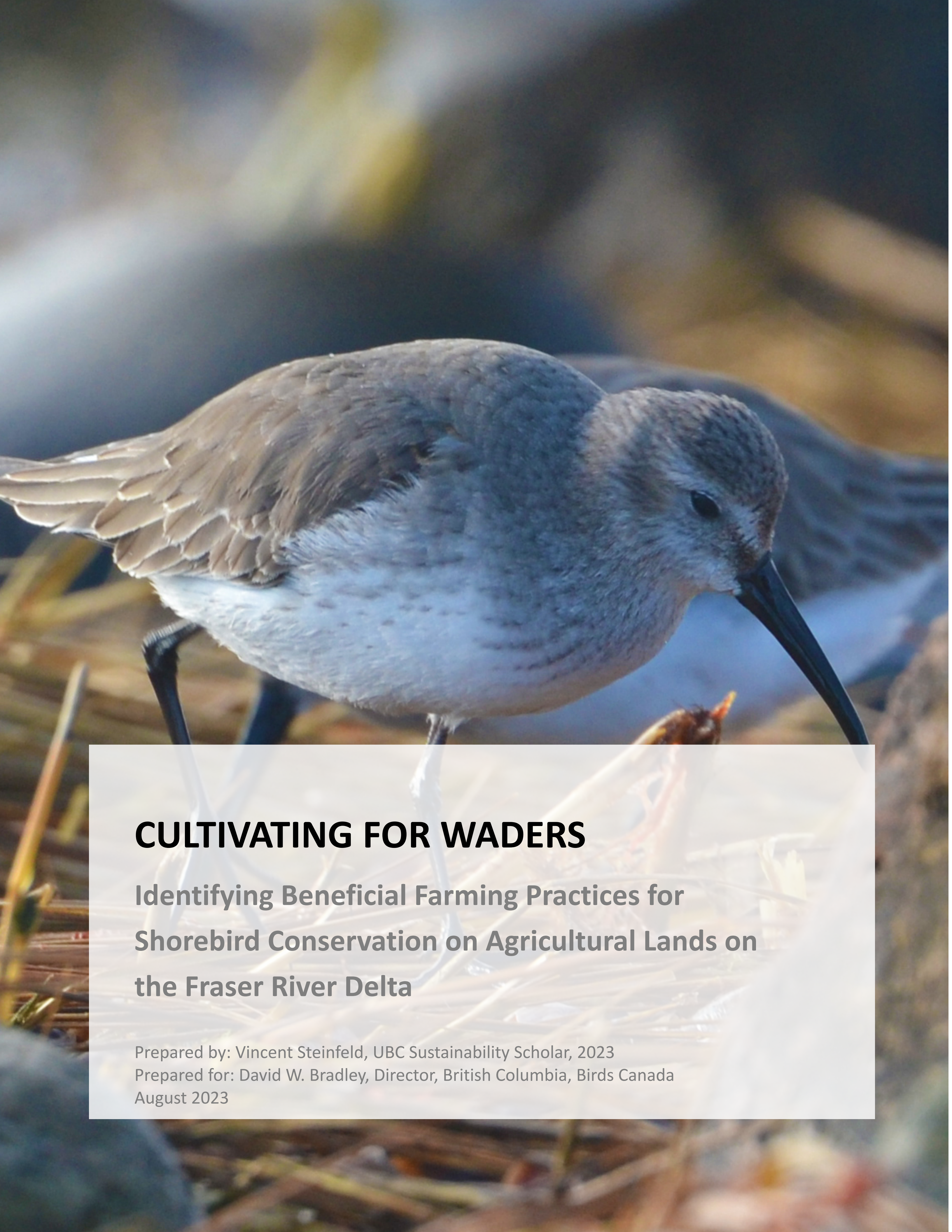

CULTIVATING FOR WADERS

Identifying Beneficial Farming Practices for Shorebird Conservation on Agricultural Lands on the Fraser River Delta

Prepared by: Vincent Steinfeld, UBC Sustainability Scholar, 2023
Prepared for: David W. Bradley, Director, British Columbia, Birds Canada
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Cover: Dunlin. Photo by Andrew Cannizzaro

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Lesser Yellowlegs. Photo by Wolfgang Wander

Executive Summary

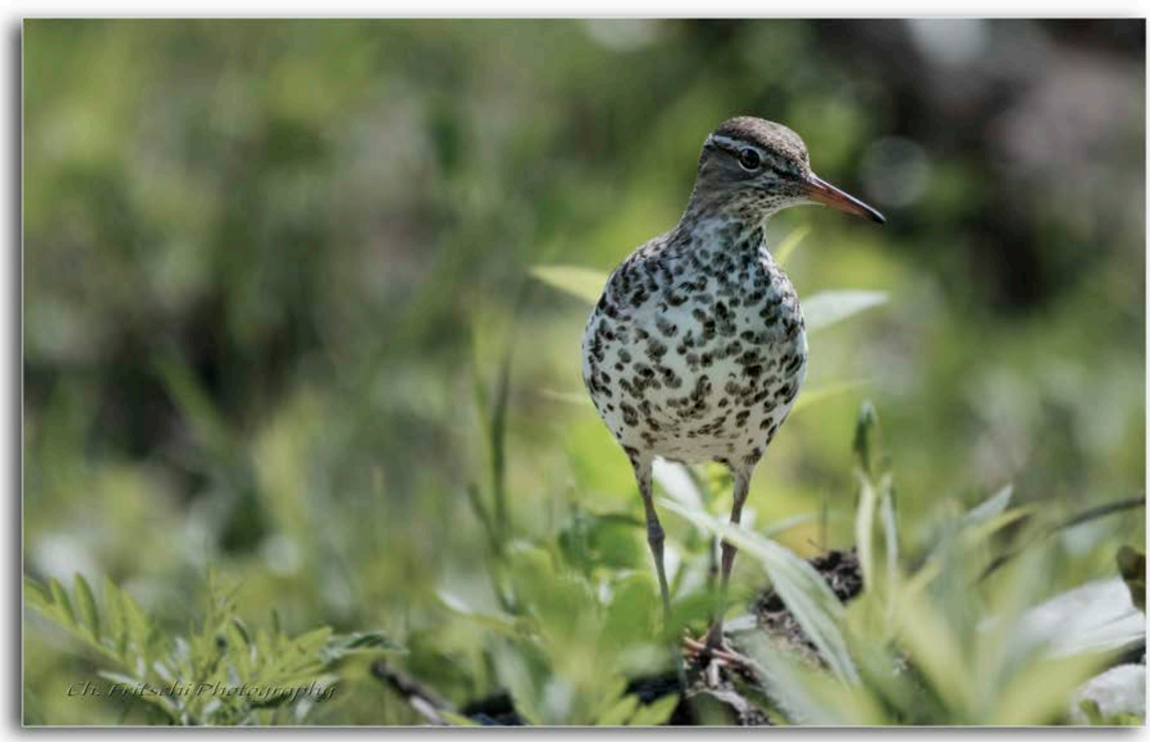
The Fraser River Delta (FRD) is a globally significant habitat for birds—during spring and fall migration, hundreds of thousands of birds pass through the Delta, where they stop to rest and feed in its rich environment. Annually, about "1.7 million waterbirds and raptors" make use of the FRD (Butler et al., 2021, p. 1). A great many of these are shorebirds, such as the Western Sandpiper, Dunlin, and Black-bellied Plover, some of which pass through the FRD as they migrate, while others spend winter on the intertidal flats and adjacent floodplain (Butler et al., 2021, p. 11).

