# A review of agricultural land use by shorebirds with special reference to habitat conservation in the Fraser River Delta, British Columbia

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[1]*Centre for Applied Conservation Research, University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z4 (e-mail: lesleyje@interchange.ubc.ca);* [2]*Pacific Agri-Food Research Centre, Agriculture and Agri-Food Canada, Agassiz, British Columbia, Canada V0M 1A0; and* [3]*Centre for Wildlife Ecology, Department of Biological Sciences, Simon Fraser University, 8888 University Drive, Burnaby, British Columbia, Canada V5A 1S6.* *Received 6 July 2006, accepted 30 August 2007.*



Evans-Ogden, L. J., Bittman, S. and Lank, D. B. 2008. **A review of agricultural land use by shorebirds with special reference to habitat conservation in the Fraser River Delta, British Columbia**. Can. J. Plant Sci. **88**: 71–83. Many estuaries worldwide are important habitats for shorebirds. Agricultural fields adjacent to food-rich intertidal areas can provide roosting and feeding habitat, particularly at high tide. The Fraser River Delta (FRD) contains rich agricultural land and is Canada's most important non-breeding site for shorebirds. We review and synthesize recent studies that have investigated agricultural land as non-breeding habitat for shorebirds in the FRD using radio-tracking, day-time and night-time surveys, stable isotope analysis of blood samples, examination of prey in stomach and faecal samples, and farmer surveys regarding field management. The three primary shorebirds studied in the FRD were dunlin (*Calidris alpina pacifica*), black-bellied plover (*Pluvialis squatarola*), and killdeer (*Charadrius vociferus*). Field use is mainly nocturnal for dunlin, but diurnal for black-bellied plovers and killdeer. Dunlin and black-bellied plovers mainly use bare or winter cover crop fields, preferring short cover. Killdeer mainly use berry and winter vegetable fields. All species prefer fields recently manured, fertilized, or laser levelled. Day length and precipitation influenced field use. Stable isotope analysis ($\delta^{13}$C, $\delta$ $^{15}$N) of dunlin blood indicates that approximately 38% of dunlin diet is obtained from agricultural habitat. Younger birds have a higher terrestrial contribution to diet (~43%) than adults (~35%). Dunlin prey includes agricultural pest species such as leatherjacket (Tipulidae) larvae and wireworm (*Agriotes* spp.). Coastal agricultural land with diverse crop types benefits shorebirds, and its loss may negatively impact fitness, especially for juveniles. Research conducted in the FRD shows the importance of farmland for wintering shorebirds and suggests conservation and management strategies to preserve and enhance the wildlife value of this agricultural habitat.

**Key words:** Farmland, agricultural land, shorebirds, Fraser River Delta, management, wildlife conservation

Evans-Ogden, L. J., Bittman, S. et Lank, D. B. 2008. **Étude de l'usage des terres agricoles par les oiseaux de rivage dans une optique de conservation de leur habitat dans le delta du Fraser, en Colombie-Britannique**. Can. J. Plant Sci. **88**: 71–83. Partout dans le monde, de nombreux estuaires servent d'habitat aux oiseaux limicoles. Les champs cultivés adjacents aux zones intertidales, riches en nourriture, servent de lieu de repos ou d'alimentation, surtout à marée haute. Le delta du Fraser (DF) comporte de riches terres agricoles et constitue l'aire la plus importante du Canada pour les oiseaux limicoles, en dehors des sites de reproduction. Les auteurs passent en revue des études récentes sur l'utilisation des terres agricoles du DF par les oiseaux de rivage à d'autres fins que la reproduction, pour en extraire des conclusions. Ces études recouraient au radioguidage, à des relevés diurnes et nocturnes, à l'analyse des échantillons de sang au moyen d'isotopes stables et aux enquêtes des agriculteurs sur la gestion des terres. Les trois principales espèces limicoles examinées dans le DF sont le bécasseau variable (*Calidris alpina pacifica*), le pluvier argenté (*Pluvialis squatarola*) et le pluvier kildir (*Charadrius vociferus*). Le bécasseau variable est une espèce essentiellement nocturne, les deux autres étant diurnes. Le bécasseau variable et le pluvier argenté se servent principalement des champs dénudés ou enneigés, surtout quand la couche de neige n'est pas épaisse, alors que le pluvier kildir affectionne les champs où poussent baies et légumes d'hiver. Toutes les espèces préfèrent des champs fraîchement amendés avec du fumier ou des engrais, ou nivelés au laser. La longueur du jour et les précipitations influent sur l'utilisation des champs. L'analyse du sang du bécasseau variable avec des isotopes stables ($\delta$ $^{13}$C, $\delta$ $^{15}$N) révèle que cet oiseau tire environ 38 % de son régime de l'habitat agricole. Les jeunes oiseaux s'alimentent plus de la terre (~43%) que les spécimens adultes (~35%). Le bécasseau variable mange les parasites des cultures comme les larves de baliste (Tipulidés) et de taupin (*Agriotes* spp.). Les espèces limicoles bénéficient des terres agricoles côtières aux cultures diversifiées et la disparition de ces dernières pourrait avoir une incidence négative sur la condition physique des oiseaux, surtout les jeunes. Les recherches effectuées dans le DF illustrent l'importance des terres agricoles pour les

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**Abbreviations: FRD**, Fraser River Delta

oiseaux de rivage qui hivernent et indiquent qu'on devrait échafauder des stratégies de gestion et de conservation afin de préserver et d'améliorer l'utilité de cet habitat agricole pour la faune.

**Mots clés:** Terres agricoles, cultures, oiseaux de rivage, delta du Fraser, gestion, conservation de la faune



Conflict between agriculture and wildlife is a global issue, and wildlife damage to agricultural crops can result in losses of millions of dollars to farmers (e.g., Wywialowski 1996). The negative effects of wildlife on agriculture often overshadow the beneficial roles that wildlife can play, and in fact wildlife and agriculture can be mutually beneficial. While birds are widely cited as crop predators, they can also play an economically significant role in controlling insect pests (Mineau and McLaughlin 1996, and references therein). At the same time, agriculture is widely cited as one of the largest contributors to the loss of biodiversity on a global scale (McLaughlin and Mineau 1995). By researching the ecology of wildlife-agriculture interactions, farmland preservation and management can seek to minimize conflict, stem wildlife population declines, increase biodiversity, and inform agricultural policy decisions.

