British Columbia Birds

Journal of the British Columbia Field Ornithologists
Volume 21 • 2011

Volume 21, 2011 **ISSN 1183-3521**

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Journal of the British Columbia Field Ornithologists
PO Box 45507, Westside RPO, Vancouver, B.C., V6S 2N5

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Front cover: Spotted Towhee in domestic apple (*Malus domestica*) on the Arndt study site, Nelson, B.C., 7 May 2011, the year following the study (see page 32). Photo: Bethany Arndt.

Recent, significant changes to the native marsh vegetation of the Little Qualicum River estuary, British Columbia; a case of too many Canada Geese (*Branta canadensis*)?

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Abstract: We document significant, negative changes to the native marsh vegetation of the Little Qualicum River estuary and strongly infer that resident Canada Geese are the principal cause. Twenty-four of 56 marsh species showed significant changes in either frequency or mean cover values and, of those, 14 increased in frequency and/or mean cover while 10 decreased. Decreasing species had a significantly higher proportion of known Canada Goose dietary items while increasing species had a higher proportion of species with high salt tolerance. Impacts to the *Carex*-channel edge community, dominated by *C. lyngbyei*, suggest that the detrital food web of the estuary is losing at least 17 tonnes dry mass from this community every year. In addition, at least 5 tonnes dry mass per year are being lost from the *Deschampsia*-flats community. Other vegetation changes and evidence suggests a concurrent change in the salinity regime of the estuary, perhaps through a reduction of the freshwater hydraulic head, which is allowing salt water intrusion to occur. This may be caused by increasing water withdrawal from the aquifer to meet the needs of a growing human population in the area. This change in the salinity regime may also be working synergistically with the geese to increase the effect of some of the impacts; however, the geese appear to be the primary agent of change. Cursory examinations of other estuaries on the east coast of Vancouver Island, including Nanoose-Bonell creeks, Englishman River and Campbell River estuaries, suggest that these systems are experiencing similar negative impacts from resident geese. These similar impacts, and the common fact that Canada Geese have increased in abundance at all the estuaries, further suggest that the geese are the primary driving force behind the changes to the vegetation. We discuss the implications of these changes and possible management options to mitigate them, including significantly reducing the number of geese and rehabilitating the marsh.

Key words: *Branta canadensis*, Canada Goose, *Carex lyngbyei*, *Deschampsia cespitosa*, grazing, grubbing, impacts, Little Qualicum River estuary, resident geese, salinity changes, Vancouver Island.

Introduction

In the late 1990s, significant changes to the estuarine marsh vegetation on the Little Qualicum River estuary (hereafter, LQRe) became apparent. Many of the changes appeared to coincide with increasing numbers of resident Canada Geese (Fig. 1). The term 'resident' refers to the exotic Canada Geese deliberately introduced to Vancouver Island, the majority of which appear to be non-migratory as opposed, for example, to a native subspecies (*B. c. fulva*) that still nests on the northern part of the island (Dawe and Stewart 2010).

In the late 1970s and early 1980s, the Canada Goose was a "rare transient" on the LQRe. It was recorded only 31 times between February 1975 and September 1984 and all but 4 of these early observations occurred during the spring and autumn migration periods or in winter. In 1984, the first pair of geese nested on the estuary and thereafter the number of breeding birds increased. These first nesters were likely tied to earlier Canada Goose introductions in Parksville and/or Nanaimo in the late 1960s and 1970s. Resident populations on the east coast of Vancouver Island (excluding the Victoria area) are currently growing exponentially ca. 8.5% per year (Dawe and Stewart 2010). In the Parksville-Qualicum Beach area, the Canada Goose population increased by over 1,500 birds between 1989 and 2006. On a January 2006 survey of the LQRe, at least 389 Canada Geese were counted and in the spring of 2010, 45

Figure 1. Canada Geese feeding at the edge of and amongst the *Juncus*-high marsh community on the Little Qualicum River estuary, 14 September 2005. The open water areas in the image were formerly part of the *Deschampsia*-flats community, which was eliminated in this area by the grubbing and grazing activities of the geese. Photo: Neil K. Dawe.

nests containing a total of 238 eggs were found (Dawe and Stewart 2010).

Other vegetation changes on the LQRe, such as the appearance of salt-tolerant species (e.g., *Distichlis spicata*) and the disappearance of salt-intolerant species (e.g., *Typha latifolia*) were noted suggesting a possible change in the salinity regime of the estuary.

In 2005, we initiated a preliminary investigation to determine the extent of these impacts and changes to the marsh vegetation on the LQRe. Results strongly infer that the introduced, and now mainly resident, Canada Geese are the primary cause behind the impacts. An apparent change in the salinity regime of the estuarine marsh, perhaps caused by increasing withdrawal of water from the Little Qualicum River aquifer, may also be playing a lesser role. We discuss the implications of the impacts focusing on the primary driver, the Canada Geese, and conclude with possible management prescriptions.

Study area

The LQRe (49.366° N, -124.492° W) is situated on the east coast of Vancouver Island some 132 km northwest of Victoria, B.C. Figure 2 shows the LQRe study area, which lies mainly within the Qualicum National Wildlife Area. A small portion of the estuary (Transect 6) is in the Parksville-Qualicum Beach Wildlife Management Area. A more complete description of the study area can be found in Dawe and White (1982).

Methods

Sampling and monitoring

In 2005, we relocated transects that had been established on the LQRe in 1978 by Dawe and White (1982) and recorded vegetation data using the same methodologies. Briefly, vegetation was sampled within 1.0 m^2 relevés spaced at 5.0-m intervals along transects. We used the Braun-Blanquet cover-abundance scale to record cover classes of all the vascular plant species in each relevé (Mueller-Dombois and Ellenberg 1974, p.59). The senior author participated in the 1978 and 2005 sampling efforts, ensuring consistency.

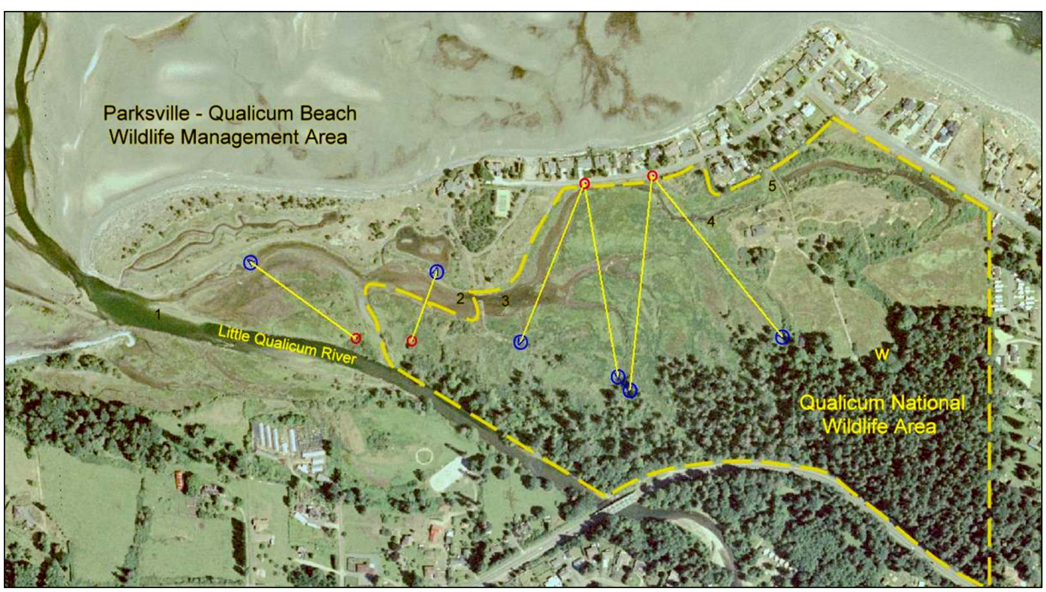

Figure 2. Air photo of the Little Qualicum River estuary, 2005, showing locations of the vegetation transects; north is to the top. Transects are numbered 1 – 6 from east to west; all but transect 6 and parts of transect 5 lie within the Qualicum National Wildlife Area, delineated by the broken yellow line. Numbers indicate inundating water salinity sampling sites. The "w" indicates the location of the two Regional District of Nanaimo wells that service the houses at the upper right of the image.

We also recorded Canada Goose activities or evidence of goose activity in the form of typical goose-grazed or -grubbed plants, goose faeces and goose trails through the vegetation.