The FRD is also home to some of Canada's most productive agricultural land (Anderson, 2010, p. 224). Metro Vancouver generates $954 million in gross farm receipts while comprising only 1.5% of the province's agricultural lands (Metro Vancouver, 2016). The relationship between agriculture and migratory birds on the FRD is very strong: of the 263 bird species that visit the delta, 189 are known to visit farmlands (Butler et al., 2021, pp. 1, 9). Butler et al. (2021) write that "[t]he agricultural lands in the Fraser River Delta subsidize nearly three-quarters of a million waterfowl, shorebirds, and birds of prey" (p. 12), which means that farming practices are sure to impact a significant number of migratory and resident birds. Ongoing efforts by organizations like the Delta Farmland & Wildlife Trust support and encourage farming practices that benefit many kinds of birds and other wildlife (Butler et al., 2021, p. 18-20). As the FRD continues to change under a range of anthropogenic pressures, the degree to which agricultural lands provide an hospitable or an inhospitable environment for wildlife, including shorebirds, will be of increasing importance.

This report examines the relationship between farming practices and shorebird conservation on the FRD and globally. It includes a description of shorebird ecology, an outline of the state of shorebird habitat and agricultural land use on the FRD, and an analysis of current research on shorebird conservation, much of which involves agricultural practices. It concludes with an array of research-based recommendations for farming practices to improve habitat for resident and migratory shorebirds on the Fraser River Delta.

These recommendations involve:

- Crop selection
- Supporting terrestrial invertebrates
- Mowing
- Timing of practices
- Postharvest field treatments
- Mosaic design
- Laser-levelling
- Roosting site preservation
- Avian predator threat mitigation
- Disturbance mitigation



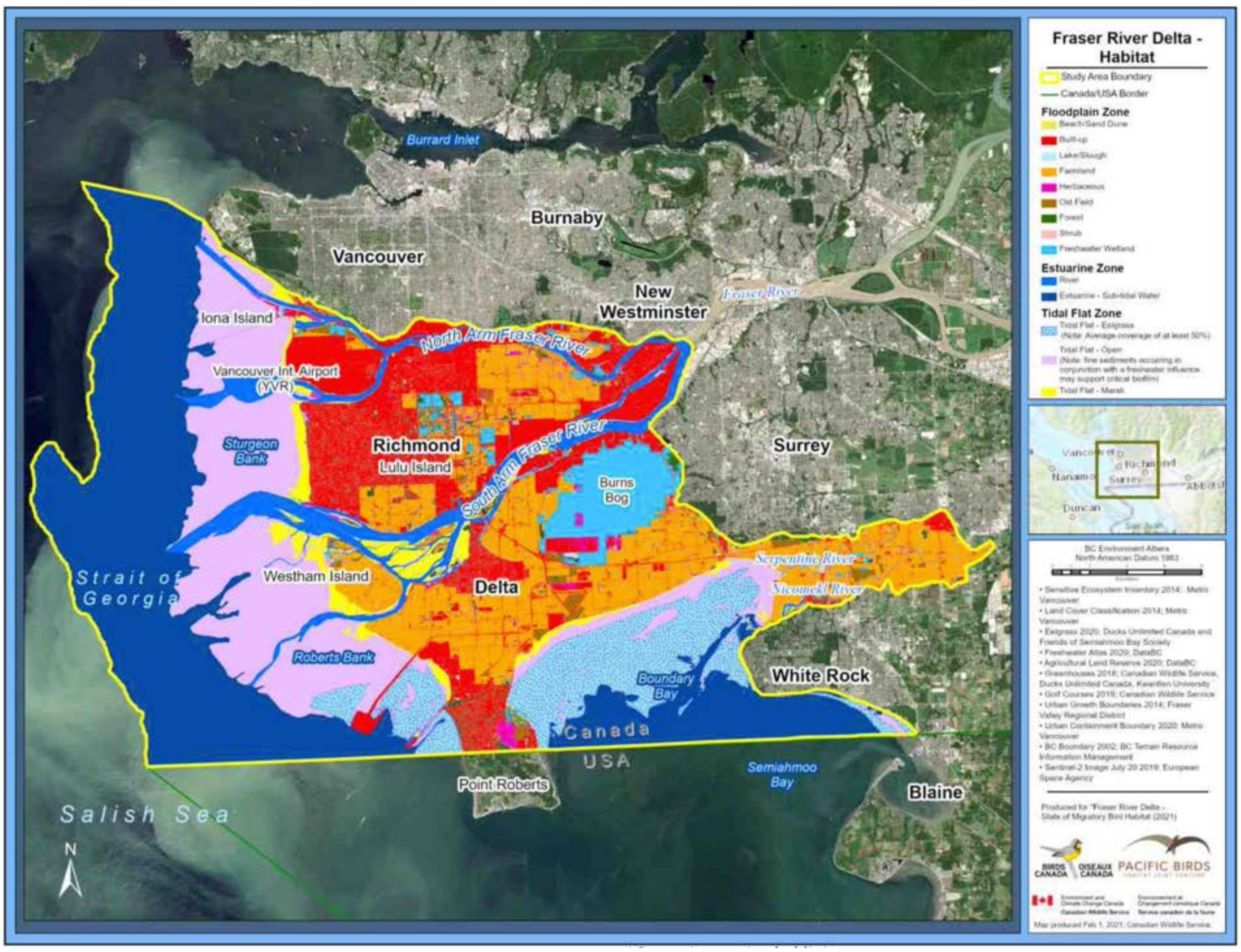
Spotted Sandpiper. Photo by Christina Fritschi.

The farming and associated land use practices recommended here will likely become more important as factors impacting intertidal shorebird feeding areas—sea-level rise, development and infrastructure projects (such as Roberts Bank Terminal 2), and increasing ecotourism and coastal recreation, to name a few—will increase shorebirds' reliance on farmlands as roosting areas and terrestrial food sources when they pass through or reside on the FRD.

While the recommendations are based on available research, opportunities for future research that could contribute to greater success of agriculture-based shorebird conservation are identified when possible. This report also identifies mechanisms for the implementation of these practices, which in general utilize existing resources to guide and support conservation activities by farmers on the Delta.