Throughout the world, coastal and riparian regions are preferred agricultural areas because of high soil fertility and favourable topography. These regions are also often important habitat for wildlife, especially waterbirds (e.g., Colwell and Dodd 1997). In some coastal areas, loss of inter-tidal foraging habitats due to "reclamation" of land for agriculture may be partially offset by agricultural land use practices that provide waterbird, particularly shorebird, feeding habitat (Colwell and Dodd 1997). Use of coastal agricultural land in addition to intertidal habitats has been widely documented in the UK for a suite of non-breeding shorebird species including Eurasian curlew (*Numenius arquata*) (Townshend 1981), ruddy turnstone (*Arenaria interpres*) (Smart and Gill 2003), golden-plover (*Pluvialis apricaria*) (Fuller and Youngman 1979), Eurasian oystercatcher (*Haematopus ostralegus*) (Heppleston 1971; Goss-Custard and Durell 1983), and common redshank (*Tringa totanus*) (Goss-Custard 1969). Fasola and Ruiz (1996) report winter use of rice fields in the Ebro Delta, Spain, for non-breeding dunlin (*Calidris alpina*), little stint (*Calidris minuta*), common snipe (*Gallinago gallinago*), black-tailed godwit (*Limosa limosa*) and northern lapwing (*Vanellus vanellus*). Rice fields in the Rhône River Delta in southern France also support northern lapwing, little ringed plover (*Charadrius dubius*), common sandpiper (*Actitis hypoleucos*), spotted redshank (*Tringa erythropus*), wood sandpiper (*T. glareola*), common greenshank (*T. nebularia*), green sandpiper (*T. ochropus*), common redshank, common snipe, whimbrel (*Numenius phaeopus*), and ruff (*Philomachrus pugnax*) (Tourenq et al. 2001).

In the United States, non-breeding use of coastal agricultural habitats by roosting and foraging shorebirds has been well documented in the Humboldt Bay region of northwest California (e.g., White and Harris 1966; Colwell and Dodd 1995, 1997; Leeman and Colwell 2005). Species documented to use fields here include black-bellied plover (*Pluvialis squatarola*), killdeer (*Charadrius vociferus*), marbled godwit (*Limosa fedoa*), long-billed dowitcher (*Limnodromus scolopaceus*), and short-billed dowitcher (*L. griseus*) (Colwell and Dodd 1997), long-billed curlew (*Numenius americanus*) (Leeman and Colwell 2005), and common snipe (White and Harris 1966; Colwell and Dodd 1997). In coastal agricultural fields in Virginia, Rottenborn (1996) reported non-breeding use by black-bellied plover, dunlin, killdeer, short-billed dowitcher, western sandpiper (*Calidris mauri*), and common snipe. In Canada, studies have documented non-breeding use of fields by shorebirds only in the Fraser River Delta (FRD) (e.g., Butler 1999; Shepherd and Lank 2004).

Although fields are sometimes used only as roosting (communal resting) areas, foraging in fields is widely reported for many species (e.g., Townshend 1981; Colwell and Dodd 1997). Agricultural fields may be less productive in terms of invertebrate availability than the marine intertidal flats (Fasola and Ruiz 1996), but provide useful feeding habitats (i) at high tide when the intertidal area is not available, (ii) when severe weather increases energy requirements and birds cannot fulfil their required intake through intertidal feeding alone (Goss-Custard and Durell 1983), or (iii) as intertidal resources become depleted over the course of the winter (Lovvorn and Baldwin 1996; Gill et al. 2001). Farmland contributes significantly to the winter diet of shorebirds such as dunlin (Evans Ogden et al. 2004) and supratidal habitats can positively impact body condition and fitness, as demonstrated elsewhere for black-tailed godwit (Gill et al. 2001). For some species such as the Eurasian curlew (*Numenius arquata*) feeding in agricultural fields may in fact be crucial to local over-winter survival (Townshend 1981).

Many species use fields opportunistically during high tides and after winter rains, but a smaller number of species are reported to be "field specialists," so defined because they have been observed using fields even when intertidal flats are available for foraging. Examples of field specialists include common snipe and killdeer (Long and Ralph 2001); northern lapwing and golden-plover (Milsom et al. 1998) and long-billed curlew (*Numenius americanus*) (Leeman and Colwell 2005). Many shorebird species are "field opportunists" (*sensu* Long and Ralph 2001), but pronounced intraspecific differences in feeding behaviour have been documented, and some individuals may act as field specialists. Examples of field opportunist species containing individuals that specialize as field feeders include dunlin (Evans Ogden et al. 2005), and Eurasian curlew (Townshend 1981). Many shorebird populations predominantly or exclusively use interior agricultural landscapes (at least 60 km from the coast) during the non-breeding season (Tucker 1992; Shuford et al. 1998; Sanzenbacher and Haig 2002a, b; Elphick and Oring 2003), rarely or never using coastal resources during this period. Thus, while coastal estuaries tend to support larger concentrations of shorebirds, inland agricultural land should not be overlooked as potentially important shorebird habitat.

Several studies have speculated that the existence of supra-tidal habitats suitable for foraging may contribute significantly to the ability of an estuary to support large non-breeding shorebird populations (Shepherd et al. 2003, and references therein). Models generated by Stillman et al. (2001) in Britain predict that Eurasian oystercatchers in estuaries lacking adjacent agricultural fields have a higher winter mortality rate than estuaries with fields. If these findings can be generalized to other wader species then comparable estuaries with and without adjacent agricultural land should show predictable differences in local wader population sizes. We know of no such comparison for shorebirds, but such a pattern has been demonstrated for waterfowl (Lovvorn and Baldwin 1996). Adjacent farmland may be particularly significant at the northern limits of a species' winter range. Knowledge about the importance and use of supra-tidal habitats such as coastal farmland during the non-breeding season will help to prioritize land for conservation. With rising sea levels, as predicted by global climate change models, coastal agricultural areas will likely become increasingly important as buffer habitats to diminishing intertidal landscapes. In the following sections we discuss particulars of field use in the FRD, a region important for both agriculture and wildlife.