Due to the encroachment of shrubs at the upper marsh extremes, we excluded relevés that fell into the upper marsh areas. We also excluded the pasture transect on the west side of the Little Qualicum River as that area was still being heavily grazed by cattle.

Digital images taken from specific ground locations in 2005 and later from 2006–2010 were compared to images from the late 1970s and early 1980s to illustrate vegetation changes or other impacts to the marsh.

In March 2006, we established 3 wire cage exclosures ca. 1 m diameter and 61 cm high in the *Carex*-channel edge community to determine visually the effects of grazing by the geese. Two were placed in the back areas of the estuary to document future impacts the geese might have; one was placed in an area between two dendritic channels that had evidence of severe grazing and grubbing. Ten *C. lyngbyei* heights were measured at random both inside and outside the latter exclosure on 10 July 2006.

Associated sampling

Interstitial water salinity was collected from the top 4 cm of exposed soil areas in sandy soils and organic soils of the *Carex*-channel edge community to determine if these areas were becoming hypersaline. A plug approximately 4 cm in diameter by ca. 4 cm deep was removed with a small hand trowel, placed in filter paper and gently squeezed until 1 or 2 drops of interstitial water fell onto a refractometer (American Optical model 10419; ± 1 ‰ accuracy). Salinity readings were in ppt.

Salinity of the inundating water was recorded as outlined in Dawe and White (1982, p.1449) except in this current study we used an American Marine Inc. Pinpoint® Salinity Meter. The salinity, read in μS, was converted to ppt using a Salinity Monitor Conversion Chart (American Marine Inc. 2010).

To account for apparent changes in the salinity regime, we reviewed precipitation and river flow data from Environment Canada (2008 and 2010a respectively) and the degree of sea level change from Mazzotti *et al*. 2008 and personal communication with Mazzotti (2010). The influence of local well fields was suggested from data provided by the Regional District of Nanaimo (2009) and to a lesser degree, the Town of Qualicum Beach (Svensen 2006).

An estimate of the areal extent of vegetation loss of the *Carex*-channel edge and *Deschampsia*-flats communities was determined using ArcView® 3.2a (ESRI 1996, p.274–275) from polygons drawn onto 2005 digital orthophotos over the areas of exposed substrate that were known to support these communities in 1978.

A literature review of Canada Goose dietary plants and the salinity tolerance of specific estuarine marsh plants that occurred on the LQRe was conducted using Google Scholar and web sites such as E-Flora BC (Klinkenberg 2010) and the Plants Database of the US Department of Agriculture (US Department of Agriculture 2010).

Vegetation nomenclature follows Douglas *et al*. (1998).

Analyses

We used the program JUICE (Tichý 2002) to determine plant species frequency and mean cover in both 1978 and 2005 (Tichý and Holt 2006, p.31). Briefly, frequency is the proportion of all relevés containing a particular plant species. Mean cover values for each species were calculated only from relevés with non-zero cover values; this plus frequency provides a good idea of the distribution of a plant species over the study area. Best estimates of mean cover-abundance for each species were calculated by using the midpoints of each species' Braun-Blanquet cover class, i.e., by setting r = 0.01, + = 0.5, 1 = 3, 2 = 15, 3 = 37.5, 4 = 67.5, 5 = 87.5, and setting the Display Parameters in JUICE to reflect these values.

We compared the changes in vegetation in the 2005 relevés with the same relevés sampled in 1978. We also compared groups of relevés that occurred within specific communities delineated in the 1978 study (Dawe and White 1982, p. 1449).

Comparisons of frequency of occurrence between years were tested with 2 x 2, χ^2 contingency tables using presence-absence data. Yates correction for continuity was applied (Zar 1974, p 62). The differences in species mean percent cover between years were tested with the paired-sample *t*-test (Zar 1974, p.121) using the entire dataset and community relevés. Percent cover data were arcsine transformed (Zar 1974, p.185). To correct for the occurrence of false positives in both the above tests, multiple testing corrections using the Benjamini and Hochberg false discovery rate test were applied (Stark 2011; Benjamini and Hochberg 1995). Comparisons between the increasing plants and decreasing plants and their characteristics were also tested with 2 x 2, χ^2 contingency tables, as above. The differences in mean *C. lyngbyei* height inside and outside the exclosure were tested with the paired-sample *t*-test.

The significance of the regression of river flow, precipitation and RDN well conductivity data were tested with Analysis of Variance (Zar 1974, p. 206).

Results

Changes in vegetation species frequency and cover

Twenty-four plant species showed significant changes in frequency and/or mean cover values between 1978 and 2005; of those, 11 increased and 8 decreased in frequency while 12 increased and 9 decreased in cover (Table 1).

Six dominant plant species in 1978 (*Potentilla egedii,*

Table 1. Changes in estuarine marsh plant species frequency of occurrence and mean cover values between 1978 and 2005 (n = 270) on the Little Qualicum River estuary. Species in bold showed significant changes in either frequency or mean cover between years. Species are sorted according to their significant change in frequency of occurrence.

	Frequency		% Change in frequency[1]	p[2]	Mean cover		% Change in mean cover[1]	p[2]
Species	**1978**	**2005**			**1978**	**2005**		
Taraxacum officinale	9	0	**-100**	***	5	0	**-100**	***
Plantago lanceolata	15	0	**-100**	***	9	0	**-100**	***
Eleocharis palustris	28	+	**-99**	***	17	+	**-99**	***
Lilaeopsis occidentalis	19	+	**-98**	***	4	3	**-25**	***
Trifolium wormskjoldii	23	3	**-85**	***	4	2	**-58**	***
Deschampsia cespitosa	41	9	**-79**	***	18	3	**-81**	***
Poa pratensis	20	4	**-78**	***	18	+	**-99**	***
Carex lyngbyei	72	59	**-17**	*	25	30	20	
Ruppia maritima	7	6	-15		40	9	**-78**	**
Juncus balticus	67	64	-3		22	18	**-18**	**
Vicia spp.	1	0	-100		3	0	-100	
Stellaria media	1	0	-100		+	0	-100	
Sisyrinchium idahoense	2	0	-100		+[3]	0	-100	
Schoenoplectus acutus	1	0	-100		2	0	-100	
Rubus ursinus	1	0	-100		2	0	-100	
Ranunculus repens	3	0	-100		3	0	-100	
Geranium molle	+	0	-100		+	0	-100	
Cirsium vulgare	+[3]	0	-100		+	0	-100	
Cirsium arvense	2	0	-100		3	0	-100	
Hypochaeris radicata	2	+	-82		1	+	-92	
Rosa nutkana	3	1	-73		3	8	136	
Ranunculus cymbalaria	3	1	-73		+	+	0	
Plantago maritima	2	1	-53		0	3	2900	
Bromus hordaceus	3	2	-27		11	4	-64	
Fritillaria camschatcensis	6	5	-7		7	5	-24	
Achillea millefolium	14	14	3		11	9	-24	
Triglochin maritima	49	54	10		9	9	-1	
Grindelia integrifolia	2	2	27		8	12	47	
Hordeum brachyantherum	4	8	90		6	2	-56	
Trifolium dubium	0	+	-		0	+	-	
Schoenoplectus americanus	1	1	-		+	+	0	
Rumex sp.	0	+	-		0	3	-	
Rumex acetosella	0	+	-		0	+	-	
Polygonum aviculare	0	2	-		0	1	-	
Lonicera involucrata	0	+	-		0	3	-	
Juncus bufonius	0	+	-		0	3	-	
Festuca rubra	1	1	-		15	2	-88	
Erodium cicutarium	0	+	-		0	+	-	
Cerastium sempervirans	0	1	-		0	+	-	
Bromus tectorum	+	+	-		15	+	-99	
Allium accuminatum	0	+	-		0	+	-	
Aira praecox	0	1	-		0	2	-	
Potentilla egedii	76	72	-6		18	26	**43**	**
Glaux maritima	49	58	20		2	5	**168**	***
Agrostis spp.	50	62	**22**	*	17	14	-15	
Lolium arundinaceum	10	20	**108**	**	17	9	-48	
Elymus repens	6	15	**135**	**	12	37	**207**	***
Plantago major	3	8	136		+	7	**7186**	**
Aster subspicatus	2	30	**1245**	***	6	29	**411**	***
Sonchus arvensis	2	21	**1307**	***	5	13	**170**	***
Atriplex patula	2	34	**1464**	***	+	3	**3142**	***
Isolepis cernua[4]	+	23	**5650**	***	15	7	**-53**	***
Distichlis spicata	0	3	**-**	*	0	13	**-**	*
Cuscuta salina	0	16	**-**	***	0	3	**-**	***
Cotula coronopifolia	0	26	**-**	***	0	4	**-**	***
Spergularia canadensis	0	26	**-**	***	0	3	**-**	***

[1] Discrepancies in % change values are due to rounding errors of frequency and mean cover values

[2] * = p<0.05; ** = p<0.01; *** = p<0.001

[3] + = < 0.5% frequency or cover

[4] Mean cover values indicate a decrease; however, in 1978, only one relevé contained *Isolepis cernua* with relatively high cover, compared with 62 relevés, each with relatively lower cover in 2005, which tends to skew the results.