Introduction

The geographic focus of this report is a relatively small area—agricultural lands used by shorebirds on the Fraser River Delta—but this small area is of outsized significance due to its centrality on what is known to birders and ornithologists as the Pacific Americas Flyway. The Flyway, which stretches along the West Coast of the Americas from the southern tip of South America north to Alaska, is one of three major migratory routes used by hundreds of bird species and millions of individual birds to traverse North and South America twice each year (Iglecia & Winn, 2021, p. 13; Butler et. al, 2021, p. 1). The FRD not only supports birds that pass through it on biannual journeys along the Flyway, but also provides breeding and wintering habitat for many species. As noted in the *Pacific Americas Shorebird Conservation Strategy* (Senner et al., 2017), "[s]horebirds are highly site faithful across their annual cycles and often depend on a few, discrete stopover, breeding and wintering sites" (p. 6). The FRD, now classified as a Key Biodiversity Area, is one of the most important such sites along the Flyway and is considered to be of hemispheric significance (KBA Canada, 2022; Senner et al., 2017, p. 17, 64).



The Fraser River Delta. Map from Butler et al. (2021).

The following sections will outline the history and significance of the FRD as it pertains to shorebirds, describe shorebird ecology and threats to their future persistence, describe agriculture in the FRD and partnerships between farmers and conservationists, and review research that examines the relationship between shorebirds and agriculture both globally and in the FRD/southern coastal British Columbia.

Following this background information are recommendations of farming practices to benefit shorebirds in the FRD in the form of a table and detailed descriptions of the practices. The table offers an overview of the practices and describes key species and benefits as well as considerations for and challenges to implementation. The recommendations entail a few approaches and together indicate the various potentials for the role of agriculture in shorebird conservation on the FRD. Some practices—such as laser leveling, manure application, and lime application—are typical farming practices with known carryover benefits to shorebirds and so can benefits farmers and shorebirds alike. Others—such as minimizing habitat fragmentation, creating landscape mosaics, and mitigating disturbance—are outside of standard farming practices and involve more ambitious planning and effort on the part of conservationists. The latter will also rely more heavily on the capacities and cooperation of farmers in the region. Additionally, some approaches demand consideration of potential impacts on other wildlife, which, while indicated here when apparent, is outside the scope of this report.

Finally, Appendix A features a table that predicts the approximate beneficial impact that each practice may or may not have on each species of shorebird who is known to visit the FRD.

History and Significance of the Fraser River Delta

First Nations Before Colonization to the Present

Relative to the human history of the FRD, the intensive industrial and urban development brought by colonization and European settlement is a quite recent change. For thousands of years prior to European settlement, which began to advance rapidly in the 1860s, Indigenous peoples had a relationship to the FRD quite different from that seen today. Butler et al. report that Indigenous people of the Delta managed the peat bog landscape for blueberries with intentional burning, keeping part of the delta floodplain clear of forests (which almost certainly favoured wintering shorebirds), and that the floodplain was home to several settlements (Butler et al., 1987, pp. 13-17; Butler et al., 2021, p. 6). Butler et al. (2021) also write that little is known about birds of the FRD prior to European settlement, but early reports suggest abundance (pp. 6-7). A comprehensive history of how Indigenous peoples have managed the landscape of the FRD in the longer term, as well as First Nations' (including the Stó꞉lō, xʷməθkʷəy̓əm, Tsawassen, Semiahmoo, Kwantlen, Kwikwetlem, and Katzie Nations) continued relationship with the FRD today, while essential to ecological efforts, is outside the scope of the present report.

Colonization and Industrialization

In the early 1900s, just decades after Europeans began farming the area, "the land was quickly cleared, cultivated and eventually urbanized" (Butler et al., 1987, p. 14). The ecological impacts of the dramatic landscape alterations brought by settler colonial immigrants since then are difficult to fully catalog or quantify, but significant habitat loss has resulted from the intensive urbanization of what is now Metro Vancouver. Europeans colonized and settled the Lower Mainland in just the past few hundred years, while the FRD has an ecological and human history that stretches back for thousands (Butler et al., 2021, p. 6). The industrialization of the Delta has been nothing short of catastrophic for the region's prior inhabitants, including many bird species, marine and terrestrial mammals, and countless others. Given the perilous situation that many beings who rely on the FRD face and the increasing public will to not only acknowledge these harms but to begin to mitigate them, the adaptation of farming practices to support migratory birds could be a modest step toward sustaining the biodiversity of the region.

Ecological Significance and Conservation of the Fraser River Delta

Today the Fraser River Delta is widely recognized as a significant ecological area, achieving Key Biodiversity Area (KBA) designation in 2022, in addition to its several other conservation designations (KBA Canada, 2022). Butler et al. (2021) note that 332 km^2 had received legal protections, amounting to about 38% of the designated conservation areas at the time (p. 17). An area receives KBA status by meeting an array of scientific criteria set by the International Union for the Conservation of Nature. While KBA status does not confer specific legal protections, the stringent criteria and systematic designation of sites means that designation is an indicator that "can be used to advance or support diverse conservation goals" (KBA Canada, 2022).

Orca. Photo by Thomas Hubauer

The high populations of shorebirds on the FRD throughout the year are just one aspect of the ecological significance and diversity of the area. Many species of birds and other wildlife—including ducks and geese, songbirds, and raptors, as well as salmon, orca, land mammals, reptiles, and amphibians (not to mention other taxa), many of which are rare, endangered, threatened, or of special concern—are all part of the Delta's rich ecology. These species face many of the same risks associated with habitat loss, climate change, and introduced species. All stand to gain from additional legal protections, conservation measures, and a general shift toward more ecologically-minded practices.

Shorebird Ecology on the Fraser River Delta

The birds who use the FRD can be divided into four categories: migrants, migrant non-breeders, residents, and migrant breeders. Each category reflects the approximate times of year and length of stay of a species on the FRD (Butler et al., 2021, p. 9). Most shorebirds who visit the FRD are either migrant non-breeders, who spend winter here between breeding seasons, or else migrants, who pass through the region twice per year between breeding and nonbreeding locations (pp. 9, 11). This means that some farming practices that benefit shorebirds in winter, such as establishing and/or maintaining low-sward cover crops, will benefit the large populations of non-breeding migrant species, such as Dunlin and Black-bellied Plover. Others, such as measures that support terrestrial invertebrates, will benefit birds who feed terrestrially throughout the year, such as Killdeer and Long-billed Curlew. See Appendix A for more information on which practices are likely to benefit which particular species.

Landscape Use

There are three primary landscape types in the FRD: estuarine, floodplain, and tidal flats (Butler et al. 2021, p. 11). Shorebirds spend much of their time on the tidal flats where they roost and feed. During high tides shorebirds roost or feed on land unless under pressure from disturbance or predators, in which case some species wait out high tide on the wing (Dekker, 1998, p. 694). Terrestrial roosting and feeding sites are crucial to shorebird survival, and their significance for feeding has only recently been recognized. Butler (1992) was first to find evidence of “Dunlins and Black-bellied Plovers forag[ing] regularly in farmlands” (p. 83), while Shepherd and Lank (2004) later found unexpectedly high numbers of shorebirds foraging farmlands at night (p. 61). Evans-Ogden et al. (2006) found that Dunlin derive a significant portion of their diet from terrestrial invertebrates. Others have correlated roosting and feeding site selection to a combination of proximity, food availability, and the presence of avian predators (Dias et al., 2006; Pomeroy et al. 2008). Because of the significance of the FRD as a key site along the Pacific Flyway, well-placed and desirable roosting sites and rich, nearby, and abundant floodplain foraging habitat can play a key role in ensuring the success of shorebird species. The farming practices proposed in this report seek to achieve these aims, and the descriptions below further elaborate research findings that support the proposals.