## Fraser Delta Agricultural Land as Wildlife Habitat During the Non-Breeding Season

The Fraser River Delta (49°10′N, 123°05′W), the largest estuary on Canada's Pacific coast, represents an area with high agricultural value as well as globally significant wildlife habitat (Butler and Campbell 1987). Located in southwestern British Columbia, approximately 10 km south of Vancouver, Canada's third largest and one of its fastest growing cities, the FRD is characterized by an extensive intertidal zone (approximately 20 000 ha) consisting of alluvial deposits, sands, silts and clays (Butler and Vermeer 1994). This estuarine habitat is surrounded by a mosaic of urban areas and agricultural land (Lovvorn and Baldwin 1996). The tidal regime in the Delta is semidiurnal, with two high tides and two low tides each lunar day and the interval between successive tides advancing by about 1 h each 24-h day (Butler and Campbell 1987, and references therein). Tides are generally higher in winter than in summer, and winter tides range from 0.04 to 5.0 m. The winter climate in the Delta is one of the mildest in Canada with average daily winter temperatures above freezing (typical range 0 to 14°C), and a mean total annual rainfall of 1055 mm, with generally more than two-thirds of the rain falling between November and March. The moderate climate allows for an extended growing season for farmers, in contrast to most of Canada, where farmland is frozen during winter months.

Prior to the arrival of European settlers, the FRD consisted of salt marsh, seasonal wet meadows, bog, trees and shrubs. Native peoples are reported to have hunted in the area for at least 3000 yr, and burned extensive areas to prevent successional growth of trees in bog areas (Butler and Campbell 1987). The Delta formerly flooded each spring due to the river freshette. In 1894, European settlers began construction of a system of dikes and water channels, enabling drainage of 75% of the flooded section for conversion to agricultural land, preventing further annual flooding and virtually eliminating the transition zone between tidal and terrestrial land that was likely used by shorebirds.

In winter, the FRD supports the highest densities of migratory waterbirds and raptors in Canada (Butler and Campbell 1987). In 2005, the Fraser River estuary was designated as a Western Hemisphere Shorebird Reserve Network (WHSRN) site of hemispheric importance to shorebirds. In an average year, about 135 000 waterbirds (including shorebirds) spend the winter in the Delta, and 300 000 to 750 000 waterfowl, over a million shorebirds, and 60 000 gulls pass through the area on migration.

Recent studies have provided information on what factors contribute to agricultural field use by the most common non-breeding shorebird species [dunlin, black-bellied plover (hereafter "plover"), and killdeer] (Butler 1999; Shepherd 2001; Evans Ogden et al. in press). These studies used a variety of methods to examine agricultural habitat use, during daytime and night-time, at both individual and population levels. Here we review and synthesize the findings of these studies which quantified: (I) the relative contribution of fields to winter diet, (II) the range of prey types shorebirds obtained from farmland feeding, and; (III) the temporal and spatial variation in use of fields as related to environmental factors and farming practices.

## Quantifying Shorebird Use of Farmland in the Fraser Delta

*I. Relative Contribution of Fraser Delta Fields to Winter Diet*. The relative contribution of fields to the winter diet of dunlin captured over four field seasons (1997–2000) in both field and intertidal habitats was investigated using stable isotope analysis (Evans Ogden et al. 2005), a method by which the relative contribution of terrestrial vs. marine prey in the diets of individual animals can be estimated using stable-carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$) isotope ratios (reviewed by Hobson 1999). The study focussed on dunlin since the investigators were not able to capture statistically appropriate numbers of black-bellied plovers or killdeers for comparative analyses (Evans Ogden 2002). The diet of birds was estimated from dunlin blood samples and referenced against isotopic endpoints determined from known estuarine and terrestrial prey items of dunlin. Stable isotope analysis enabled the determination of the proportional contribution to an individual's diet of these two distinct foraging habitats. Field results were interpreted with reference to species-specific turnover rates and tissue fractionation factors of $^{15}N$ and $^{13}C$ in dunlin blood (Evans Ogden et al. 2004). Blood analyses of free-living dunlin provided an indication of diet assimilated over approximately the previous 20 d.

Individual, age, sex, morphological, seasonal, and weather-related differences in the extent to which individuals obtained diet from the two adjacent habitats were examined. Based on both single- ($\delta^{13}C$) and dual-isotope ($\delta^{13}C$, $\delta^{15}N$) mixing models (Phillips and Gregg 2001), the agricultural habitat contributed approximately 38% of dunlin diet averaged over four winters, with the balance from intertidal flats (Evans Ogden et al. 2005). A comparable supra-tidal contribution to diet was also reported for a population of common redshanks wintering in southwestern Spain, where individuals obtained a mean of 23% of their total daily energy requirement during winter (82% during pre-migration) from feeding in salinas (anthropogenic salt pans) (Masero and Pérez-Hurtado 2001).

The extent of agricultural feeding in the Delta varied widely among individuals, ranging from little to very high use (up to $95 \pm 22\%$ of diet) (Fig. 1). Some individuals therefore appeared to be "field specialists", obtaining the majority of their diet from fields. This is consistent with observations of small numbers of dunlin seen feeding in fields even at low tide (Evans Ogden 2002) when the majority of dunlin forage on the large areas of exposed intertidal flat. Such wide intraspecific differences in behavioural strategies have been found in other studies of dunlin (Warnock et al. 1995; Shepherd 2001).