Juncus balticus, Agrostis spp., C. lyngbyei, Glaux maritima and *Triglochin maritima* (Dawe and White 1982) were still among the dominants in 2005, with frequencies of occurrence greater than 20% (Table 1). However, 4 dominants in 1978 (*Deschampsia cespitosa, Trifolium wormsjkoldii, Eleocharis palustris* and *Lilaeopsis occidentalis*) occurred in less than 10% of the relevés in 2005. *Poa pratensis* also showed a significant decline in frequency and 2 species from 1978 were no longer present at all in 2005 (*Plantago lanceolata* and *Taraxacum officinale*).

Excluding species that occurred in 1978 but were not found in 2005, 6 species showed a significant reduction in cover of at least 50% (*E. palustris, T. wormsjkoldii, D. cespitosa, P. pratensis* and *Ruppia maritima)*. Although *J. balticus* showed no change in frequency, its cover declined by nearly 20%.

In comparison to the above declines, 6 new dominant species appeared, occurring with frequencies greater than 20% (*Atriplex patula*, *Aster subspicatus*, *Spergularia canadensis*, *Cotula coronopifolia*, *Isolepis cernua* and *Sonchus arvensis*; Table 1). Of those, *S. canadensis* and *C. coronopifolia* were not found on any of the 1978 transects. Also new in 2005 were *Cuscuta salina* and *Distichlis spicata*. In 1978, *D. spicata* did occur on the west side of the river in the pasture transect; however, it was not found on any transects on the east side of the river. In addition to being found on the 2005 transect data (see Fig. 15), *D. spicata* was present in fairly large patches in at least 7 other locations in the marsh. *Agrostis spp.* also showed an increase in frequency in 2005 and *Elymus repens*, with less than 10% frequency in 1978, increased its occurrence significantly by 2005.

Six species (*G. maritima, E. repens, P. major, A. subspicatus, S. arvensis* and *A. patula*) more than doubled their cover values between 1978 and 2005. While there was no significant difference in the frequency of *P. egedii* between years, the cover of this species increased by over 40%.

Tables 2 and 3 present some characteristics of the 10 decreasing and the 14 increasing plant species, respectively. The decreasing species had a significantly higher proportion of known Canada Goose dietary items ($\chi^2 = 5.874$; $p = 0.015$) while the increasing species had a higher proportion of species with high salt tolerance ($\chi^2 = 4.286$; $p = 0.038$). There were similar proportions of exotic species in both categories ($\chi^2 = 0.313$; $p = 0.575$).

All the vegetation communities defined by Dawe and White (1982) showed evidence of impacts by Canada Geese and attendant vegetation changes, but 3 communities (*Carex*-channel edge, *Carex-Agrostis*-slope and *Deschampsia*-flats) showed the most severe impacts and are discussed in detail below.

Carex-channel edge community

The tall growth form of *C. lyngbyei* was still dominant in this community (see Dawe and White 1982) but its frequency had declined by 23%; there was no change in its cover (Table 4). A notable change included the disappearance of *E. palustris*. Three species increased their frequencies (*G. maritima, I. cernua* and *T. maritima*). Two new ruderal species appeared in the community in 2005 (*C. coronopifolia* and *S. canadensis*), occurring in over 40% of the relevés. All of the plant species with significant increases in frequency also had significant increases in percent cover. Throughout much of this community *C. lyngbyei* had been heavily grazed by geese, particularly at the lower elevations of the marsh and directly adjacent to the channels; significant goose grubbing activity with its attendant erosion was also evident. Through the activities of the geese, much of this community had been reduced to exposed sediments populated by ruderal

Table 2. Some characteristics of plant species on the Little Qualicum River estuary showing decreasing frequency and/or cover values between 1978 and 2005.

Species	Recorded in Canada Goose diet	Species status	Salt tolerance	Sources
Carex lyngbyei	Shoots, rhizomes, seeds	Native	Medium	Prevett et al. 1985; Craven 1984; Cadieux et al. 2005; Klinkenberg 2010; USDA 2010
Deschampsia cespitosa	Leaves	Native	Low	Sedinger 1997; USDA 2010
Eleocharis palustris	Leaves & seeds	Native	Low	Martin et al. 1951; Prevett et al. 1985; Craven 1984; USDA 2010
Juncus balticus	Young plants and seeds	Native	High	Craven 1984; Drociak 2005
Lilaeopsis occidentalis	Leaves	Native	High	ODSL 2009
Plantago lanceolata		Exotic invasive, noxious; disturbed sites	Some	Klinkenberg 2010; Ungar 1991
Poa pratensis	Leaves	Exotic invasive, noxious; disturbed sites	Low	Conover 1991
Ruppia maritima	Leaves	Native	Medium	Martin et al. 1951; USDA 2010
Taraxacum officinale		Exotic invasive, noxious; disturbed sites	None	Klinkenberg 2010; USDA 2010
Trifolium wormskjoldii	Rhizomes	Native	Medium	USDA 2010

[1] Genera only, recorded in diet.

Table 3. Some characteristics of plant species on the Little Qualicum River estuary showing increasing frequency and/or cover values between 1978 and 2005.

Species	Recorded in Canada Goose diet	Species status	Salt tolerance	Sources
Agrostis spp.	Leaves[1]	Exotic	High	Conover 1991; Klinkenberg 2010; USDA 2010
Aster subspicatus		Native	High	Klinkenberg 2010; WSUE 2010
Atriplex patula		Exotic; disturbed sites	High	Klinkenberg 2010; Burke 2010
Cotula coronopifolia		Exotic	High	Klinkenberg 2010; ODSL 2009
Cuscuta salina		Native	High	Klinkenberg 2010; Frost et al. 2003
Distichlis spicata	Leaves	Native	High	Martin et al. 1951; Klinkenberg 2010; USDA 2010
Elymus repens		Exotic invasive, noxious; disturbed sites	None	Klinkenberg 2010; USDA 2010
Glaux maritima	Leaves in very small amounts (<1% frequency)	Native	High	Prevett et al. 1985; Klinkenberg 2010
Isolepis cernua		Native	High	Klinkenberg 2010; ODSL 2009
Lolium arundinaceum	Disliked by Canada Geese	Exotic; disturbed sites	Medium	Conover 1991; Klinkenberg 2010; USDA 2010
Plantago major		Exotic invasive, noxious; disturbed sites	Low	Klinkenberg 2010; Burke 2010; USDA 2010
Potentilla egedii	Rarely eaten by Canada Geese	Native	High	Prevett et al. 1985; Klinkenberg 2010; ODSL 2009
Sonchus arvensis		Exotic, invasive; disturbed sites	Low	Klinkenberg 2010; Ungar 1970
Spergularia canadensis		Native	High	Klinkenberg 2010; ODSL 2009

[1] Genera only, recorded in diet.

Table 4. Changes in estuarine marsh species frequency of occurrence and mean cover values between 1978 and 2005 (n = 39) in the *Carex*-channel edge community on the Little Qualicum River estuary. Species in bold showed significant changes in either frequency or mean cover over the 27-year period. Species are sorted according to their change in frequency of occurrence.