Dynamics: Vegetation, Disturbance, Predators, Distance

With some exceptions, the way that shorebirds use landscapes follows a few key principles. These general principles can assist farmers and conservationists to identify sites of greater or lesser importance as shorebird habitat. Under ideal circumstances, shorebirds stay close (within 0.5-2 km) to tidal flats (Milsom et al., 1998; Evans-Ogden, 2002, p. 111). They avoid frequent or distant movement, avoid areas with any significant vegetation (grass longer than 10 cm as well as all shrubs and trees), avoid anthropogenic disturbance (noise, traffic, recreationists), and attempt to keep their distance from avian predators (though some birds will risk predation for favorable feeding habitat) (Iglecia & Winn, 2021; Milsom et al., 1998; Pomeroy et al., 2008; Rehfisch et al., 1996). Some shorebirds use agricultural lands to feed and roost; some species feed at these terrestrial sites at night, others tend to do so during diurnal high tide (Shepherd & Lank, 2004; Evans-Ogden et al., 2008). Some species roost on agricultural lands during high tide, so roosting areas need to be near marine foraging areas and free from vegetation, and, as Dias et al. (2006) show, feeding areas need to be close to roosting sites (p. 448). When suitable roosting sites are unavailable, or when birds are disturbed while roosting, they will often expend energy resources by moving and/or waiting out high tide on the wing in flocks (Dekker, 1998). This behaviour is energy intensive for the birds, which can be especially detrimental to those who use the FRD to build up energy reserves during long migratory flights (Rehfisch et al. 1996; Farmer et al. 1997, p. 706). As Rehfisch et al. (1996) write, "[i]t might be considered strange that waders able to travel such long distances" while migrating "move so little between roosts, but waders may have a very tight energy budget in winter" (p. 685).

Given these behavioural characteristics, Milsom et al. (1998) summarize general principles for optimum terrestrial shorebird sites well:

> In general, larger fields will be used more frequently, and by greater numbers of birds, than smaller ones, provided the sward is suitable [by "suitable," authors mean <10 cm]. Fields enclosed by tall hedges, trees or other barriers should be avoided when more open alternatives are available… The attractiveness of fields to waders will be enhanced if they are situated away from sources of frequent human disturbance, particularly roads… fields located within 0.5 km of the sea will tend to be more attractive to waders than those located further away. (p. 128)

Threats to Shorebird Persistence on the FRD

One of the primary threats to shorebirds on the FRD is habitat loss (Iglecia & Winn, 2021, p. 34; Butler et al., 2021, pp. 19-20). The preservation of mudflats is of primary importance (and is a relatively new field of research), but as sea level rise threatens to limit access to these flats (Galbraith et al., 2014), tidal flat adjacent agricultural fields are likely to become more important for shorebirds. Roosting and feeding sites can be provided by these fields, and an awareness of shorebird ecology can facilitate the effective siting and maintenance of suitable agricultural habitat. As described above, shorebirds need large open areas near the shoreline with little to no vegetation.

Other threats to shorebird habitat include increasing ecotourism and recreation, off-leash dogs, urban pollution/runoff, fishing industry impacts, and introduced species (KBA Canada, 2022). The "proposed port expansion on Roberts Bank" is also a threat to shorebirds, as the impacts of the project "could impact the quality and quantity of biofilm," which is an essential food found on the intertidal mudflats for migrating Western Sandpipers (Butler et al., 2021, p. 30).

While few of these threats pertain directly to agriculture, farmers can help to mediate their impacts by providing suitable high tide roosting and feeding areas. Because of their proximity to the mudflats, agricultural lands on the FRD are uniquely situated to aid shorebirds as habitat loss and other pressures mount.

Key Shorebird Species of the Fraser River Delta

The table on the next page features some of the key shorebird species of the Fraser River Delta. Whereas this list features a few prominent species, see Appendix A for a comprehensive list of those observed on the FRD. Information on this table is from Butler et al. (1987), Butler et al. (2021), Weber et al. (2018), and COSEWIC (2022).

Table 1: Featured Shorebirds of the FRD

SPECIES	ATTRIBUTES
Pacifica Dunlin	*Migrant non-breeder*; occurs in large numbers each winter from mid-October until June; Dunlin rely heavily on agricultural fields.
Black-bellied Plover	*Migrant non-breeder*; Abundant from August until May; these birds rely on agricultural lands to roost and feed.
Killdeer	*Common* year-round, though some pass through on migration. Killdeer rely on agricultural.
Long-billed Dowitcher	*Migrant non-breeder*; Common from August-November. Not much is known about this bird's ecology on the FRD, though it frequents ponds and tidal flats.
Western Sandpiper	*Migrants*; These birds are very abundant in spring and fall, with impressively large numbers passing through on migration. Western Sandpipers feed on inter-tidal mudflats and probably roost on adjacent agricultural lands during high tide.
Sanderling	*Migrant Non-breeder*; Very common from about August until May. Not much is known about Sanderling ecology on the FRD.
Lesser Yellowlegs	*Fairly Common, threatened*. Seen in freshwater, intertidal areas, and in agricultural fields (when wet) in August and September, but sightings are possible year-round.
Long-billed Curlew	*Rare*, *special concern*. Seen in mid-April until mid-May and mid-August until mid-September during migration on tidal flats or agricultural lands of the FRD.
Red Knot	*Rare*, *threatened*. This species may be seen on Boundary Bay or Brunswick Point in May, August, or September. Very little is known about its ecology on the FRD.
Wilson's Snipe	*Common* in wetland areas and may be seen on agricultural lands year-round (though more numerous from October to March).

Agriculture on the Fraser River Delta

Agriculture has played a major role in the development on the FRD since the late 19th century (Butler et al., 1987, pp. 13-14). Today, much of the floodplain land on the FRD comprises the cities of Richmond, Delta, and Surrey, major portions of which are classified as Agricultural Land Reserve (ALR). This provincial designation, originating in the 1970s, established “a de facto urban growth boundary” that regulates and restricts development on some of the province’s richest agricultural lands (Anderson, 2010, p. 226). Major crops in the area include cranberries and blueberries, greenhouse produce, vegetables, grains, livestock, and poultry (Metro Vancouver, 2016, p. 29).