Age was a significant factor influencing origin of diet. Younger birds had a significantly higher terrestrial contribution to diet (43%) than adults (35%). Among the Dunlins in the FRD, 6% of adults and 13% of juveniles were obtaining at least 75% of their diet from terrestrial sources. Given this age difference, an alternative explanation to true field "specialization" for some individuals is that younger birds feed more in fields because they are excluded from intertidal flats by adults via direct or indirect competition. Adult and juvenile dunlin appeared to show a differential response to weather in terms of which habitats were used for foraging. Adult dunlin obtained a greater proportion

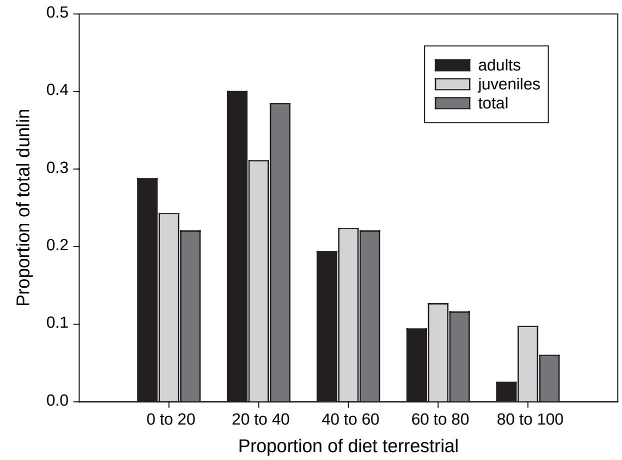


**Fig. 1.** Frequency distribution of percentage of diet derived from fields in the Fraser Delta, 1997–2000, for all Dunlin ($n = 268$) and by age class. Frequencies represent the proportion of individuals from within that age class. From Evans Ogden et al. 2005. Reproduced with permission.

of their diet terrestrially during periods of lower temperatures and high precipitation, whereas no such relationship existed for juveniles. Our data suggest that farmland is a more consistently important habitat for juveniles than for adults, which may use farmland largely as a supplemental feeding site during periods of extreme weather. Observed seasonal variation in field use, peaking in early January, suggests that agricultural habitat is used more during energetically stressful periods.

*II. Range of Prey Types Shorebirds Obtained from Farmland Feeding*. Dunlin, black-bellied plover and killdeer feed predominantly on invertebrates (Paulson 1995; Jackson and Jackson 2000; Evans Ogden 2002). To assess the range of prey types shorebirds obtained from farmland feeding, we opportunistically collected faecal samples (33 samples from plovers, 22 from dunlin) from fields where dunlin and black-bellied plover had recently fed. In addition, we were given a sample of dunlin carcasses collected by wildlife control personnel at the Vancouver International Airport, located along the shore approximately 15 km north of our study area. Additional dunlin carcasses were also collected opportunistically from fields adjacent to hydro wires, where bird collisions sometimes occurred. We examined stomach contents of 50 dunlin obtained from 1994 through 2001. A summary of stomach contents is provided in Table 1, and faecal contents in Tables 2 and 3. It was not possible to determine definitively whether the bivalves and/or gastropod fragments in samples were from terrestrial or marine sources, since both terrestrial and marine snails exist in our study region. However, the majority of insect parts identified were consistent with a terrestrial origin. Although seeds were

**Table 1. Summary of stomach contents from 50 dunlin (*Calidris alpina pacifica*) in the Fraser River Delta. (Evans Ogden, unpublished data)**

| Common name | Phylum | Class | Order | Family | Sub-family | Genus | Species | Number of samples | Number of specimens |
|---|---|---|---|---|---|---|---|---|---|
| Ant | Arthropoda | | Hymenoptera | Formicidae | | | | 1 | 1 |
| Army worm (catepillar) | Arthropoda | | Lepidoptera | Noctuidae | Hadeninae | | | 1 | 1 |
| Clams | Mollusca | Bivalvia | | | | | | 31 | 31+ |
| Flea | Arthropoda | | Siphonaptera | Pulicidae | | | | 1 | 1 |
| Glassy cutworm (catepillar) | Arthropoda | | Lepidoptera | Noctuidae | | Apamea | | 1 | 1 |
| Leatherjacket | Arthropoda | | Diptera | Tipulidae | | Tipula | paludosa | 11 | 288+ |
| Seed | | | | Caryophyllaceae (Chickweed Family), Polygonaceae (Buckwheat Family) Roseaceae (Strawberry/ Raspberry type), Chenopodiaceae or Amaranthaceae Carex lyngbei or obnupta (Sedge) | | | | 37 | 497 |
| Shot (steel/lead pellet from shotgun) | | | | | | | | 1 | 1 |

found in both stomach and faecal samples, most seeds in faeces were whole and apparently undigested, suggesting that they may not be assimilated as food, but rather are eaten incidentally during consumption of soil fauna. Most seeds were from farmland weeds, consistent with a terrestrial rather than intertidal origin.

Amongst the terrestrial prey consumed, leatherjacket larvae (*Tipula paludosa*) were the most numerically dominant. This species, known in its adult form as the European crane fly, is native to Europe and is an introduced pest species in the Pacific Northwest of North America, where it causes considerable damage to grass and forage crops (Mowat and Jess 1986). Although these leatherjacket larvae occurred in only 11 of 50 dunlin stomachs examined, the number of individual larvae per stomach ranged from 1 to at least 97, and four dunlin stomachs each contained more than 48 larvae (Table 1). Remains of Tipulidae larvae were also evident in three dunlin and three black-bellied plover faecal samples. (Note that the stomach and faecal samples were independent data sets and do not represent the same individual birds.) These larvae have been reported to be an important dietary component for shorebirds in Europe, where the crane fly is a native agricultural pest (Zwarts and Blomert 1996). Single samples of two other agricultural pest species, Army worm (subfamily: Hadeninae), and Glassy cutworm (*Apamea* sp.), were found in dunlin stomachs.

Examination of dunlin and plover stomachs and faeces established that shorebirds not only benefit from farmland, but in turn may provide possible benefits to farming in that several pest species are included in their diet. Feeding in large flocks in fields, and being the most numerically dominant wintering shorebird species in the Delta (numbering approximately 30 000), dunlin could potentially impact the abundance of some invertebrate pests, particularly given the large quantities of leatherjacket larvae consumed by certain individuals. Indeed, shorebirds are one of the groups of birds cited as likely to have the most important economic impact in contributing to pest control (Kirk et al. 1996). Elsewhere, Killdeer have been previously reported to be consumers of agricultural pest species (Jackson and Jackson 2000, and references therein).