	***Carex*-channel edge**						
	Frequency of Occurrence (%)			**n 39**	**Mean Cover** (%)		
	78	**05**	**% Change**		**78**	**05**	**% Change**
Eleocharis palustris	51	0	**-100** ***		21	0	**-100** ***
Carex lyngbyei	100	77	**-23** **		63	65	3
Lilaeopsis occidentalis	13	0	-100		8	0	-100
Ranunculus repens	5	0	-100		8	0	-100
Deschampsia cespotosa	3	0	-100		3	0	-100
Plantago maritima	3	0	-100		1	0	-100
Ranunculus cymbalaria	3	0	-100		1	0	-100
Fritillaria camschatcensis	3	3	0		1	1	0
Achillea millefolium	0	3	-		0	3	-
Cuscuta salina	0	3	-		0	15	-
Plantago major	0	3	-		0	3	-
Sonchus arvensis	0	3	-		0	1	-
Atriplex patula	0	10	-		0	2	-
Ruppia maritima	0	10	-		0	12	-
Agrostis spp.	31	44	42		17	9	-47
Aster subspicatus	0	15	**-**		0	7	**-**
Potentilla egedii	41	56	37		12	14	17
Juncus balticus	5	23	360		9	18	100
Glaux maritima	15	44	**193** *		2	5	**150** *
Isolepis cernua[1]	3	33	**1000** **		15	14	**-7** *
Triglochin maritima	3	33	**1000** **		1	8	**700** ***
Cotula coroponifolia	0	41	**-** ***		0	5	**-** ***
Spegularia canadensis	0	41	**-** ***		0	4	**-** ***

*p<0.05; ** p<0.01; *** p<0.001

[1] Mean cover values indicate a decrease; however, in 1978, only one relevé contained *Isolepis cernua* with relatively high cover, compared with 13 relevés each with relatively lower cover in 2005, which tends to skew the results.

Figure 3. North dendritic channel of the Little Qualicum River estuarine marsh, 29 August 1980 (top) and 18 August 2005 (bottom) where the tall form of *Carex lyngbyei*, adjacent to the channel, has largely been eliminated. Photos: Neil K. Dawe.

Figure 4. Heavily spring-grazed *Carex lyngbyei* along the main channel edge on the Little Qualicum River estuary, 26 June 2005. Note the increasing length of the *C. lyngbyei* leaves upland from the channel and signs of grubbing activities along the *C. lyngbyei* edge. Photo: Neil K. Dawe.

species (Figs. 3 and 4). For example, near the river an area that in 1978 supported extensive *Carex*-channel edge and *Deschampsia*-flats communities growing on organic soils

Table 5. Changes in estuarine marsh species frequency of occurrence and mean cover values between 1978 and 2005 (n = 11) in the *Carex-Agrostis* slope community on the Little Qualicum River estuary. Species in bold showed significant changes in either frequency or mean cover over the 27-year period. Species are sorted according to their change in frequency of occurrence.

	***Carex-Agrostis* slope**							
	Frequency of Occurrence (%)			**n** **11**	**Mean Cover** (%)			
	78	**05**	**Change**		**78**	**05**	**Change**	
Eleocharis palustris	100	0	**-100**	***	28	0	**-100**	***
Agrostis spp.	100	45	**-55**	*	19	5	**-74**	***
Lilaeopsis occidentalis	45	0	-100		7	0	-100	
Carex lyngbyei	100	100	0		33	48	45	
Potentilla egedii	91	100	10		15	15	0	
Triglochin maritima	55	100	82		9	7	-22	
Deschampsia cespitosa	0	9	-		0	1	-	
Distichlis spicata	0	27	-		0	27	-	
Juncus balticus	0	36	-		0	18	-	
Glaux maritima	36	73	103		2	4	100	
Cotula coronopifolia	0	91	**-**	***	0	1	**-**	***
Isolepis cernua	0	91	**-**	***	0	3	**-**	**
Spergularia canadensis	0	91	**-**	***	0	1	**-**	***

* p<0.05; ** p<0.01; *** p<0.001

Figure 5. Adult and young Canada Geese in impacted area adjacent to the Little Qualicum River, 31 May 2006. This area now consists primarily of exposed substrate and ruderal species, including *Glaux maritima*, *Spergularia canadensis*, *Cotula coronopifolia*, and *Isolepis cernua*. In 1978, it consisted of robust growth of the *Carex*–channel edge and *Deschampsia*-flats communities. Photo: Neil K. Dawe.

had been replaced by an "alternative stable state" (Jefferies et al. 2006a) of *G. maritima* (27% cover in this area) and other ruderal species, each having no more than 2% cover (*I. cernua, C. coronopifolia, P. egedii, A. patula* and *S. canadensis*) growing on an exposed, sandy substrate with little organics (Fig. 5; see also Fig. 9). Further east into the main marsh, the exposed soils along the channel edges showed considerable grubbing evidence and subsequent erosion but still had organic content.

The exclosure at the intersection of the main channel and a branching channel illustrated the substantial effects the geese were having on the *Carex*-channel edge community where, by 2009, the evidence indicates they had eliminated most of the *C. lyngbyei* (Fig. 6). In 2006, leaf length of *C. lyngbyei* plants inside the exclosure (mean = 77.1 cm ± 2.9cm SE (n=10)) was significantly greater ($t = 13.040$; $t_{0.05(2),9} = 2.262$; $p < 0.001$) than the heavily grazed plants growing outside the exclosure (mean = 34.5 cm ± 2.9 cm SE (n=10)).

***Carex-Agrostis*-slope community**

In 1978, dominants in over 90% of the relevés in this transitional community included *C. lyngbyei*, *Agrostis* spp., *P. egedii* and *E. palustris*. By 2005, *C. lyngbyei, P. egedii, T. maritima, C. coronopifolia, I. cernus* and *S. canadensis* were found in over 90% of the relevés, the latter 3 new to the community (Table 5). *E. palustris*, found in all the relevés in 1978, was not found there at all in 2005 and the frequency of *Agrostis* spp. was reduced by over 50%. A large patch (> 130 m^2) of *D. spicata* had formed in the community, which did not occur in 1978 (see Figure 15). The largest change in cover

Figure 6. Canada Goose grazing evidence at one exclosure site adjacent to the main dendritic channel on the Little Qualicum River estuary. Note the heavy grazing of the *Carex lyngbyei* outside the exclosure (top; 10 July 2006, inset 12 June 2007) and subsequent reduced growth of *C. lyngbyei* in the same area in 2009 (bottom; 26 June 2009). Photos: Neil K. Dawe.

was *Agrostis* spp., down 74%. The short growth form of *C. lyngbyei* occurred in this community and in those above it (Dawe and White 1982). Heavy grazing of *C. lyngbyei* and *T. maritima* was evident in the community.

***Deschampsia*-flats community**

Vegetation changes in this mid-marsh community were extensive (Table 6). *D. cespitosa, P. egedii, C. lyngbyei, G. maritima, J. balticus* and *T. maritimum* were dominants in 1978 all with close to 80% or greater frequency. In 2005, all those species, with the exception of *D. cespitosa* (down 78%) were still dominant. *Agrostis* spp. was the only abundant species in 1978 that showed an increase in frequency and cover in 2005. The frequency of *C. lyngbyei* was down by 14% in 2005. *T. wormskjoldii, E. palustris* and *L.*

Table 6. Changes in estuarine marsh species frequency of occurrence and mean cover values between 1978 and 2005 (n = 107) in the *Deschampsia*-flats community on the Little Qualicum River estuary. Species in bold showed significant changes in either frequency or mean cover over the 27-year period. Species are sorted according to their change in frequency of occurrence.

	***Deschampsia*-flats community**						
	Frequency of Occurrence (%)			**n** **107**	**Mean Cover** (%)		
	78	**05**	**Change**		**78**	**05**	**Change**
Taraxacum officinale	7	0	**-100** *		4	0	-100
Plantago lanceolata	9	0	**-100** *		3	0	**-100** *
Lilaeopsis occidentalis	34	1	**-97** ***		4	3	**-25** ***
Eleocharis palustris	35	1	**-97** ***		12	1	**-92** ***
Poa pratensis	8	1	-88		12	1	**-92** *
Trifolium wormskjoldii	48	7	**-85** ***		5	2	**-60** ***
Deschampsia cespitosa	79	17	**-78** ***		20	4	**-80** ***
Carex lyngbyei	99	85	**-14** **		15	20	33
Potentilla egedii	98	90	-8		20	32	**60** *
Sisyrhynchum idahoensis	5	0	-100		1	0	-100
Ranunculus repens	4	0	-100		2	0	-100
Schoenoplectus acutus	2	0	-100		2	0	-100
Ranunculus cymbalaria	6	1	-83		1	1	0
Plantago maritime	2	1	-50		1	3	200
Plantago major	6	5	-17		1	14	1300
Glaux maritima	84	80	-5		2	3	50
Juncus balticus	87	84	-3		19	22	16
Achillea millefolium	5	5	0		12	7	-42
Triglochin maritima	80	80	0		10	10	0
Aira praecox	0	1	-		0	1	-
Distichlis spicata	0	1	-		0	15	-
Fritillaria camschatcensis	0	1	-		0	1	-
Juncus bufonius	0	1	-		0	3	-
Ruppia maritima	0	1	-		0	1	-
Lolium arundinaceum	1	8	700		3	2	-33
Agrostis spp.	58	80	**38** **		13	17	**31** **
Elymus repens	3	12	300		11	56	**409** **
Hordeum brachyantherum	0	7	**-** *		0	2	-
Sonchus arvensis	0	7	**-** *		0	4	**-** *
Cuscuta salina	0	9	**-** *		0	3	**-** *
Isolepis cernua	0	16	**-** ***		0	11	**-** *
Cotula coronopifolia	0	17	**-** ***		0	4	**-** ***
Spergularia Canadensis	0	18	**-** ***		0	4	**-** ***
Aster subspicatus	0	23	**-** ***		0	34	**-** ***
Atriplex patula	0	28	**-** ***		0	2	**-** ***