A few trends and developments that have taken place over the past few decades inform the proposed farming practices in this report. First, farmers on the FRD today face increasing economic pressures, not least of which are costs associated with rising land prices across Metro Vancouver. The City of Richmond identified several threats to farmers, including, “pressure to urbanize the ALR; pressure to subdivide land within the ALR; rural/urban conflicts; high land values; economics of farming; servicing and infrastructure limitations; drainage” (City of Richmond, 2022, p. 3). These pressures have pushed farmers to turn to more profitable crops, including blueberries and large greenhouses, which result in habitat losses for shorebirds and other wildlife (Anderson, 2010, p. 225; Evans-Ogden et al., 2008, p. 253). An awareness of these pressures should inform how conservationists take up the recommendations in this report.

Second, the establishment in the early 1990s of the Delta Farmland & Wildlife Trust (DFWT) bridged a widening gap between farmers and conservationists on the FRD (Anderson, 2010, p. 223). DFWT uses funds from government and other sources to subsidize and cost share a variety of conservation activities with farmers, mostly in Delta (Delta Farmland, n.d.). The group helps to fund cover crops, grassland set-asides (GSAs), laser-leveling, hedgerows and grass margins, liming, and more (Delta Farmland, n.d.). Over the years, DFWT has forged and strengthened relationships between farmers and conservationists, supported practices that improve habitat and soil, and increased the scope and extent of their offerings to now include ongoing research into the impacts of their own initiatives (Anderson, 2010, p. 223; Delta Farmland, n.d.; see Hawey, 2022 and Kulikowski, 2023).

Existing Research on Shorebirds, Shorebird Conservation, and Agriculture on the FRD and Elsewhere

Much research has been done on the relationship between shorebirds and agriculture, and much of the research informing this report was carried out specifically in the Fraser River Delta. Shorebirds and largescale agricultural lands have a strong relationship throughout North America and the world. While each locale is unique, researchers across the globe have identified elements of farming that can benefit or harm shorebirds.

International Shorebird Research and Conservation

International research on shorebirds and agriculture often focuses on agricultural sites at major points on Flyways and explores how farming methods can support the large assemblages of waterbirds that visit them. In the Central Valley of California (which, like the FRD, is on the Pacific Flyway), for example, research suggests that postharvest treatments such as the flooding and incorporation of crop residue strongly favours shorebirds and waterfowl alike and that strategically planning such practices can provide significant benefits to waterbird populations (Elphink & Oring, 1998; Fleskes et al., 2012; Golet et al., 2018; Shuford et al. 2015). Other research finds a strong correlation between sward height (the length of grass in pastures, grain crops, and fields) and shorebird use, supporting recommendations for mowing or grazing grasses or leaving fields bare to support shorebirds (Evans-Ogden et al., 2008, p. 257; Milsom et al., 1998; Colwell & Dodd, 1997). Other studies find that resting shorebirds, whether migrating or wintering, tend to minimize movements, probably to conserve energy, unless disturbed by human activity, avian predators, or other sources (Butler et al., 2002, p. 488-489; Dekker, 1998). Researchers have also examined methods by which farmers and conservationists can work together to achieve otherwise difficult ends. Golet et al. (2018) present a useful example of encouraging farmer participation in organized conservation programs through the use of a “reverse auction” process that, while requiring funding to carry out, facilitates time-sensitive and complex landscape-wide flooding programs involving multiple farmers (p. 413).

Two comprehensive reports of international scope merit attention here: the *Pacific Americas Shorebird Conservation Strategy* (Senner et al., 2017) and *A Shorebird Management Manual* (Iglecia & Winn, 2021). Both underline the importance of Flyway-wide, international coordination of research and conservation programs. These reports provide substantive information about shorebird ecology on both regional and local scales, including migration patterns and trends, major threats, and examples of successful research and conservation initiatives. Senner et al. (2017) highlight partnerships between farmers and environmental groups in California’s Central

Valley that provide a model for industry-supported conservation programs (p. 32). Senner et al. (2017) also offer a range of case studies as well as detailed ecological information for shorebirds found across the Americas. Together, these studies provide a concise and up-to-date view of largescale shorebird conservation efforts, organization, and coordination as well as results from the latest research in shorebird conservation strategies.

Research on Shorebirds on the Fraser River Delta

A landmark report titled *The Birds of the Fraser River Delta: Populations, Ecology and International Significance*, written by Butler and Campbell, was published in 1987 and provides comprehensive data on bird populations, ecology, and habitats while also outlining threats to birds and providing conservation recommendations. Butler and Campbell's work is an indispensable source for the study of shorebirds both on the Delta and, because of the international nature of shorebird ecology, globally. This work was recently updated in a special issue of the *Journal of the British Columbia Field Ornithologists* (titled *The Status, Ecology and Conservation of Internationally Important Bird Populations on the Fraser River Delta, British Columbia, Canada*). It features new data on populations, endangered status, habitat loss and other threats, and ecology (Butler et al., 2021). Together these texts provide and essential primer on birds and bird ecology of the FRD.

Since Butler's initial report, a significant amount of research centred on the FRD has examined the relationship between agriculture and birds, including shorebirds. From about 2002 to the present, studies have repeatedly underlined the significance of agricultural lands for shorebird health and survival and have identified shorebird preferences and use patterns within them. Shepherd et al. (2004) published a paper finding that Dunlin often feed on agricultural lands (mostly crop residue and pasture) at night, meaning that the conventional diurnal counts of such activity were underestimates (pp. 67-69). Evans-Ogden and others published a flurry of papers elaborating on the relationship between shorebirds (primarily Dunlin, Black-bellied Plover, and Killdeer) and the agricultural lands in Delta, Richmond, Westham Island, Surrey, and surrounding areas. Evans-Ogden (2005) studied Dunlin diets, finding evidence that they consist of high ratios of terrestrial to marine invertebrates, and that though terrestrial feeding followed trends based on time of day and the age and sex of birds, a high variation of dietary behaviours among Dunlin was also found. Most of these studies conclude by recommending some combination of the farming practices and approaches offered in the present report: the regular application of natural manure, the minimization of habitat fragmentation and maintenance of large fields, laser leveling, the creation of landscape mosaics, and the maintenance of fields with low sward height.

These practices and the research supporting them are elaborated on in the farming practices descriptions below.

Areas for future study are also identified below, and they fall into some general categories:

- Research into the ecology of particular species who visit the FRD, with attention to diet/feeding behaviours, roosting behaviours, movement and locations, and migration and population trends
- Research that identifies ideal mosaic design patterns for shorebirds and other wildlife
- Research that furthers understanding of interspecies bird population dynamics (such as the relationships between Peregrine Falcons, Bald Eagles, and Dunlin)
- Research that identifies and quantifies the impacts of farming practices on shorebirds
- Research that furthers understanding of shorebird needs on the FRD
- Research that anticipates impacts of increasing anthropogenic pressures (development, sea-level rise, recreation) on shorebirds

In addition to the following recommendations, Flyway-wide (and multi-flyway) partnerships between researchers, conservationists, and farmers can support, inform, and magnify local practices, as "[t]he geographic scale of the annual cycle of shorebirds dictates that a collective and collaborative approach is needed to fully achieve conservation success" (Senner et al., 2017, p. 12).