*III. Temporal, Spatial, Environmental and Farming-related Variation in Field Use*. With diurnal and nocturnal high-tide shorebird surveys, temporal and spatial variation and the impact of environmental factors and specific farming practices on farmland use by resident non-breeding shorebirds and raptors was determined from October to April (1998–2000) (Evans Ogden et al. in press). The study focussed on dunlin, black-bellied plover, and killdeer, as well as their avian predators (raptors), such as northern harriers (*Circus cyaneus*), red-tailed hawks (*Buteo jamaicencis*), and peregrine falcons (*Falco peregrinus*).

*Daily and Seasonal Variation in Field Use and Field Preferences*. Field use by dunlin was predominantly by night, as previously found by Shepherd (2001) using radio-telemetry. In contrast, use of fields by plover, killdeer, and raptors was mainly diurnal. A nocturnal preference for fields by dunlin, the most numerically

**Table 2. Invertebrates identified in faecal contents obtained from dunlin ($n = 22$) in the Fraser River Delta (Evans Ogden, unpublished data)**

| Common name | Phylum | Class | Order | Suborder | Family | Number of samples | Number of specimens |
|---|---|---|---|---|---|---|---|
| Insects | | Insecta | Diptera | | Tipulidae | 3 | 3 |
| | | Insecta | Diptera | | Chironomidae | 1 | 2 |
| | | Insecta | Diptera | | Ceratopogonidae | 1 | 2 |
| | | Insecta | Coleoptera | | | 2 | 2 |
| | | Insecta | Collembola | | Sminthuridae | 2 | 3 |
| Molluscs | Mollusca | Bivalvia/Gastropoda | | | | 2 | 2 |
| Seeds | | | | | | 3 | 3 |



dominant species in the FRD in winter, may reflect the relative availability of prey in fields versus mud flats at different times of day. A non-mutually exclusive hypothesis is that temporal variation in field use reflects the relative vulnerability of the shorebirds to predators in the two habitats at different times (McNeil et al. 1992; Mouritsen 1992, 1994; Hilton et al. 1999). Although owls were sometimes observed in fields at night, raptor use of fields was predominantly diurnal by falcons and hawks (Evans Ogden et al. in press). Assuming the abundance of avian predators is related to actual risk of predation, the risk of predation in FRD fields may be reduced at night.

The landscape context of individual fields strongly influenced shorebird and raptor distributions (Evans Ogden et al. in press). Dunlin and black-bellied plover preferred larger fields located further from shore, whereas killdeer preferred smaller fields, but demonstrated no distance-from-shore relationship. Field use varied seasonally for all species. Dunlin use of fields remained relatively constant throughout the winter during the day, but at night use declined from October through January, and increased thereafter. Black-bellied plover use at night declined from October through January, and subsequently increased until March. During the day, plover use of fields increased marginally from October through January, declined in February, and then increased substantially through March and April. Killdeer use of fields was highly variable during the day, with high use of fields in October, a decline in use thereafter through January, and then increased use from February through April. Seasonal patterns observed for wintering shorebirds in the FRD were more complex than the linear relationships found between pasture use and time of season for killdeer, common snipe, and marbled godwit at a coastal site in California (Colwell and Dodd 1997). In the FRD, increased field use by all shorebird species in early spring, prior to migration, suggests that fields may be particularly important during premigratory fattening. Raptor use of fields remained relatively constant throughout the season at night, but during the day showed a strong seasonal increase from October through January, declining markedly from February through April.

All shorebirds and raptors demonstrated preferences for particular crop types that remained relatively constant over the non-breeding season (Evans Ogden et al. in press). Dunlin and black-bellied plover most frequently used bare or winter cover crop fields. Killdeer most frequently used berry and winter vegetable crop fields. Dunlin and black-bellied plover preferred shorter vegetation fields, while killdeer use of fields had no strong association with vegetation height. Cover type and vegetation height preferences may reflect relationships to food availability and species-specific habitat/food preferences (Butler and Gillings 2004; Devereux et al. 2004; Diurez et al. 2005). Alternatively, cover type or vegetation height may be a proxy for predation risk, since field types avoided by dunlin and plover, such as grassland set-aside fields, were those preferred by raptors.

**Table 3. Invertebrates identified in fecal contents obtained from black-bellied plover ($n = 33$) in the Fraser River Delta (Evans Ogden, unpublished data)**

| Common name | Phylum | Class | Order | Suborder | Family | Number of samples | Number of specimens |
|---|---|---|---|---|---|---|---|
| Shrimp-like crustaceans | Anthropoda | Malacostraca | Amphipoda | | | 1 | 1 |
| Insects | | Insecta | Diptera | | Tipulidae | 3 | 11 |
| | | Insecta | Diptera | Cyclorrhapha | | 1 | 1 |
| | | Insecta | Coleoptera | | | 5 | 5 |
| | | Insecta | Collembola | | Sminthuridae | 3 | 3 |
| | | Insecta | unknown | | | 4 | 6 |
| Polychaete worms | Annelida | Polychaeta | | | | 5 | 5+ |
| Seeds | | | | | | 1 | 2 |

*Farming Practices Effect on Shorebird Winter Field Use*. All three shorebirds showed positive relationships with farming practices designed to improve production: laser levelling, recent manure and fertilizer application (Evans Ogden et al. in press). The influence of fertilizer application on field usage was stronger for killdeer than for dunlin and plover. A propensity for invertebrate-feeding birds to use fields fertilized with nitrogen is consistent with other studies (e.g., Atkinson et al. 2004), likely reflecting a positive relationship between fertilizer use and invertebrate abundance (McNeil 1973), although some studies show this relationship to be inconsistent (Linzell and Madge 1986; Vickery et al 2001). The effect may, therefore, depend on a combination of fertilizer type and dose, crop type and invertebrate species.