* p<0.05; ** p<0.01; *** p<0.001

occidentalis, significant constituents of the community in 1978 and all known Canada Goose dietary items, were virtually eliminated by 2005. Species new to the community in 2005 included *Hordeum brachyantherum, S. arvensis, C. salina, I. cernua, C. coronopifolia, S. canadensis, A. subspicatus* and *A. patula*. Many obvious goose trails and faeces were evident in the *Deschampsia*-flats community as the geese foraged in from the channel edges. Evidence that *C. lyngbyei*, *T. maritima*, *D. cespitosa* and *Agrostis* spp. had been grazed was commonplace. Light grubbing activity was evident in parts of this community. In the spring, these grubbed areas quickly filled in with *P. egedii* and *Agrostis* sp., both stoloniferous species (Fig. 7). A large area of this community near the river had been completely eliminated (see Figs. 5 and 9).

Estimated above-ground biomass loss to the Little Qualicum estuarine system

C. lyngbyei and its co-dominants were eradicated from large portions of the *Carex*-channel edge community that was extant in 1978 (total area = 10,056 m^2; Fig. 8). Based on this figure and the peak standing crop biomass reported by Dawe and White (1982; 1692 $g \cdot m^{-2}$ dry mass) and Kennedy (1982; 1746 $g \cdot m^{-2}$ dry mass), we estimate that a minimum of 17 tonnes of *Carex*-channel edge above ground dry mass were being lost annually to the estuarine detrital food web by

Figure 7. Evidence of winter grubbing activities in the higher areas of the *Deschampsia*-flats community and the resulting exposed substrate (top; 3 April 2009). These areas are not as heavily impacted as those adjacent to the channels and seemed to recover quickly; however, the vegetation is somewhat stunted compared with the surrounding vegetation of the community and often a few stoloniferous species, such as *Potentilla egedii* and *Agrostis* spp., become dominant (bottom; 26 June 2009). Photos: Neil K. Dawe.

Figure 8. Little Qualicum River estuary showing locations of former *Carex*-channel edge (purple polygons) and *Deschampsia*-flats (blue polygon) communities that have been reduced to exposed substrates and ruderal species by the grazing and grubbing activities of resident Canada Geese. North is to the top of the image.

2005. This is a conservative estimate because peak biomass is less than total plant production over the growing period due to leaching of organics and death of leaves. *C. lyngbyei* had also declined by 23% in areas where the *Carex*-channel edge community was still extant and by 14% in the *Deschampsia*-flats community, so the total annual loss of detrital input contributed to the Little Qualicum estuarine food web involving *C. lyngbyei* alone has been considerable.

A portion of the *Deschampsia*-flats community near the river was also reduced to exposed substrate (ca. 5,500 m^2; Figs. 5, 8 and 9) and from this we estimate a further annual loss of ca. 5 tonnes of above ground dry mass.

Salinities

Mean interstitial soil salinities from the *Carex*-channel edge community in 1978 were approximately 4.4‰ (7.1 ± 0.5 SE mmhos/cm; n = 5; Dawe and White 1982). In 2005, the mean interstitial soil salinity in the exposed sandy soils from the same community was 14.8 ‰ ± 1.4 SE (n = 7). In the

Table 7. Inundating water salinities of the Little Qualicum River estuary, 1978 and 2010. Readings were taken during the high tide (4.8 m Above Chart Datum (ACD) of 20 July 1978 and 9 August 2010. Location numbers are the same as those that appear in Figure 1.

	Salinity (‰)			
	1978		2010	
Location	Surface	Bottom	Surface	Bottom
1 - In river adjacent to old river channel	1	24.9	3.2	27.8
2 - West of haul road constriction	13.1	20.6	11.4	26.1
3 - East of haul road constriction	19.4	20.7	15.8	22.9
4 - Easternmost north-south channel	14.9	16.3	19.8	20.1
5 - Northeasternmost corner of marsh	7.5	8.6	15.3	19.1

exposed organic soils of the same community, adjacent to the dendritic channels in the main marsh, the mean interstitial soil salinity was 22.1‰ ± 0.7 SE (n = 7). There was a significant difference between all 3 mean salinity values (ANOVA; $F_{2, 16} = 73.5$; $p < 0.001$; Newman-Keuls test; Zar 1974). The 2005 soil salinities were significantly higher than those reported in 1978; however, neither would yet be considered hypersaline (32 –>65‰: Eleuterius 1989; Gauthier *et al*. 2006; Jefferies and Rockwell 2002).

LQRe inundating water salinities are given in Table 7. There was no significant difference in the surface or bottom salinity means between years ($F_{3, 16}= 2.2$; $p>0.05$).

Changes in precipitation rates ($F_{1, 17}= 0.62$; $p = 0.44$; Environment Canada 2008) and river flows ($F_{1, 17}= 2.74$; $p = 0.12$; Environment Canada 2010) were not significant. Relative sea-level trends in the Parksville-Qualicum Beach area have been very stable or slightly negative over the last 30–50 years (Mazzotti *et al*. 2008). Between 1978 and 2005, the total relative sea-level change was -8.1 ± 21.6 (SE) mm (range = -30 mm to +14 mm) (Mazotti 2010).

Water use from the river and its aquifer on the Little Qualicum River delta has increased concurrently (e.g., there was a nearly five-fold increase in the population of the Town of Qualicum Beach between 1976 and 2006 which grew from 1,725 to 8,502; BC Stats 2007). In 1975, the Town established the first of 7 municipal wells on the delta, with a capacity of 15.2 litres/sec, followed by another in 1989, with the same capacity, and the remainder shortly thereafter (Svensen 2006), 5 of which currently operate.

Another 2 wells, operated by the Regional District of Nanaimo (RDN), are located on the Qualicum National Wildlife Area (Fig. 2; RDN 2009). From 2000–2005, both of the RDN wells experienced saltwater intrusion during low river flows in September and significantly increasing water conductivities over that period. In September 2004, well #2 exceeded the Canadian Drinking water Guidelines for conductivity (< 700 µS/cm). Both well #1 ($F_{1, 21} = 23.7$; $p < 0.001$) and well #2 ($F_{1, 23} = 23.5$; $p < 0.001$) showed significant increases in conductivity, an indicator of salt-water intrusion.

Figure 9. Estuarine marsh adjacent to the main river channel on the Little Qualicum River estuary, (top) August 1980 and (bottom) 24 August 2005. Note the extensive *Carex lyngbyei* stands of the *Carex*-channel edge community (dark green in the centre-left of the top image), which has been eliminated completely (bottom) through the grazing and grubbing activities of the resident Canada Geese. Large portions of the *Deschampsia* -flats community have also been eliminated, immediately upland of the *Carex*–channel edge community. Photos: Neil K. Dawe.

Circumstantial and photographic evidence of resident Canada Goose impacts

We and others (e.g., Monty 2011) have made numerous observations of resident Canada Geese grazing and grubbing in the LQRe. Exposed rhizomes and heavily-grazed vegetation, isolated mud clumps, goose trails through the *Deschampsia*-flats community and goose faeces in all the plant communities were common on the estuary. Resident Canada Geese were also the only grazing/grubbing bird species that occurred in sufficient numbers on the LQRe that could do such extensive damage. While blacktail deer (*Odocoileus hemionus columbianus*) also visited and fed in the marsh, they are browsers and their numbers and sign were minimal. Trumpeter Swans *(Cygnus buccinator*) occasionally used the LQRe but primarily in winter and normally only during periods of cold weather when agricultural fields were frozen and unavailable. Disease is an unlikely cause for the complete loss of the *Carex*-channel edge community in some areas because the *C. lyngbyei* in the exclosures appeared healthy and grew well.