Recommendations

This report draws from and elaborates findings and recommendations made in the FRD shorebird studies mentioned above. Many of the following recommendations, while augmented by more recent research and adjusted to the dynamic conditions of the FRD, echo the closing words of one chapter of Evans-Ogden's (2002) doctoral dissertation:

> In terms of 'managing' farmland for shorebirds in the Fraser River Delta, our results suggest that maintaining a mosaic of winter field types (one that includes bare fields, grasslands, winter vegetables, and cover crops), long-term use of farmyard manure, mowing or grazing to maintain short vegetation, laser levelling, moderate use of inorganic fertilizers, and long crop rotations, are strategies likely to maintain and enhance the value of farmland to Dunlin, Black-bellied Plover and Killdeer. In addition, conservation efforts should focus on securing relatively large fields close to shore. Experimental research is necessary to assess the most effective combinations of these field manipulations, and to determine if such treatments are more widely applicable to shorebirds that use agricultural habitats in other over-wintering locations. We recommend that the delta's existing land stewardship programs aimed at waterfowl and raptors be augmented and expanded to include a shorebird field management component to ensure continued availability of farmland favourable to non-breeding shorebirds. (p. 125)

Some of these practices will be easier to implement than others. Laser-leveling and lime amendments are already encouraged and subsidized by DFWT within Delta, while the use of manure is practiced by (and perhaps limited to) farmers who have access to it (C. Schmalz, personal communication, June 5, 2023). Bearing in mind the range where shorebird conservation measures will be most effective (within a few km from tidal flats) means that such practices can be made most useful to shorebirds by encouraging and prioritizing their effective placement.

Every effort has been made for the recommendations to be appropriate to agriculture as it is practiced on the FRD and/or to anticipate changing climatic and environmental conditions (sea-level rise, less predictable seasons, multiple and ongoing anthropogenic threats). Timed and prolonged flooding of fields after harvest and during winter, for example, have been found to significantly benefit shorebirds in the Central Valley of California (Shuford et al., 2015, pp. 238-239), but such practices are unnecessary on the FRD in winter as soil moisture is generally very high then and intentional flooding might be avoided by farmers out of concern for saltwater intrusion (personal communication, C. Schmalz, June 5, 2023).

Beneficial Farming Practices Table

This table presents the recommended farming practices, highlighting key species affected, carryover benefits, and challenges and considerations that each one entails. See Appendix A for a detailed table that indicates estimated species impacts of each farming practice. For elaboration on the content of this table, see the descriptions in the section that follows.

Color Key:
Ecological benefits
Agricultural benefits

Table 1: Costs and Benefits of Proposed Farming Practices

PRACTICE	BENEFITS & SPECIES AFFECTED	COSTS & CONSIDERATIONS
Prevent Future Greenhouses/ Berry Crops	Preserves habitat for all wildlife who visit the floodplain	Farmers turn to these crops due to economic pressure and need; incentivizing other crops or subsidizing farmers to grow wildlife-friendly crops may be needed.
Mow cover crops	Dunlin Western Sandpiper Black-bellied Plover American Golden Plover Increases forage availability for *all* shorebirds who forage on farmland increased shorebird presence would likely put pressure on insect pests	Need to balance needs of shorebirds and other birds. Feasibility will be dependent on available time and labor as well as seasonal conditions.
Incorporate Crop Residues	Killdeer Dunlin Black-bellied Plover American Golden Plover Likely increases soil invertebrate populations and so forage availability for *all* shorebirds who forage on farmland; additional benefits include soil health, and increased shorebird presence	Feasibility will be dependent on available time and labor as well as seasonal conditions.

	would likely put pressure on insect pests	
Apply Manure	Dunlin Killdeer Black-bellied Plover Wilson's Snipe; Likely increases soil invertebrates and so benefits *all* shorebirds who forage on farmland; increased shorebird presence would likely put pressure on insect pests; Benefits soil in production	Economic investment; limited supply of manure.
Apply Fertilizer at moderate levels	(Killdeer Black-bellied Plover Dunlin) Benefits crop yield	Fertilizer provides less benefit that manure; may be detrimental in higher quantities or over time.
Apply Lime	Long-billed Curlew American Golden Plover Dunlin Likely increases soil invertebrates and so benefits *all* shorebirds who forage on farmland; increased shorebird presence would likely put pressure on insect pests Benefits soil in production	More research needed to determine extent of benefits.
Control Vegetation for Avian Predators	American Golden Plover Semi-palmated Sandpiper Western Sandpiper	Need to balance needs of shorebirds and raptors.
Maximize Field Area/ Limit Habitat Fragmentation	Dunlin Black-bellied plover Whimbrel American and Pacific Golden-plovers Likely to benefit many non-shorebird species	May be limited by field use/availability and farmer cooperation.
Laser Level Fields	Black-bellied Plover	Costly.

	Wilson's Snipe Killdeer Benefits soil in production, mitigates impacts from waterfowl grazing	
Create Landscape Mosaics	Significantly increases benefits of other conservation measures. Probably carryover benefits to all wildlife	Possibly difficult to implement at scale. More research needed to refine ideal mosaic layout.
Mitigate Human Disturbance	Likely to benefit all wildlife	Need research to identify highest priority sites; may face resistance from recreationists and farmers.
Improve Roosting Sites	Dunlin Greater and Lesser Yellowlegs Long and Short-billed Dowitcher	Need research to identify highest priority sites.

Descriptions of Beneficial Farming Practices

The following descriptions identify the essential elements of proposed farming practices represented on the Farming Practices Table. To see in detail which species are most likely to benefit from each practice, see Appendix A.

Prevent further greenhouses and berry crops

A major threat to shorebirds and other wildlife on the Fraser River Delta is the increase in acreage dedicated to growing berry crops and the construction of large-scale greenhouses over the past twenty years. Greenhouses and berry crops now comprise a significant portion of agricultural land use on the FRD. According to the author of a forthcoming report on crop trends in the City of Delta, greenhouses, permitted under ALR, reached over 350 ha (or about 3.5% of the approximately 11,000 ha of Delta land studied), while berry crops reached over 1,300 ha (approximately 12%) (personal communication, Kathleen Moore, June 8, 2023). Large-scale greenhouses “eliminate habitat previously available to wildlife and fragment remaining habitat” (Shepherd & Lank, 2004, p. 71). For shorebirds (with the exception of Killdeer), berry crops are known to be substantially less suitable foraging habitat, likely due to shorebirds’ avoidance of vegetation, though Dunlin can be found in berry crops at night (Evans-Ogden et al., 2008, p. 255). Even before considering other conversions in the study area (such as the conversion of lands to non-agricultural uses), in other words, greenhouses and berry crops represent a sizable area of effective habitat loss for shorebirds.

Given the extent of this loss, in addition to other factors impacting usable habitat (many of those interviewed for this report named habitat loss as one of the primary threats to wildlife on the FRD), municipal planners, conservation groups, and farmers in the Delta should work together to avoid the further establishment of such crops and greenhouses when possible. Due to the cumulative impacts of habitat already lost and fragmented to date, addressing this issue should be considered a top priority. Bearing in mind that the resort to these high-value uses of agricultural lands is driven by economic pressures that farmers in the FRD face, alternatives should aim to financially incentivize alternatives.