Manure was more strongly linked to dunlin field use than was fertilizer (Evans Ogden et al. in press). Killdeer also showed a positive relationship to manure, while plover showed least effect. Manure is likely more beneficial than fertilizer to soil invertebrates (Whalen et al. 1998; Forge et al. 2005a,b), and is known to substantially increase densities of earthworm, nematode, carabid beetle, arthropod and hymenoptera (Evans and Guild 1947; Smith and Rutz 1991; Raworth et al. 2004; Forge et al. 2005a, b). Earthworms were a preferred food for dunlin, as indicated by observations of earthworm "tug-of-war" type interactions between individuals (Evans Ogden, personal observation). Increased use of manured fields could also be attributed to the field types that typically receive manure in our study region, usually short grass and cultivated crops rather than grassland set aside and berries.

Laser levelling was most positively associated with field use by killdeer and weakly associated with dunlin field use at night. Laser levelling improves drainage and reduces wet depressions, particularly during the wet periods and likely makes soil softer and more penetrable by causing water to form a shallow sheet over a large surface area, potentially affecting the activity of soil invertebrates and shorebird foraging success (Kelsey and Hassall 1989).

*Environmental Factors*. The relationships between environmental factors and agricultural land use by shorebirds recently examined in the FRD (Evans Ogden et al. in press) largely support previously reported relationships elsewhere (Table 4). Two environmental factors, day length and precipitation, were a common influence for all three shorebird species. Day length negatively influenced field use by dunlin, but positively influenced field use for black-bellied plover and killdeer. The amount of precipitation over the previous 24 h was positively related to dunlin and negatively related to black-bellied plover and killdeer field use. These species-specific effects may relate to anatomical differences in feeding structures, with plover and killdeer being more visual, surface foragers than dunlin that can use tactile foraging in deeper substrate. While environmental factors cannot be manipulated, understanding their effects on habitat use is useful for making predictions about how climate change may influence future habitat use.

## SHOREBIRD HABITAT ENHANCEMENT STRATEGIES IN THE FRASER DELTA

Little is known about the composition of non-breeding bird communities in the FRD prior to the conversion of the area to agricultural land, but waterfowl were reported to be abundant. Farmland now represents the single largest terrestrial component (about 41%) of the landscape (Butler and Campbell 1987 and references therein). Currently, less than 5% of the FRD has been designated protected habitat for wildlife. A proportion of the FRD was designated as an Agricultural Land Reserve (ALR) in the 1970s to protect the high-quality soils against encroaching urban development (Campbell 2006). This provincial ALR designation precludes use of the land for most non-agricultural purposes. Nevertheless, ALR status does not protect the land from conversion to greenhouses, a development that has seen the transformation of significant tracts of previously open-soil farmland near the shore over the past decade. This trend presents obvious conservation concerns, representing a source of habitat loss and fragmentation for the wildlife that use agricultural habitat. In recent years, the ALR designation has also been successfully challenged, in some cases allowing the encroachment of urban development (Campbell 2006).

Agricultural land makes a substantial contribution to the winter energy budget of dunlin in the FRD (Evans Ogden et al. 2005). The contribution of fields to the diet of black-bellied plover or killdeer could not be broadly quantified, but isotopic data from a small sample of plovers captured and blood sampled ($n = 3$, 1 captured in each of 3 yr), indicated an average $\delta^{13}C$ of $-15.00 \pm 2.19$, and $\delta^{15}N$ of $13.30 \pm 1.10$, translating to approximately 12.5% of diet from fields (Evans Ogden 2002).

In addition to providing habitat that supplements intertidal foraging areas, fields are used as roosting habitat by shorebirds to varying extents throughout the non-breeding season. The availability of these habitats for roosting may contribute to over winter survival by providing a microclimate that is more sheltered than the open intertidal flats. Dunlin are small ($\sim$55 g) shorebirds with high metabolic rates, and farmland may provide an important buffer against starvation during stormy, cold weather. At night, fields may provide a lower predation-risk environment than during the day. For dunlin, the habitat segregation that occurs in this population, with farmland providing a larger proportion of winter diet for juveniles, may have important conservation implications. Isotopic insights into the winter diets of dunlin in the FRD suggest that loss or

**Table 4. Summary of representative published studies on environmental influences on shorebird field/habitat use[z]**

| Factor | Habitat use effect | Shorebird species (common name) | Shorebird species (scientific name) | Source | Supported this study[y] |
|---|---|---|---|---|---|
| Tide | Increased field use with increased tide level | Dunlin | *Calidris alpina pacifica* | Butler (1999), Shepherd (2001) | Yes (DUNL, BBPL, KILL) |
| | | Ruddy turnstone | *Arenaria interpres* | Smart et al. (2003) | |
| Rain | Increased field/pasture use with increased rain | Dunlin | *Calidris alpina pacifica* | Colwell and Dodd (1997) | Yes (DUNL) |
| | | Black-bellied plover | *Pluvialis squatarola* | Colwell and Dodd (1997), Warnock (1995) | No (BBPL, KILL) |
| | | Eurasian curlew | *Numenius arquata* | Townshend (1981) | |
| | | Long billed curlew | *Numenius americanus* | Leeman and Colwell (2005) | |
| | | Willet, marbled godwit | *Catoptrophorus semipalmatus, Limosa fedoa* | Kelly and Cogswell (1979) | |
| Cloud cover | Increased field use with increased cloudiness | | | | Yes (DUNL); No (KILL) |
| | Effected which habitat types used on a coastal estuary | Double banded plover, black-winged stilt, variable oystercatcher, masked lapwing | *Charandrius bicinctus bicinctus, Himantopus himantopus leucocephalus, Haematopus unicolor, Vanellus miles novaehollandiae* | McConkey and Bell (2005) | |
| Moon phase | Increased use of pastures near new moon | Dunlin, black-bellied plover, killdeer | *Calidris alpina pacifica, Pluvialis squatorola, Charadrius vociferus* | Colwell and Dodd (1997) | Yes (BBPL, KILL) |
| | | Northern lapwing | *Vanellus vanellus* | Milsom et al. (1985), Gillings et al. (2005) | |
| | Increased (nocturnal) use of coastal habitat near full moon | Semipalmated and Wilson's plover | *Charadrius semipalmatus,* Charadrius wilsonia | Robert et al. (1989) | |
| | | Eurasian oystercatcher | *Haematopus ostralegus* | Swennen (990) | |
| | | Curlew sandpiper, bar-tailed godwit, common redshank, dunlin, black-bellied plover, red knot | *Calidris ferruginea,* Limosa lapponica, *Tringa totanus, Calidris alpina, Pluvialis squatarola, Calidris canutus* | Zwarts et al. (1990) | |
| Temperature | Decreased temperature increases use of pastures | Eurasian curlew | *Numenius arquata* | Townshend (1981) | Yes (KILL); Yes (DUNL) |
| | Decreased temperature increases use of fields | Ruddy turnstone | *Arenaria interpres* | Smart et al. (2003) | |
| Wind speed | Negatively related to presence on mudflat | Dunlin, dowitchers | *Calidris alpina pacifica, Limnodromus spp.* | Dodd and Colwell (1998) | |
| | Positively related to presence in fields | Black-bellied plover | *Pluvialis squatorola* | Baker (1974) | Yes (DUNL, BBPL) |
| | Wind increased movement to sheltered areas | Double banded plover, black-winged stilt, variable oystercatcher, masked lapwing | *Charandrius bicinctus bicinctus, Himantopus himantopus leucocephalus, Haematopus unicolor, Vanellus miles novaehollandiae* | McConkey and Bell (2005) | Yes (DUNL, BBPL) |
| Time of day (day/night) | Mainly nocturnal use of fields | Dunlin | *Calidris alpina pacifica* | Shepherd (2001) | Yes (DUNL); No (BBPL, KILL) |
| Day length | Field use negatively related | Dunlin | *Calidris alpina pacifica* | | Yes (DUNL, BBPL) No (KILL) |

