pea straw had been added was always greater than that in other substrata. The difference was most dramatic 16 weeks after substrate additions to Aviary Wetland ponds. At that time mean biomass in pea straw was over 18 times that in control and topsoil quadrats, and *c.* 6 times that in quadrats containing large or small stones. High invertebrate biomass in pea straw was brought about mainly by high densities of *Xanthocnemis zealandica* larvae and, to a lesser extent, *Physa acuta* (except at Mailbox Inlet) and Oligochaeta.

Results of these initial substrate experiments using pea straw are very encouraging. We have been able to produce high invertebrate biomass, including an abundance of *X. zealandica*; a large, slow moving, easily visible species that is likely to provide an accessible food source for black stilts.

Samples from large and small stones had consistently higher mean biomass than samples from controls. Although these differences were usually not statistically significant, the addition of stones to wetlands to increase black stilt food supplies seems worth further investigation. *Deleatidium* sp. and *Aoteapsyche* sp. were generally more abundant on stones than on other substrata, whereas *Hudsonema amabilis* spp. and *Sigara* sp. were most abundant in control quadrats in ponds. All these species are known to be taken by black stilts (Budgeon 1977, Pierce 1982, 1985), but whether they differ in their value as food is unknown.

Topsoil was added to ponds in Aviary Wetland in a attempt to simulate the highly productive mudflats that occur at many wetlands. However, rather than being very productive, topsoil areas had the lowest densities and biomass of all experimental quadrats, including controls, and will not be investigated further.

FUTURE DIRECTIONS

Several questions need to be addressed before substrate addition is considered as a technique for the enhancement of food supplies in large wetlands (i.e. several hectares in area). Firstly, will this technique work at a large scale? Lining an entire wetland with straw, for example, will almost certainly affect water chemistry and temperature (and therefore potentially affect invertebrates) more strongly than 1 m^2 quadrats of straw. Furthermore, invertebrate community composition and abundance in small patches of habitat (as in the present study) may well differ from those in an entire wetland of the same habitat type.

Secondly, what long-term effects will substrate additions have? Interstices between stones may become filled with silt and the straw will decompose. Large-scale (5-10 m diameter ponds), long-term experiments are currently under way in the Mackenzie Basin to test the feasibility of substrate additions as a management technique.

Finally, will black stilts feed in wetlands to which substrata have been added? Our study did not examine whether the invertebrates on particular substrata are actually *available* as food for black stilts, nor whether certain food types are *preferred*. Black stilt adults have been described as generalist, opportunistic feeders, that take whatever invertebrates are available (Budgeon 1977, Pierce 1982, 1985). Nevertheless, observations of captive adults and chicks suggest that some prey may be preferred (e.g. larval Hydrobiosidae, Hydropsychidae and *Deleatidium* spp.), whereas others are avoided (e.g. large *Lymnaea stagnalis*), or are less available (e.g. newly hatched chicks have difficulty in eating *Hudsonema amabilis* (MDS unpubl. data)). If wetland enhancement aims to provide successful breeding areas, suitable food supplies for chicks must be identified and enhanced. Therefore, food preferences of Black Stilts, focusing on food selectivity of chicks, should be investigated.

ACKNOWLEDGEMENTS

We thank Dave Murray, Simon Elkington, and Christine Reed, Department of Conservation, Twizel for logistic support and advice on black stilts, and Prof. Mike Winterbourn for comments on a draft of this paper. We also thank Malcolm Walls of Omahau Station, Twizel, for permission to work in Aviary Wetland. Thanks also to Kate Hobsley for sorting most of the samples and to Workscorp, Twizel for providing stones and topsoil. MDS is supported by funding from Project River Recovery (Department of Conservation) and the Electricity Corporation of New Zealand.

REFERENCES

Budgeon, L. 1977. Aspects of the biology of the black stilt (*Himantopus novaezealandiae* Gould) in the Upper Waitaki River Basin. Unpublished BSc (Hons) thesis, Zoology Department, University of Canterbury, Christchurch.

Hammer, D.A. 1992. Creating freshwater wetlands. Lewis Publ., Chelsea, USA.

Hayman, P., Marchant, J., Prater, T. 1986. Shorebirds. An identification guide to the waders of the world. Croom Helm, London.

Jowett, I.G., Richardson, J., Biggs, B.J., Hickey, C.W., Quinn, J.M. 1991 Microhabitat preferences of benthic invertebrates and the development of generalised *Deleatidium* spp. habitat suitability curves, applied to four New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research 25*: 187-200.

Michaelis, F.B. 1974. The Ecology of Waikoropupu Springs. PhD thesis, Zoology Department, University of Canterbury, Christchurch.

Pierce, R.J. 1982. A comparative ecological study of Pied and Black Stilts in South Canterbury. PhD thesis, Zoology Department, University of Otago.

Pierce, R.J. 1984. The changed distribution of stilts in New Zealand. *Notornis 31*: 7-18.

Pierce, R.J. 1985. Feeding methods of stilts (*Himantopus* spp.). *New Zealand Journal of Zoology 12*: 467-472.

Pierce, R.J. 1986a. Differences in susceptibility to predation during nesting between Pied and Black Stilts (*Himantopus* spp.). *The Auk 103*: 273-280.

Pierce, R.J. 1986b. Foraging responses of stilts (*Himantopus* spp.: Aves) to changes in behaviour and abundance of their riverbed prey. *New Zealand Journal of marine and Freshwater Research 20*: 17-28.

Quinn, J.M. and Hickey, C.W. 1990. The magnitude of the effects of substrate particle size, recent flooding, and catchment development on benthic invertebrates in 88 New Zealand rivers. *New Zealand Journal of Marine and Freshwater Research 24*: 411-427.

Reed, C.E.M., Murray, D.P., Butler, D.J. 1993. black stilt recovery plan (*Himantopus novaezealandiae*). *Threatened Species Recovery Plan Series No.4*. Department of Conservation, Wellington.

Robertson, C.J.R., O'Donnell, C.F.J., Overmars, F.B. 1983. Habitat Requirements of Wetland Birds in the Ahuriri River Catchment, New Zealand. *New Zealand Wildlife Service Occasional Publication No. 3*, Department of Internal Affairs, Wellington.

Rowe, R.R. 1987. The Dragonflies of New Zealand. Auckland University Press, Auckland.

Ryan, P.A. 1991. Environmental effects of sediments on New Zealand streams: a review. *New Zealand Journal of Marine and Freshwater Research 25*: 207-221.

Street, M. 1982. The use of waste straw to promote the production of invertebrate foods for wildfowl in manmade wetlands. In Scott, D.A. (Ed), *Managing wetlands and their birds: a manual of wetland and waterfowl management: proceedings of the Third Technical Meeting on Western Palearctic Migratory Bird Management*, pp. 98-103. Slimbridge, England.

Williams, G.R. and Given, D.R. 1981. The red data book of New Zealand: Rare and endangered species of endemic terrestrial vertebrates and vascular plants. Nature Conservation Council, Wellington, New Zealand.