Mow cover crops

Researchers frequently identify mowing (or its result, low sward height) as one of the single most important considerations in grassland management for shorebirds (Milsom et al., 1998). Evans-Ogden et al. (2008) write that “[t]he strongest relationships between farming practices and shorebird field usage involved vegetation height and crop type effects” (p. 257). Due to feeding behaviour, avoidance of predators, and/or morphology, shorebirds generally forage in areas of low to no vegetation when feeding away from tidal flats, though many other factors are in play (Evans-Ogden, 2002, p. 116-125). Early fall mowing of cover crops increases shorebird foraging, while still providing foraging habitat for ducks and geese. Mowing of some cover crops to "a mean height < 10 cm" proximate (< 5km) to intertidal feeding areas ensures important late fall and early winter terrestrial foraging habitat for shorebirds (Milsom et al., 1998, p. 128). Many crops will regrow if cut early, allowing for waterfowl forage later in the season. Late fall mowing of some cover crops significantly increases foraging habitat for shorebirds (Milsom et al., 1998, p. 128). A combination of both early and late fall mowing would contribute to a mosaic landscape as described below. As mowed cover crops are exhausted, those managed for and grazed by waterfowl over the course of winter become suitable to shorebirds, creating a succession of low to no vegetation areas ideal for wintering shorebirds (Milsom et al., 1998, p. 128; Shepherd & Lank, 2003, p. 41).

The planting of fall cover crops on the FRD is usually constrained by harvest, weather conditions, and soil moisture levels: cover crop seeding happens within a very narrow window after harvest and before fall rains begin (personal communication, C. Schmalz, June 5, 2023). This timing makes a planned mowing difficult or even unfeasible, yet the importance of areas of low sward for shorebirds is nonetheless essential. As fall weather becomes less predictable, as it has been in recent years, an awareness of the significance of sward height for shorebird conservation is likely to become a more important consideration in the future.

There is a further possibility that GSAs could be managed specifically for shorebirds by placing them very close (<1 km) to shorelines, keeping them well mowed (<5cm), and, when feasible or necessary, wet throughout the winter.

Finally, Evans-Ogden (2002) also notes that shorebirds who feed in agricultural fields may provide some benefit by controlling invertebrate pests. She writes that "several important pest species were included in the stomach contents" of Dunlin collected "from hydro wire kills and shot at Vancouver airport" (p. 231). This potential carryover benefit to farmers applies to all of the recommendations below that encourage and/or enhance terrestrial foraging for shorebirds on agricultural lands.

Incorporate crop residues postharvest

Postharvest treatments that incorporate crop residues into soil include mowing, discing (or other tilling methods), and flooding (Iglecia & Winn, 2021, p. 53). Another method, 'chop and roll,' entails "machinery… with rotating blades… that cuts [crop] stubble close to the ground and then rolls over it, leaving crop residues on the soil surface as a layer of mulch" (Shuford et al., 2015, p.

497). It is easy to imagine that such a crop treatment, when sufficiently wet, would favor many invertebrate species and thus the shorebirds who feed on them.

Fall harvested crop residues on the FRD (such as corn, wheat, legumes) provide both vegetative and invertebrate feeding opportunities for birds (Bradbeer et al., 2012, p. 46). Studies have documented that both shorebirds and waterfowl prefer harvested crops that have been mown, chopped (rough till and incorporation), and/or flooded (Shuford et al., 2015). In one study, shorebirds were found in greater numbers in fields treated with a chop and roll or till method postharvest, while such treated fields that were also flooded were found in greater numbers still (p. 500).

Shuford et al. (2015) identify flooded corn fields with rough postharvest incorporation as highly favoured by shorebirds in California's Central Valley (p. 500). Iglecia & Winn (2021), write that incorporating crop residues postharvest to favor shorebirds as it "create[s] a mudflat-like habitat when water is applied" (p. 53). Elphink & Oring, (1998) find that unlike other birds they studied, several shorebird species "were most abundant in fields where straw had been incorporated into the soil prior to flooding" (p. 103). While intentional flooding is needed in places like the Central Valley, fields in the FRD likely receive enough winter rain to achieve a similar effect as that observed by Shuford et al. and Elphink & Oring.

While flooding may not be a necessary or feasible practice in all situations, it should be noted that many shorebirds require moist to wet soils to feed. In a typical winter on the FRD, soil moisture levels are generally appropriate for shorebird foraging purposes. Nonetheless, since high soil moisture levels are essential for many shorebirds—Dunlin and Sanderling, for example—they should be kept in mind for planning purposes (Senner et al., 2017, p. 168). Finally, more research is needed to determine which postharvest methods most favour shorebirds on the FRD.

Apply manure

Manure amendments to cover crops, pastures, and set asides increase populations of invertebrate species and have been shown to be favoured by shorebirds and waterfowl to fields that have not had such treatments (Evans-Ogden, 2002, p. 113). Evans-Ogden notes that manure's effects on invertebrate populations may take time (>1 year) to show benefits and support shorebirds (p. 113). Evans-Ogden also describes several studies that find "[e]arthworm density…to be five times higher and biomass twelve times higher in field patches with cow dung as compared to patches without" and that several other classes of terrestrial invertebrates increase with manure applications as well (Evans and Guild, 1947, as cited in Evans Ogden, 2002, p. 113). Evans-Ogden lists manure among practices that "appear[] to enhance field usage" of Killdeer, Dunlin, and Black-bellied Plover, particularly when applications have taken place repeatedly over years (pp. iii, 88). Evans-Ogden further emphasizes that "[l]ong-term use of farmyard manure was significant predictor for the use of fields by Dunlin" (p. 104). Shepherd and Lank (2004) recommend that long-term pastures be maintained with regular use of manure as a means to support terrestrial feeding sites for Dunlin, as "[p]astures in the Fraser River delta are fertilized heavily and naturally with cattle manure, and likely support higher densities of terrestrial invertebrates compared to crop fields" (p. 70). Outside of the FRD, Tucker (1992) found that "[t]he use of cultivated fields by birds was…associated with high frequencies of farmyard manure application" and that "earthworm densities were positively correlated with input of farmyard manure" (p. 779).

Difficulties associated with this practice may be the supply of animal manure, maintaining applications on fields over consecutive years, and funding and labour to purchase and apply manure. Metro Vancouver reports that between 2011 and 2016, farmers using manure to fertilize crops dropped by 50%. (Metro Vancouver, n.d., 29).

Snipe with worm. Photo by Boni Herdiawan.

Apply fertilizer

Similar to manure but less effective, fields treated with inorganic fertilizer have been found to be favoured by shorebirds (Evans-Ogden et al., 2008, p. 257). However, Evans-Ogden (2002) cautions however that an observed negative relationship between fertilizer application and invertebrates suggests a moderate approach to such applications until further research can be done (pp. 114, 125). Fertilizer application is primarily included here to note its marginal carryover benefits when used for other purposes and to encourage moderation. When possible, farmers intending to boost invertebrate populations in their soils should opt instead for manure and liming.

