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ORIGINAL ARTICLE

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Decline of Canada geese (*Branta canadensis*) and common goldeneye (*Bucephala clangula*) associated with a collapse of eelgrass (*Zostera marina*) in a Nova Scotia estuary

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Abstract Mean numbers of migrant Canada geese (*Branta canadensis*) in Antigonish Harbour in the southern Gulf of St. Lawrence (Canada) during October to December were similar (approx. 450–500 birds) for the period 1998–2000. Similarly, during this period, geese used two foraging sites. However, in 2001, the average number of birds decreased by half and the primary foraging sites were used only rarely. This coincided with a decline of about 95% in the biomass of roots and rhizomes of eelgrass (*Zostera marina*) that occurred between October 2000 and 2001. Eelgrass is the principal food of geese in this estuary. In addition, there was a reduction of around 50% in the numbers of common goldeneye (*Bucephala clangula*), which feed on invertebrates associated with eelgrass. Lower than usual weekly abundances of geese and goldeneye are probably the result of an unusually short residence time in the estuary, rather than a decline in the total number of visiting migrants. We attribute these changes in the distribution and abundance of geese and goldeneyes to the dramatic decline in eelgrass.

Keywords *Branta canadensis* · *Bucephala clangula* · Canada geese · Common goldeneye · Eelgrass · *Zostera marina*

Introduction

The importance of vertebrate herbivory on the perennial eelgrass *Zostera marina* as a primary energy flow pathway in marine systems has largely been ignored in the North American botanical and marine biological literature (e.g. Mann 1982; Dawes 1998; Levinton 2001). The main exception in both North America and Europe is an extensive literature on the dependence of migratory brant geese (*Branta bernicula*) on intertidal and shallow subtidal populations of *Zostera* spp. (e.g. Ganter 2000; Nacken and Reise 2000). Although Canada goose (*Branta canadensis*) herbivory on eelgrass in eastern Canada (Erskine 1997; Martell 1997; Newman-Smith 1997) and the eastern United States (Thayer et al. 1984) is known, it has not received wide attention. Throughout most of the range in North America, Canada geese commonly feed during migration in agricultural fields (see Gates et al. 2001). Comparable agricultural fields are limited on Nova Scotia shores of the Gulf of St. Lawrence, and even when present adjacent to shorelines, are used infrequently for foraging (Erskine 1997). Historically, geese were abundant in the region and these numbers predated European agriculture (Denys 1672).

The southern Gulf of St. Lawrence has a coastline that includes numerous shallow embayments and estuaries with extensive meadows of eelgrass (*Z. marina*). This was noted as early as 1672, by Denys in Antigonish Harbour, who commented on goose feeding behaviour and on the lushness of the eelgrass which he described as "a grass of the length of a fathom and more... that is the feeding ground they like the best". Large numbers of breeding and migratory wildfowl still feed in these areas. In one of these estuaries, Antigonish Harbour, the foraging behaviour of both breeding wildfowl, including black ducks (*Anas rubripes*), and migratory wildfowl, including Canada geese (*Branta canadensis*), has been described as part of a 25-year study of the wildfowl ecology of the estuary (Murphy et. al. 1990; Seymour 1997).

In this paper, we describe the decline in numbers of migratory Canada geese and common goldeneye (*Bucephala clangula*) in the estuary during the autumn of 2001. This decline correlates with a collapse of the *Zostera* meadows in the same year. For at least 25 years before 2001, the *Zostera* meadows had covered almost 90% of the bottom, in dense swards with the erect shoots being abundant during summer and winter and less so in the spring and winter. In the Maritime Provinces of Canada