Consistent with the transect data, photographic evidence shows that the most significant and obvious impacts in the LQRe occurred in the *Carex*-channel edge community. Air photo interpretation suggests that the channel edge communities near the river (Fig. 9) and along the edges of the larger, open-water areas suffered the first impacts followed

Figure 10. Main dendritic channel of the Little Qualicum River estuarine marsh, 12 August 1978 (top) and 24 August 2005 (bottom). The tall form of *Carex lyngbyei* has been eliminated from large portions of the *Carex*-channel edge community by resident Canada Geese. It has been replaced by ruderal species such as *Spergularia canadensis* and *Isolepus cernua*. Note log in centre right of both images. Photos: Neil K. Dawe.

by the dendritic channels in the main marsh. Over much of these areas, the *Carex*-channel edge community has been eliminated altogether, replaced with an alternate stable state of exposed substrate and ruderal species such as *G. maritima*, *I. cernua*, *C. coronopifolia* and *S. canadensis* (Fig. 10). We seldom observed geese feeding or grubbing where the channels were deep and narrow. In those backshore areas, the *Carex*-channel edge community remained apparently healthy and intact, much as it was in 1978 (Fig. 11).

Goose grubbing removed *C. lyngbyei* rhizomes and exposed the peaty, organic soils to erosion (Fig. 12), which, in some cases, occurred down to parent material (Fig. 13). In the eastern areas of the marsh, grubbing activities and the subsequent erosion led to the infilling of some dendritic channels that were formerly at least 30 cm deep (Fig. 14).

Discussion

Resident Canada Geese and marsh vegetation

Evidence strongly suggests that resident Canada Geese have caused significant impacts to and changes in the marsh vegetation of the LQRe. Most of the plant species showing

Figure 11. The *Carex*-channel edge community in backshore areas of the Little Qualicum River estuary appears much as it did in the late 1970s, although some minor grazing even of these areas was noted, 28 June 2005. Photo: Neil K. Dawe.

Figure 13. In some areas of the Little Qualicum River estuary, goose grubbing and subsequent erosion have removed the organic soils exposing the parent material, 29 April 2010. Photo: Neil K. Dawe.

Figure 12. Substrate erosion, a result of goose grubbing activities in the former *Carex*–channel edge community, on the Little Qualicum River estuary; (top) 12 June 2007 and (bottom) 26 June 2009. Photos: Neil K. Dawe.

significant declines in frequency or cover by 2005 are known to be preferred dietary items of Canada Geese (Table 2). In addition, the many observations and abundant evidence of goose grazing on much of the vegetation in the lower marsh communities as well as considerable grubbing evidence is particularly condemning.

Of particular concern at the LQRe is the significant loss of the keystone species *C. lyngbyei* and especially those areas of the *Carex*-channel edge community that have been reduced to exposed sediments, colonized by ruderal species. *C. lyngbyei* is one of the most productive plant species in eastern Pacific coast estuaries. On the LQRe, Dawe and White (1982) and Kennedy (1982) determined a peak standing crop for the *Carex*-channel edge community, where *C. lyngbyei* is the major constituent, of 1692 and 1746 $g \cdot m^{-2}$ dry mass, respectively, which is comparable to other estuaries in the Pacific Northwest (1259–1746 $g \cdot m^{-2}$ dry mass: Burg *et al*. 1980; Dawe and White 1986; Eilers 1974; Ewing 1986). *C. lyngbyei* has also been shown to decompose within months, contributing to the detrital food web relatively quickly, compared to other estuarine plant species such as *J. balticus* (Eilers 1974, p. 311).

Even many of the plant species that were new to the marsh by 2005 or exhibited an increase in frequency and/or cover, were likely influenced by the foraging activities of Canada Geese. Most of these were ruderal species of low productivity, either annuals, such as *I. cernua, S. canadensis* and *A. patula,* or pioneer, colonist perennials such as *C. coronopifolia* and *G. maritima.* All these species were able to take advantage of the altered conditions created by the geese.

The estimated loss of 22 tonnes of above-ground biomass from the *Carex*-channel edge and *Deschampsia*-flats communities undoubtedly has had a negative effect on the detrital food web of the estuary. When we factor in other plants

Figure 14. Main dendritic channel on the Little Qualicum River estuary showing in-filling of the channel habitat over time, a result of the grubbing activities of the resident geese and the attendant erosion of the substrate. Note the channel depth, in excess of 30 cm, and the over-wintering shoots of *Carex lyngbyei* that grow right up to the channel edge; the extent of the *Carex*-channel edge community can be clearly seen on either side of the channel until it meets the clumps of *Deschampsia cespitosa* and the *Deschampsia*-flats community (top left image; late March 1984). Much in-filling of the channel habitat has occurred by 20 September 2005 (top right), and the *C. lyngbyei* no longer grows up to the channel edge. Extent of the over-winter grubbing activities can be seen (bottom left; 19 March 2006). Further erosion and in-filling of the channel habitat continues, as does the loss of the *Carex*-channel edge community (bottom right; 22 June 2010). Photos: Neil K. Dawe.

known to be preferred foods of Canada Geese (Table 2) that have been essentially eliminated from the marsh (e.g., *E. palustris*) or those severely reduced in frequency (e.g., *D. cespitosa*), the loss of primary production has been significant.

Less than 10% of estuarine marsh primary production is consumed *in situ.* The majority enters the detrital food web which supports the higher trophic levels of the estuary (Thayer *et al*. 2005). Detritivores, such as amphipods, copepods, isopods, mysids, chironomids and annelids, are known to depend on *Carex* meadows (Aitkin 1998; Maier and Simenstad 2009; Shreffler et al. 1992). These invertebrates are major prey organisms of animals at the higher trophic levels in nearshore areas, including salmonids and migratory birds (Maier and Simenstad 2009; Simenstad et al. 1979). Thus, the loss of large areas of the *Carex*-channel edge and *Deschampsia*-flats communities on the LQRe and the attendant decline in frequency and cover of other plant species, could have serious implications to the detrital food web and its ability to support the myriad species dependent upon it.

Another area of concern on the LQRe is the in-filling of estuarine channel habitats through erosion of the substrate that results from the grubbing activities of the geese (Fig. 14). Channels allow movement of water, minerals and animals between the marsh and open-water areas. They increase the ratio of edge to area and maximize the amount of accessible marsh edge, providing salmonids with a refuge during low water and greater access to the marsh surface during high water (Thayer *et al*. 2005). In addition, the lush *C. lyngbyei* growth that typically overhangs the estuarine channels, now lacking from much of the LQRe channel edges, provides juvenile salmonids with protective cover from predators such as herons and kingfishers (Aitkin 1998).

Similar impacts by geese to those mentioned above have been noted across North America. Ankney (1996) discusses the exponential increases in giant Canada Geese (*B. c. maxima*) and Greater (*Chen caerulescens atlanticus*) and Lesser (*C. c. caerulescens*) Snow Goose populations, principally in mid and eastern North America and the Arctic along with their impacts and methods of controlling their numbers. Closer to home, one of us (WSB) has been studying impacts to the Fraser River delta marshes by overwintering Lesser Snow Geese. Their numbers have increased by as much as 23 times in the last decade and, coincidentally, their grubbing effects have caused the bulrush (*Schoenoplectus pungens*) marsh to decline dramatically to the point where some marsh areas are expected to go functionally extinct in 10–15 years.

An "apparent trophic cascade" affecting other taxa has resulted from Snow Goose impacts to marshes in the Canadian Arctic through their foraging activities. Aside from eventual impacts to the geese themselves (e.g., decline in clutch size, immature survival rate), studies have shown the changes the geese cause to the habitat, impact non-forage vegetation (such as willows) and invertebrates—particularly spiders, beetles and midges—which ultimately affect shorebirds and passerines that depend on them for nesting and feeding (Jefferies *et al*. 2003). At La Pérouse Bay in Northern Manitoba, Savannah Sparrows (*Passerculus sandwichensis*) nest at the base of live willows where grasses provide adequate cover. There, the number of nesting Savannah Sparrow pairs declined by 77% coinciding with a 63% reduction in vegetation cover (including the death of the willow shrubs) caused by the destructive foraging of the geese (Rockwell *et al*. 2003). Marked decreases in some shorebird populations in the Hudson's Bay Lowlands are also likely due, at least in part, to habitat degradation by Snow Geese (Jefferies *et al*. 2003).