[z]Note: This table is not intended to provide an exhaustive list of all shorebird studies on farmland, but provides a representative overview.
[y]DUNL = dunlin, BBPL = black-bellied plover, KILL = killdeer.

reduction of agricultural habitat may negatively impact shorebird fitness, with juveniles disproportionately affected (Evans Ogden et al. 2005). Plovers, and particularly killdeer, are also likely to be adversely affected by loss of agricultural habitat. Predictive modelling of the effects of farmland habitat loss (e.g., Sutherland 1996) on wintering shorebird populations would be a valuable next step in testing these preliminary conclusions and further quantifying the value of the farmland.

The dual value of farmland in the FRD to agriculture and wildlife has led to considerable conflict, especially over the impacts of waterfowl. Waterfowl, particularly American wigeon (*Anas americana*), mallards (*A. platyrhnchos*), northern pintail (*A. acuta*), green-winged teal (*A. crecca*) snow geese (*Anser caerulescens*), and trumpeter swans (*Cygnus buccinator*) cause economic losses for farmers as a result of grazing of perennial forage and winter cover crops as well as causing ponding and compaction of soils. Studies suggest that for one herbivorous species in the Delta, the American wigeon, overwinter survival is dependent upon food resources such as clover and grasses from farmland, since the biomass of wigeon's preferred marine food, eelgrass (*Zostera japonica*) is insufficient as an exclusive food source throughout the winter (Lovvorn and Baldwin 1996). A measurable decline in marine invertebrate biomass during the winter (Lovvorn and Baldwin 1996) may be responsible for the abrupt marine to farmland habitat shift observed for dabbling duck species (northern pintail, mallard, and green-winged teal) in late November. A comparison of 64 Puget Sound sites with and without adjacent farmland suggested that sites with adjacent farmland supported larger numbers of ducks than sites without farmland (Lovvorn and Baldwin 1996).

While waterfowl grazing causes extensive losses for farmers, some bird species suffer directly from the impacts of farming. Agricultural pesticide applications have had considerable detrimental effects on raptors that winter in the FRD, and investigation of pesticide poisoning of raptors has resulted in the voluntary withdrawal of several pesticides from the British Columbia marketplace (Elliott et al. 1996; Elliott et al. 1997). This in turn has resulted in some farmers perceiving that sharing their farmland with wildlife limits their choices of farming practices (Delta farmers, personal communication).

The need to address such conflicts and bridge the gap between farmers and wildlife conservation advocates in the FRD region led to the formation of the Delta Farmland and Wildlife Trust (DFWT), a non-governmental organization that promotes the preservation of farmland through sustainable farming and land stewardship programs. Land stewardship programs are an essential conservation strategy, since much of the FRD's farmland is privately owned, and conservation by land acquisition is prohibitively expensive. DFWT programs have been developed to maintain and enhance agricultural habitat for waterfowl, raptors, and passerines, while simultaneously providing benefits to farmers. Waterfowl benefit from a cover crop program (''Greenfields''), established in 1990. This program provides subsidies to farmers to plant crops of cereal grains, ryegrass (*Lolium* spp.) or clover (*Trifolium* spp.) during autumn that grow over the winter or die off and become mulch. These crops stabilize the soil structure by maintaining soil surface infiltration and providing protection from the effects of heavy rains. Cover crops also provide food for wintering waterfowl and provide inputs of organic matter when ploughed under in spring. A grassland set-aside program, whereby agricultural fields are planted with a mix of tall grass species and left to grow unharvested until July, for several years, has been implemented to augment the input of soil organic matter, improve the structure of degraded soils, and provide foraging habitat for raptors. A hedgerow program is also in place to increase the availability of this habitat to passerines.

Waterfowl are often maligned by the farming community because of the economic costs of the crop damage they inflict. Incidences of raptor deaths due to the effects of chemical pesticides were also detrimental to farmers in that they resulted in product removals and reduced options for pest control. In contrast, shorebirds do not damage crops and are even potentially beneficial for pest control because of their invertebrate diet, suggesting that wildlife and agriculture can be mutually beneficial. Shorebirds, and dunlin in particular, may be a useful ''flagship species'' for promoting the joint benefits of sustainable agriculture and wildlife conservation. A strategy to maintain and improve the value of farmland habitat to shorebirds has been lacking from FRD habitat stewardship programs thus far. This may be due in part to the perception by local farmers that the impacts of shorebirds on farmland are benign, with stewardship programs traditionally aimed at species that have detrimental impacts.