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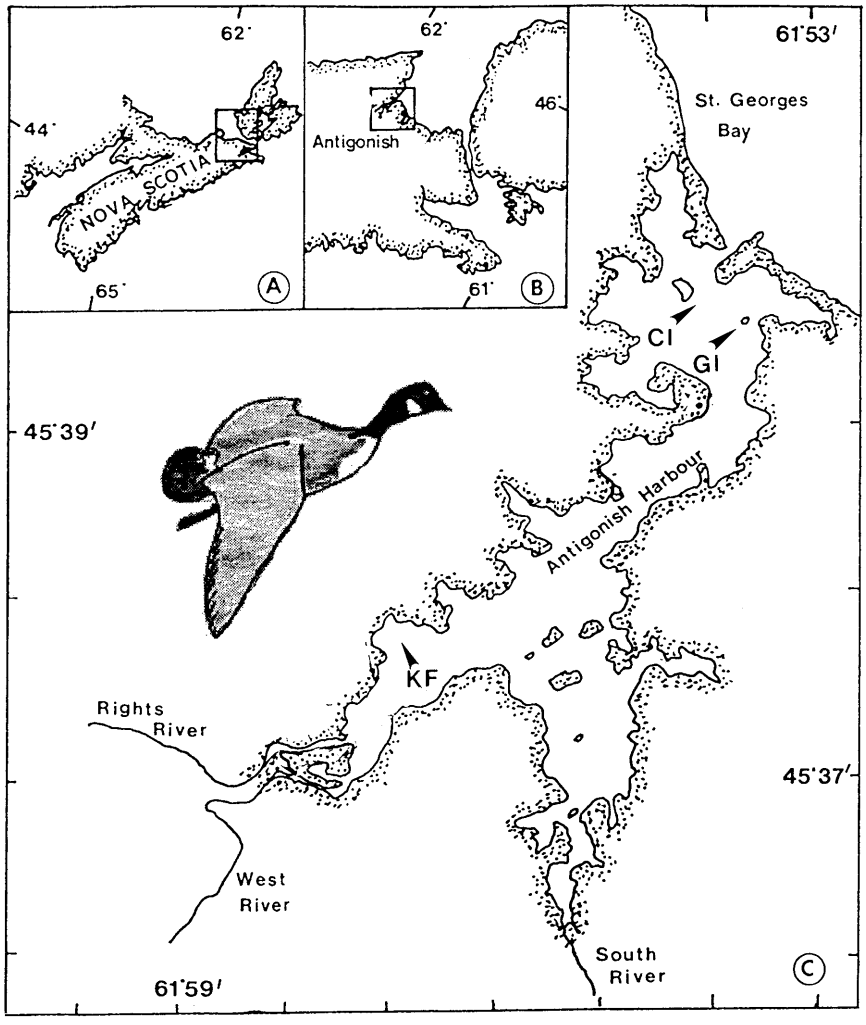

Fig. 1 Map of Nova Scotia (**A**) with insert of St. Georges Bay (**B**) and insert of Antigonish Harbour (**C**) indicating primary survey sites for *Branta canadensis* and *Bucephala clangula* at Captain's Island (*CI*) and Kennedy's Farm (*KF*) as well as sites for quantitative assessment of assessment of *Zostera marina* (CI and Gooseberry Island, *GI*)

the extensive, and perhaps obligate, herbivory of Canada geese on *Zostera* is well established (Erskine 1997; Martell 1997; Newman-Smith 1997). We attribute the decline in the numbers of Canada geese and the changes in foraging distribution in the autumn of 2001, to the collapse of the *Zostera* meadows. We further argue that a generalized decline of *Zostera* in Nova Scotia will have a major impact on migrating Canada geese and other waterfowl.

Methods

Study area

Antigonish Harbour is a drowned river estuary characteristic of the southern Gulf of St. Lawrence. It is mostly shallow, with only the channel formed by the old river and some isolated basins being more than 2 m deep. It has not been used as a harbour since the early 1900s, when the water was presumably deeper. The Antigonish estuary has a NE/SW orientation and is about 15 km^2 in area. Tidal amplitude is usually less than about 1 m, and the depth of water over the *Zostera* is seldom more than 0.5 m. Except in the immediate inflow sites of rivers, the salinity is 15–28‰ (Garbary and Barkhouse 1987). The primary foraging areas for the Canada geese were off Captain's Island and off Kennedy's farm (Seymour 1997; see Fig. 1).

Abundance of Canada geese and common goldeneye

The entire estuary was efficiently surveyed from a number of vantage points easily accessible by vehicle. Observations were made with a spotting scope and binoculars. The entire estuary could be surveyed within 1 h. Observations of the main foraging sites off Captain's Island and Kennedy's Farm were made almost every day during the autumn migration (September to December) by the principal investigator (N.S.) and by two observers who resided along the shores of the estuary. Mean values for the daily surveys during each third of each month were calculated. These calculations were done for the years 1989–2001. Surveys by vehicle were conducted to determine distribution and abundance of geese in Antigonish Harbour at least twice per week from early September until January during the period reported here (1998–2001 inclusive). These surveys were part of a continuous 29-year-long monitoring of the waterfowl using this estuary. Data for the years 1972–1992 were previously published by Seymour (1997). Less intensive surveys were conducted along a 90 km section of coastline that includes Antigonish Harbour and other estuaries (N.R. Seymour, unpublished results).