A changing salinity regime?

We recognize that some of the vegetation changes on the LQRe may not entirely be due to Canada Geese. Ecosystems are "moving targets" with uncertain and unpredictable futures (Holling 1978; Walters 1986); they can change as a result of natural variation and/or human activities.

For example, some of the vegetation changes we report are likely the result of natural succession, such as the increasing areas of *E. repens* and *A. subspicatus*. Other changes, such as the appearance of plants with a high salinity tolerance (e.g., *D. spicata* and *Polygonum aviculare* (Table 3; Fig. 15) or the elimination of some plant species entirely (e.g., the *Typha latifolia* phase of the *Carex*-channel edge community; see Dawe and White 1982) or the general die-off of Nootka rose (*Rosa nutkana*) and Pacific crabapple (*Malus fusca*) at the higher elevations of the estuarine marsh (evident by 1995; NKD, pers. obs.) may be associated with a changing salinity regime.

The *Carex*-channel edge community soil salinities have shown a significant increase, likely a result of goose grazing and grubbing and the resultant exposure of the soil to higher surface water evaporation rates with its attendant build-up

Figure 15. Canada Geese and Mallards (*Anas platyrhynchos*) engaged in feeding and maintenance activities on the Little Qualicum River estuary, 4 September 2005. Transect 4 runs directly through this area from central left to upper right. The lighter-green vegetation just above the geese, in the *Carex-Agrostis* slope community, is a large area (> 130 m^2) of *Distichlis spicata*, a plant that did not occur there in 1978. Most of the geese are standing in the former *Carex*-channel edge community, since reduced to ruderal species. Photo: Neil K. Dawe.

Figure 16. Looking along transect 21 (reported in Dawe *et al.* 2000) at the extensive *Carex lyngbyei* beds on the lower elevations of Nunn's Island on the Campbell River estuary (29 June 1988; left). By 2009, the *Carex* beds have all but disappeared with only scattered stands of *Juncus balticus* remaining (right; 20 July 2009). Stakes indicating transect 21 can be seen just right of centre, running from the bottom of the image to the *Juncus* stand. Note also, the resident goose grubbing sign across the centre of the right image, which was evident to varying degrees throughout the general area.

of salts. Generally, increasing soil salinities lead to decreasing plant productivity and biodiversity with fewer species able to tolerate the saline conditions (Thayer *et al*. 2005).

However, goose grubbing and grazing cannot explain the appearance of *D. spicata* throughout the marsh, the dieback of rose and crabapple and the elimination of the *Typha* phase of the *Carex*-channel edge community. These changes, coupled with the proximate well data from the RDN (2009), suggest increased salt water intrusion has occurred on the estuary.

Saltwater intrusion could result from a number of factors including 1) decreased precipitation, 2) decreased river flows, 3) sea level rise and 4) reduction of freshwater input due to the radius of influence of local well fields. Each or a combination of these factors could result in a decreased hydraulic head allowing the intrusion of salt water into the marsh (Liebscher 2005).

Precipitation rates, river flow and sea level increases associated with the LQRe have not changed significantly over the study period. Sea level changes of -0.3 ± 0.8 mm/a (Mazzotti *et al*. 2008) would not have been sufficient to cause the complete loss of *C. lyngbyei* in some areas of the LQRe. Because sea level changes were so small over such a long period (27 y), the vegetation could likely have adapted as *C. lyngbyei* normally occurs through a broad elevational range (Eilers 1974, p.184; Dawe and White 1982).

Considering the high population growth of humans in the area, however, withdrawal of freshwater from the Little Qualicum River aquifer may have created a reduced hydraulic head which allowed the salt water to intrude into the estuarine marsh much further than it did in years past. Apparent changes in the salinity regime and the accompanying changes in vegetation may be an example of the effects of human population growth at a local scale.

However, we emphasize that salinity changes cannot account for the relatively rapid elimination of large areas of the *Carex*-channel edge and *Deschampsia*-flats communities. This is because both *C. lyngbyei* and *D. cespitosa* can remain a dominant species where soil salinities average 30 ‰ and inundating water salinities exceed 27 ‰, far higher than the salinities we found on the LQRe (Anchor EnvironmentalLLC 2004; Hutchinson 1989; Morlan 1991). The changes in the salinity regime, however, could be working synergistically with the geese to accelerate some of the other vegetation changes.

Impacts to other Vancouver Island estuaries

Because of the significant increase in resident Canada Goose numbers on the east coast of Vancouver Island (Dawe and Stewart 2010) and the obvious severity of the impacts on the LQRe, we also made cursory examinations of 3 other estuaries in the mid-island area, including the Nanoose-Bonell, Englishman River and Campbell River estuaries. Impacts similar to those on the LQRe were observed to be occurring on all these systems (e.g., Campbell River estuary; Fig. 16). In an earlier contribution (Dawe *et al*. 2000), the potential for Canada Geese to become a factor on the success of a marsh restoration project on the

Campbell River estuary was highlighted. A common factor on all these estuaries is the increasing numbers of Canada Geese using the systems.

Introduced, resident Canada Geese

Canada Goose populations on the east coast of Vancouver Island consist largely of hybrid subspecies that are a result of deliberate introductions in the 1920s and 1930s and again in the 1970s, 1980s and early 1990s. From these introductions, populations totaling ca. 15,000 geese now frequent the east coast of Vancouver Island from Sooke to Campbell River. There is also a smaller population of resident geese in the Port Hardy area (Dawe and Stewart 2010).

Compared to migrant Canada Geese, resident birds have very different life history strategies which allow the geese to devote more time and energy to reproduction and survival. In addition to having a consistent, available food source, unlike the periods of restricted food availability that migrants must endure, resident geese are not exposed to the energy requirements and the risks imposed by long-distance migrations. In the study area, most resident geese spend the winter on or near their nesting areas and are ready to lay eggs by early March and perhaps even late February (Monty 2010). Compared to migrants, resident geese breed at a younger age, experience fewer nesting failures and produce larger clutch sizes, all of which contribute to rapid population growth rates (U.S. Fish & Wildlife Service 2005).

In their review of invasive alien species and their threats to biodiversity in British Columbia, Rankin & Associates (2004) consider the invasiveness of the resident Canada Goose (south coast populations) to be "insignificant." We disagree with that assessment. Our study suggests that Canada Geese are effectively reducing or eliminating large areas of vegetation that contribute to the detrital food web of estuarine marshes along the east coast of Vancouver Island. The impacts likely affect negatively a myriad of other organisms dependent on these systems.

Estuarine marsh recovery

Holling and Meffe (1996) suggest a "Golden Rule" for natural resource management: strive to retain critical types and ranges of natural variation in ecosystems, as opposed to manipulating or controlling them. The default condition, they argue, should be the maintenance of the natural state. Unfortunately, this rule was overlooked when Canada Geese were deliberately introduced to the east coast of Vancouver Island (Dawe and Stewart 2010). Based on returns and observations from preliminary banding results on the LQRe, and in the Parksville-Qualicum Beach area in general, nesting geese there appear to consist entirely of resident birds (Cooper 2011) but more effort is needed to confirm this. Thus, marking and monitoring the geese will be necessary to determine local movements, goose numbers and distribution of resident birds, as well as any use by native geese.

Canada Goose numbers appear to be well above the current carrying capacity of the LQRe, likely aided by food augmentation from nearby agricultural areas and golf courses, playing fields, etc. If the negative effects caused by the resident geese are to be remedied, their numbers must be reduced to levels below the *current* carrying capacities of the estuarine ecosystems supporting them or they may have to be eliminated altogether. To do nothing is a management decision that would ensure the continued decline of productive estuarine ecosystems on Vancouver Island. Restoring the marshes to some semblance of their former states will likely require the following actions: 1) continued egg-addling efforts, 2) reduction or perhaps elimination of (primarily) adult, resident geese and 3) intensive habitat rehabilitation. Adaptive management or "learning by doing," would be an important component, conditional on a long-term view (McCarthy and Possingham 2007; Wallington *et al*. 2005; Walters and Holling 1990).