Providing a mosaic of field types, including bare fields, perennial grass fields, grazed pasture, and winter vegetable fields (e.g., cabbage) may be important in maintaining a range of foraging opportunities and roosting sites for dunlin, black-bellied plover, and killdeer. A preference by dunlin and plover for larger fields further from shore suggests that minimizing terrestrial habitat fragmentation and preventing barriers between near-shore and more inland sites will benefit shorebirds wintering in the FRD. Vegetation height is a feature that can be manipulated on some fields and we propose, as did Milsom et al. (1998), that fall mowing of grass fields is a feasible management option for increasing the attractiveness of farmland to wintering shorebirds. Mowing itself (independent of sward height) has been demonstrated to improve the efficiency at which invertebrate-feeding birds can extract prey from soil, at least over the short term (Devereux et al. 2006).

Our review supports previous recommendations that fertilized fields be included in the mosaic of agricultural fields available to shorebirds (Shepherd and Lank 2004). Manure and fertilizer spreading are management strategies that would potentially benefit both shorebirds and farmers by increasing soil fertility and the abundance of beneficial invertebrates. The effects of specific drainage mechanisms on non-breeding waders are poorly understood, and testing the impact of laser levelling on soil penetrability and invertebrate distribution and abundance during winter would be valuable in determining whether laser levelling indeed represents a viable habitat enhancement strategy for shorebirds within coastal farmland. Other studies indicate that variability in water depth increases waterbird species diversity (Colwell and Taft 2000). Thus, the apparent benefit of uniformly shallow water that laser levelling creates for numerically dominant species such as dunlin must be carefully weighed against the desire for increasing biodiversity. An additional research need is to examine the potential toxicological impacts of farmland feeding on shorebirds. While it appears that shorebirds are benefiting from farmland as a source of invertebrate food, this benefit could be offset if the toxicological load of prey were high.

Some of the DFWT enhancement programs are synergistic and benefit more than one suite of birds, such as the cover crop program, in which intensive grazing of cover crops by waterfowl creates areas of short vegetation or bare patches preferred by shorebirds. In other cases, the needs of one group of species conflicts with another. For example, grassland set-aside fields, created to provide small mammal and raptor habitat, are avoided by shorebirds. In recent years, a grassland set-aside program added 253 ha (as of winter 2001–2002) of tall grass habitat to the existing tall grass fields already available in the FRD. This compares with 1367 ha of cover crop fields that benefit waterfowl (with FRD's total agricultural habitat estimated at 10 000 ha) (M. Merkens, personal communication).

While raptors are an important component of the over-wintering bird community, they represent the highest trophic level. If habitat enhancement increases their numbers even by a relatively small amount it may have a disproportionately large effect on species occupying lower trophic levels. As predators, raptors exert both lethal (i.e., mortality) and non-lethal (e.g., behavioural) effects on their prey. A study of dunlin in California determined that during one winter (1972–1973), one individual merlin (*Falco columbarius*) was responsible for approximately half of the observed predation events on dunlins by all raptors (Page and Whitacre 1975). Myers (1984) reports that in Bodega Bay, California, a resident merlin is present in some years, but not others. In years when a merlin is present, sanderling (*Calidris alba*) are non-territorial, flock sizes triple, and individuals have home ranges double the size of those in non-Merlin years.

Similar behavioural changes were noted for common redshank and ruddy turnstone in Scotland with respect to the daily presence or absence of sparrowhawks (*Accipiter nisus*) (Whitfield 1987). Increased disturbance by raptors may reduce time spent foraging, with implications for shorebird energy budgets (e.g., Urfi et al. 1996). Additionally, raptors are known to cause higher mortality for juvenile wintering shorebirds than for adults [e.g., dunlin: Kus et al. 1984; dunlin, common redshank, ruddy turnstone, common ringed plover (*Chariadrius hiaticula*): Whitfield 1985]. In the FRD, behavioural changes and an overall decline in mass for wintering dunlin have also been observed over a period of decades, apparently in response to rebounding peregrine falcon populations following a ban on DDT use in many countries (R. C. Ydenberg unpublished data).

While the behavioural impacts of raptors on wintering shorebirds are widely known in the FRD and elsewhere, relationships between raptor numbers, habitat management, and the population dynamics of shorebirds are less clear. In adding shorebird agricultural habitat enhancement to the existing multi-species program in the FRD, population monitoring and predictive modelling will be required to ensure a balance of treatments appropriate to the population sizes of over-wintering waterfowl, shorebirds, and raptors, as well as their conservation status. Given its close proximity to the rapidly growing city of Vancouver, the FRD faces increasing development pressure on its terrestrial landscape. Loss of farmland to greenhouse agriculture expansion and urban encroachment, specifically airport and harbour expansion, may adversely affect the fitness of non-breeding shorebirds. The FRD is, in fact, the northernmost site at which significant numbers (>10 000) of dunlin overwinter (Butler and Campbell 1987), and adjacent farmland may be contributing substantially to the estuary's ability to support such a large population.

Factors that reduce the availability or profitability of intertidal foraging areas for shorebirds, such as intensive invertebrate harvesting (Piersma et al. 2001), the spread of exotic vegetation such as *Spartina* spp. (Goss-Custard and Moser 1988), and rising sea levels (Stillman et al. 2000) may increase the future importance of fields and other supratidal lands as buffer habitats (Masero 2003). In the FRD, increased use of fields by dunlin during periods of rain and by dunlin and plover during high winds (Evans Ogden et al. in press), suggests that fields may become increasingly important habitat if the frequency of severe weather increases, another predicted effect of climate change. Our review suggests that proactive protection of coastal agricultural habitats will contribute to the long-term stability of non-breeding shorebird populations. Ideally, effective habitat conservation strategies for shorebirds will protect a mosaic of coastal farmland, managed to enhance foraging opportunities but balanced with the habitat requirements of other wintering wildlife species.

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