Common goldeneye (hereafter referred to as goldeneye) are commonly associated with Canada geese in Antigonish Harbour where they presumably feed on invertebrates associated with eelgrass as they do, for example, in Sweden (Pehrrson 1976). Surveys for goldeneye were conducted only during December, the usual month of their peak abundance.

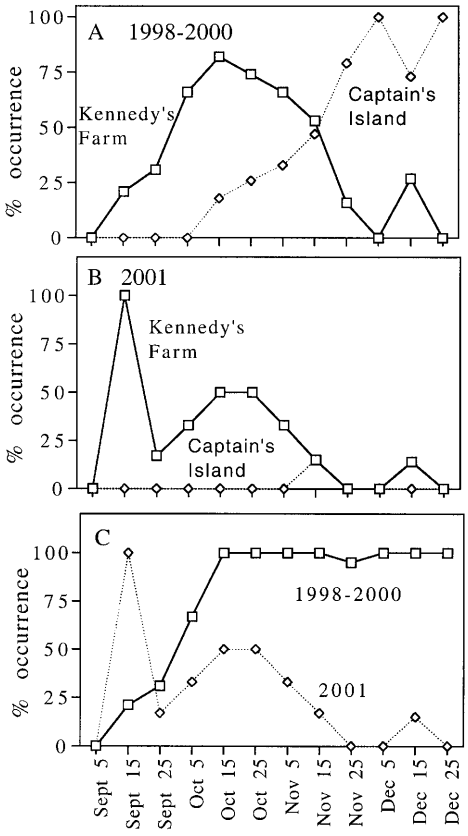

Fig. 2 Frequency of individual surveys during which *Branta canadensis* occurred at two sites in Antigonish Harbour during surveys in 1998–2000 (**A**) and 2001 (**B**). For each 10-day period the number of surveys varied from 11 to 19, also percentage occurrence during the period 1998–2000 combined, and 2001 (**C**)

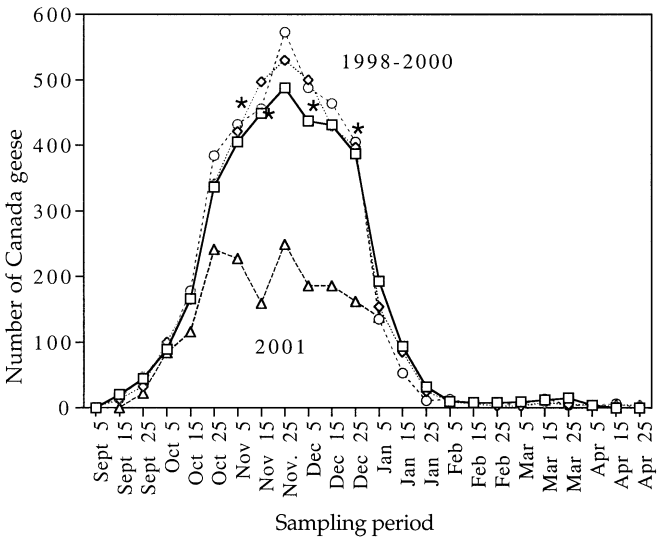

Fig. 3 Numbers of *Branta canadensis* in Antigonish Harbour (September to January) during the period 1998–2001. *Asterisk* indicates single observations of large numbers of birds that arrived in 2001 but left within 48 h

Table 1 Biomass estimates (fresh mass) of roots and rhizomes of *Zostera marina* at Captain's Island between 2000 and 2001 (n=22 and 23 cores, respectively)

	2000 (g m^{-2}±SE)	2001 (g m^{-2}±SE)	Significance
Total biomass	2133±279	175±42	P<0.001
Living biomass	1505±201	70±27	P<0.001
Living biomass (%)	70.6	40.9	

Density and abundance of eelgrass

The density of *Zostera* rhizomes in the major foraging site off Captain's Island (Fig. 1) was determined from core samples taken along a transect in October of 2000 and 2001. Cores were taken to a depth of about 20 cm and were 15 cm (October 2000; 22 cores) or 10 cm (October 2001; 23 cores) in diameter. Core sampling locations were selected haphazardly so as to cover the full extent of the *Zostera* meadow in both 2000 and 2001. Cores were placed in separate plastic bags for storage (4°C), and were sorted within 7 days of collection. Sorting involved removing *Zostera* from the surrounding sediment with a sieve. Fragments of *Zostera* (mostly rhizomes and roots) were then separated into living and dead material. The wet mass of both was determined after blotting to remove surface moisture. Two-tailed Student's *t*-tests were used to determine whether *Zostera* biomass was different in 2001 than in 2000.