Available methods for controlling Canada Geese in urban and rural environs are not practical in natural or protected habitats. Typical management prescriptions such as habitat alteration, lure crops, electric or barrier fences, surface coverings, visual deterrents, dogs, repellents, hazing, scarecrows, distress calls, pyrotechnics and propane cannons (Environment Canada 2010; McFarlane-Tranquilla *et al*. 2008; U.S. Fish & Wildlife Service 2005) would also affect the other native wildlife species dependent on the protected area. Goose control via hunting is difficult, if not impossible, often because of proximate residential dwellings or municipal closures to the discharge of firearms. Even where hunting is an option, geese quickly seek refuge within more urban environments.

Continued egg addling on the LQRe may slow the growth rate of local goose populations but it has not always been effective in reducing numbers elsewhere (U.S. Fish & Wildlife Service 2005). Increasing adult mortality rates, on the other hand, is 9–15 times more effective in reducing the growth of goose populations (Ankney 1996).

Assuming the nesting geese are principally introduced residents, it should be possible to reduce or eliminate specific, local populations without impacting non-target, native races of Canada Geese. The optimum time to do this is during the molt period when large numbers of birds can be rounded up and euthanized in a humane manner.

Marsh restoration will probably need to involve more than reducing goose numbers. Changes in the structure of the estuarine marsh by excessive goose herbivory can often be asymmetric and simply lowering herbivory levels may not be sufficient to restore the system. Recovery may take decades, which is particularly true if changes in abiotic conditions, such as hypersalinity, organic matter loss, or compaction of sediments, cannot easily be returned to their former states (Handa *et al*. 2002; Jefferies *et al*. 2006a; Jefferies *et al*. 2006b). Some areas of the LQRe marshes appear to have already flipped to an alternative stable state and soil salinity levels are increasing. The sooner restorative actions are undertaken the better the chance of success in restoring the marsh to its former areal extent and productivity.

Haramis and Kearns (2007) found that wild rice (*Zizania aquatica*) and other marsh vegetation recovered following a major reduction of some 1,700 Canada Geese over a four-year period, combined with fencing and widespread seeding and planting. We favour a similar approach and suggest a pilot program be implemented in the LQRe.

Our preliminary study on the LQRe, along with results from cursory examinations of other estuaries on the east coast of Vancouver Island, should alert wildlife managers to the threat posed by resident Canada Goose populations. All estuarine marshes where resident geese occur need to be assessed for ecological impacts. We strongly suggest that, where impacts are found, a management strategy be implemented to reduce and maintain at low numbers or eliminate from local estuaries the introduced, alien and now resident Canada Geese. The effect of local human population growth on the coastal wetlands of Vancouver Island is another issue requiring further investigation. Human population growth and its consumptive demands are often ignored by wildlife managers (Holling and Meffe 1996).

Acknowledgements

Peter Arcese (University of B.C.) and Erika Lok (Canadian Wildlife Service) commented on an early draft of the paper. Holly Clermont provided some of the current Canada Goose nesting data for the LQRe. Heather Svensen and D. Churko provided well data for the Town of Qualicum Beach and the Qualicum National Wildlife Area, respectively. Stephane Mazzotti provided the sea level rise data and sample calculations for the Little Qualicum River area. Roland Stark provided advice on the statistical multiple testing corrections. Stephen J. Liddell and Renate Sutherland provided assistance in the field. Faye Smith (Mid Vancouver Island Habitat Enhancement Society) provided the salinity meter. Journal reviewers, Rob Butler and John Cooper, provided valuable comments. We thank them all.

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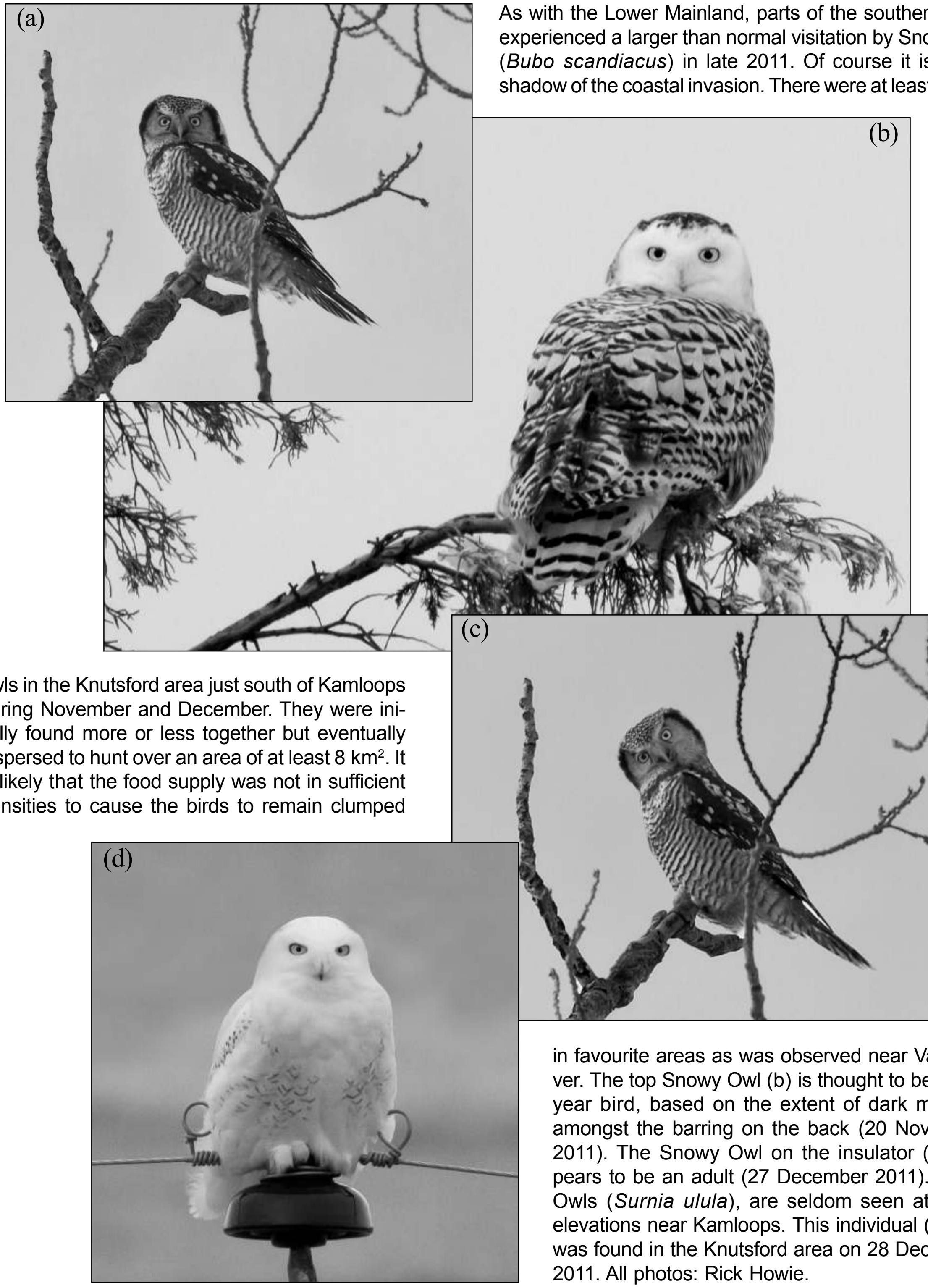
Photo essay


(a) (b) (c) (d)

As with the Lower Mainland, parts of the southern interior experienced a larger than normal visitation by Snowy Owls (*Bubo scandiacus*) in late 2011. Of course it is a mere shadow of the coastal invasion. There were at least 3 snowy owls in the Knutsford area just south of Kamloops during November and December. They were initially found more or less together but eventually dispersed to hunt over an area of at least 8 km^2. It is likely that the food supply was not in sufficient densities to cause the birds to remain clumped in favourite areas as was observed near Vancouver. The top Snowy Owl (b) is thought to be a first year bird, based on the extent of dark mottling amongst the barring on the back (20 November 2011). The Snowy Owl on the insulator (d) appears to be an adult (27 December 2011). Hawk Owls (*Surnia ulula*), are seldom seen at lower elevations near Kamloops. This individual (a & c) was found in the Knutsford area on 28 December 2011. All photos: Rick Howie.

Back cover: Canada Geese interrupted while foraging in the *Deschampsia*-flats (6 geese, left foreground) and *Carex*-channel edge (3 geese, right foreground) communities on the Little Qualicum River estuary, B.C., 23 April 2007 (see page 11). Photo: Neil K. Dawe.

British Columbia Birds

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Volume 21 • 2011