Results

Geese were in small, dispersed flocks from arrival in mid-September until early October, when they typically remained in one flock during foraging, resting and nighttime roosting. Figure 2A shows that during 1998, 1999 and 2000, geese used two principal foraging sites, Captain's Island and Kennedy's Farm (Fig. 1). This was consistent from mid-October until the main flock left late in December when the upper two-thirds of the estuary was frozen. After mid-November, Captain's Island was used almost exclusively, a consistent pattern since the mid-1970s (Seymour 1997). These published data show the baseline that provides the starting point for the present results (1998–2001). However, Fig. 2B shows that there was a dramatic departure from this pattern during 2001, when the Canada geese only rarely foraged at Captain's Island after early November. They then predominantly foraged at a site in the lower estuary that had not been used during the previous 3 years, and was only rarely used during the previous decade. Figure 2C further illustrates the shift in use of the two sites in 2001.

During 2001, there was also a decline in population size over that of the previous 3-year average (Fig. 3). In fact, the population was usually less than half its former size during the peak months of November and December. Figure 3 also shows that on four occasions during 2001, the flock increased by 250–300 birds, only to decrease by approximately the same number after 2 or 3 days.

Table 1 shows that at the Captain's Island site, total biomass of eelgrass, consisting of both living and dead rhizomes and attached roots, decreased by 80% between sampling dates in October 2001 and October 2002, a sig-

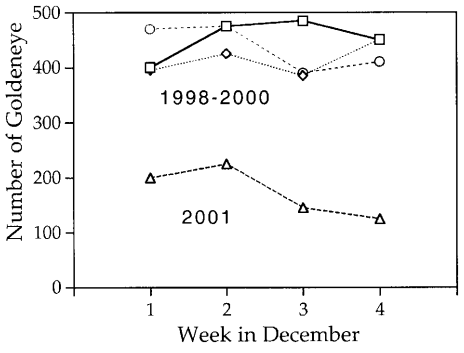

Fig. 4 Numbers of *Bucephala clangula* in Antigonish Harbour during December 1998–2001

nificant ($P<0.001$) decline. The former sample consisted of 70% living material (biomass), while only 39% of the latter was living, a significant ($P<0.001$) decline of 95%.

During the period 1972 to 2000, migratory goldeneye arrived in late October; typically there were 15–25 birds (maximum 55). These numbers increased to about 300 birds (maximum 360) during November, with a peak abundance of about 450 (maximum 520) in December. Numbers dropped to about 100 birds (maximum 140) in January, when ice conditions forced birds to leave the estuary. The monthly abundance of goldeneye during 2001 was dramatically lower than during the previous 18 years. Monthly means were lowered by 0%, 75%, 60% and 70% for the months of October to January, respectively. When compared with the previous three years, the mean weekly number was >50% lower (Fig. 4). Goldeneye foraged almost exclusively at three traditional sites during the period 1972–2000. These sites included Kennedy's Farm and Captain's Island. However, during 2001, they rarely foraged at Captain's Island.

Discussion

Anecdotal evidence suggests that the decline in *Zostera* was general. For example, throughout the 1990s, there was a dense stand at Gooseberry Island, approximately 0.5 km from our sample site. However, erect shoots were absent in November 2001, and only dead rhizomes were present in a small sample of cores. Wrack that had accumulated on the island shore consisted only of dead rhizomes. Historically, the estuary has had abundant wrack on its shores, with mounds 70 cm or more deep. *Zostera* wrack was virtually absent at all sites where it was formerly common, and in most places it was no more than 1–2 cm deep. By the early summer of 2001, residents around the estuary were commenting on the lack of *Zostera* wrack in the lower estuary. Later that summer, boaters commented that they could travel in the estuary without the usual need to frequently remove *Zostera* leaves from their propellers. During extensive surveys of the estuary in the autumn of 2001 we found little *Zostera* wrack, even where it traditionally had been extensive. In several bays there was an accumulation of dead, blackened rhizomes rather than the more typical leaves. These anecdotal observations suggest that the decline in *Zostera* that we measured quantitatively at the Captain's Island site was a reflection of a more general decline throughout Antigonish estuary.

A rough estimate of the biomass of eelgrass needed to sustain Canada geese at the 1998–2000 numbers can be calculated based on the estimate that each bird requires 3.1 kg (fresh mass) of leaves and rhizomes each day (Newman-Smith 1997). Between 1998 and 2000, the goose numbers in Antigonish estuary were at or above 20% of the peak number of about 500 birds, from 5 October to 15 January. This results in an average of about 350 birds per day over this period (Fig. 3), which would require 110,000 kg of eelgrass biomass as a food source. The larger goose populations prior to 2001 had occurred in Antigonish estuary for at least the past 25 years, and our *Zostera* core-sampling site off Captain's Island had always been their major foraging area (Seymour 1997). The numbers of geese were no greater in the years just prior to the *Zostera* collapse of 2001 so there is no reason to believe that geese were a primary cause of the collapse. However, the normally high levels of grazing could have hastened the collapse of a *Zostera* population already stressed by other factors. There has been an increase in the number of houses being built around the estuary, some quite close to shore, and a large dock for a pleasure boat was built in the summer of 2000 on the south-eastern shore a few kilometres from the Captain's Island site. There is, however, no obvious correlation between the location of building sites and possible increases in turbidity, and the decline in *Zostera* that has occurred in all parts of the estuary.

The reasons for the eelgrass decline are unknown. There was no evidence in the wrack that did accumulate in 2001 of the black necrotic areas that are characteristic of the "wasting disease" of *Zostera*, which is caused by the slime mould *Labyrinthula zosterae* (Muehlstein et al. 1991; Burdick et al. 1993; Short and Burdick 1996). Eutrophication has been implicated in the decline of *Zostera* beds (e.g. Short and Wyllie-Echeverria 1996; Hauxwell et al. 2001; McGlathery 2001), but there has been no recent change in nutrient input into the Antigonish estuary since 1994, when improved sewage treatment facilities for the town of Antigonish were constructed.

There has been an explosive increase in the exotic green, or shore crab (*Carcinus maenus*) in the estuary. Carapaces were noticed for the first time in 1994 and by 2000 the crab population had reached an estimated 385,000 individuals per km^2 (Campbell 2001). Pits dug by these crabs as they search for soft-shelled clams (*Mya arenaria*) result in a disruption of the fine sediments associated with *Zostera* beds that was not evident before the arrival of the green crabs. Whether this bioturbation is a cause of the *Zostera* decline remains to be seen.

High numbers of invertebrates are typically associated with *Zostera* beds (Heck et al. 1995; Asmus and Asmus 2000). Thus the integrity of wildfowl populations that feed on these invertebrates is indirectly associated with the health of the *Zostera* meadows. Accordingly, goldeneye foraging in this habitat in Sweden were abundant when *Zostera* was abundant, and in some years they fed exclusively over *Zostera* (Pehrrson 1976). In the Antigonish estuary, goldeneye invariably forage over *Zostera* (270 surveys during September to December from 1972 to 1987; N.R. Seymour, unpublished results). This was true during the period 1998–2000. However, the 50% decline in numbers during 2001 and their failure to use the Captain's Island site, where *Zostera* had collapsed, suggest that goldeneye were also responding to the *Zostera* decline.

The strong dependence of brent geese upon *Zostera* spp. as a food source has been well established in both Europe and North America (Ganter 2000). In the Maritime Provinces of Canada, *Zostera* is also an important food source for Canada geese in the autumn and winter (Erskine 1997). The Canada geese that migrate in the autumn through much of Nova Scotia may be as dependent upon *Zostera* as are brent geese in other areas (Ganter 2000). As we have previously stated, the dependence of the Canada geese upon *Zostera* is mainly due to the lack of extensive grain fields in this region. There has been a concurrent decline of *Zostera* and goose populations in other parts of Nova Scotia. During 2000 and 2001, wildlife managers (D. Archibald, N.S. Department of Natural Resources; A. Hanson, Canadian Wildlife Service; personal communication) reported declines in both *Zostera* and Canada geese on the Atlantic coast of Nova Scotia, where there has been evidence of goose starvation. Tens of thousands of Canada geese migrate through Nova Scotia in the autumn (Erskine 1997), and a generalized decline of *Zostera* is predicted to have a significant effect on these birds. The absence of other food sources may result in a major decline of Canada geese using the southern Gulf of St. Lawrence as a staging area during autumn migration. The impact of these declines on recruitment remains unclear.

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