Apply lime

Soil treatments to reduce acidity such as liming benefit earthworms in agricultural fields and thus the shorebirds who feed on them. In one study conducted in the UK, researchers found that "[d]eclining soil pH associated with a reduction in lime use on agricultural grasslands is likely to have led to declines in earthworm abundance and reduced foraging habitat quality for birds reliant on earthworms as prey, especially where underlying geology has poor buffering capacity and rainfall levels are high enough to reduce soil pH through leaching" (McCallum et al., 2016, p. 188). Given the prevailing soil and rain conditions on the FRD, the application of lime to fields for the purposes of improving earthworm habitat promises to benefit both farmers and shorebirds alike.

As liming is already practiced by farmers on the FRD, the expansion of existing programs (such as DFWT's cost share for field liming) is an excellent option for supporting shorebird habitat for species that feed terrestrially such as Dunlin and Black-bellied Plover (Delta Farmlands, n.d.).

Control vegetation for avian predators

Shorebirds exhibit site-selectivity for the presence or threat of avian predators, such as Peregrine Falcon, and will avoid areas with a perceived threat of avian predators when possible (Pomeroy et al., 2008; Sprague et al., 2008). Peregrine numbers on the FRD have increased over recent decades, and while good for raptor conservation and a success in its own right, increased raptor presence puts additional pressure on other species, including shorebirds (Butler et al., 2021, p. 19). Some heavily used roosting and feeding areas (including both terrestrial and marine) should thus be maintained to limit threats from avian predators.

Practices include keeping areas free from perching sites such as trees, poles, buildings, power lines, etc., siting shorebird conservation efforts away from such perching sites, controlling the growth of high vegetation, and siting grassland set asides (which provide habitat for other raptor prey) away from high-priority shorebird habitat such as roosting sites. Evans Ogden (2002) adds that GSA placement can negatively affect shorebirds, as "new raptor habitat may create 'neighborhoods' of fields otherwise suitable for shorebirds that are subsequently avoided" after the introduction of a GSA (p. 230). As several shorebird species feed nocturnally at terrestrial sites with high diurnal avian predator threat, some forage-focused shorebird conservation efforts in areas with heightened avian predator threat can still be beneficial. (Evans-Ogden, 2008, p.77) Nonetheless, Sprague et al. (2008) argue that "landscape features such as distance to cover may be important factors to consider when selecting candidate sites for shorebird conservation measures," because "sites that provide a safer predator landscape are… selected by migrating sandpipers, and… site safety may under some circumstances be more important than food availability in determining foraging habitat" (Sprague et al., Abstract, Conclusion).

Peregrine Falcon. Photo by Becky Matsubara

Future research on the relationship between shorebirds, avian predators, and mitigation practices could include tracking the frequency and success rates of avian predator attacks at sites preferred by shorebirds, the relationship between Peregrine site selection and the location of ducks (other prey for avian predators) and shorebirds, and the tracking of raptor and shorebird movements to determine whether, when, how, and to what extent shorebird site selection is affected by avian predation. The results of such research could inform site prioritization of many shorebird conservation measures.

This recommendation is complicated by more recent developments on the FRD. As Bald Eagle populations have increased since the end of the 20th century, Peregrine Falcon predation of shorebirds has decreased due to kleptoparasitism (Butler et al. 2021, pp. 33, 39-40). Bald Eagles rob shorebirds from Falcons; when Eagles predate birds, they tend to target ducks (as they are easier for Eagles to catch), leaving shorebirds effectively protected by the Eagles (Butler et al., 2021, p. 40; Dekker et al., 2012, p. 290). It is not clear based on current literature whether shorebirds respond to the presence of Eagles differently than that of Falcons—a study involving whether Bald Eagles disturb shorebirds would be a valuable area of new research (Butler et al., 2021, pp. 19, 33-34).

Projected benefits to species on the spreadsheet assume that vegetation control will take place adjacent to or near mudflats or large fields where shorebirds are likely to or are known to feed and roost (see p. 37).

Maximize field area/limit habitat fragmentation

Many shorebirds prefer large, open areas free of obstructions and vegetation and so to support shorebirds on the FRD, efforts should be made to preserve and/or restore large fields. Terrestrial feeding and roosting sites are more important the closer they are to the sea, with the closest 0.5km of highest significance (Milsom et al., 1998; Evans-Ogden et al., 2002, 253). Shepherd and Lank (2004) write that "[t]errestrial habitat fragmentation… should be kept to a minimum, as dunlin preferred large fields, likely in response to predation risk" (p. 61). Milsom et al. (1998) write, "[i]n general, larger fields will be used more frequently, and by greater numbers of birds, than smaller ones… Fields enclosed by tall hedges, trees or other barriers should be avoided when more open alternatives are available" (p. 128). On the FRD, Evans-Ogden et al. (2008a) find that "[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" (p. 79).

In addition to field size, the vegetation surrounding fields is also a factor. Large fields without tall (>2m) hedges, trees, or other enclosure/cover are heavily favored by most shorebird species and so should be prioritized when selecting fields for shorebird conservation measures (Milsom et al., 1998, p. 124).

Limiting factors to this practice include the availability of suitable fields and the cooperation of farmers near the shore. Despite these challenges, addressing habitat fragmentation by finding ways to enlarge field areas, to minimize obstructions near shore, and to maintain existing large fields is supported by extensive research. Addressing habitat fragmentation is identified as an area of concern in the conservation strategies of Richmond, Delta, and Surrey, as well as many shorebird conservation reports specific to the FRD and globally (City of Richmond, 2015, p. 5; City of Delta, 2018, p. 9; Coulthard & Allen, 2014, p. 15; Butler et al., 2021, p. 20). Limiting and/or reversing habitat fragmentation by fostering large fields is likely to benefit a full spectrum of bird and wildlife species.

Laser Level fields

Already practiced by farmers in the FRD, "[l]aser levelling is a technique that creates an extremely even surface across the entire field that is intended to increase the rate of surface evaporation and reduce long-term pooling of water" (Evans-Ogden, 2002, p. 94). While expensive, laser-levelling is beneficial to farmers as the "improved drainage" it provides "reduces grazing damage" from waterfowl (Bradbeer et al., 2012, p. 24). Research on the FRD suggests that laser leveled fields are favoured by Dunlin, Killdeer, and Black-bellied Plover, three important shorebird species (Evans-Ogden et al., 2008, p. 252). Existing efforts and funding sources, like DFWT's cost-share program for laser leveling, which is "highly regarded by growers in Delta" make this an obvious shorebird conservation option for farmers across the FRD (Bradbeer et al., 2012, p. 24).

Laser Levelling. Photo by Jeff Vanuga

Evans-Ogden (2002) speculates several reasons for shorebird preference for laser leveled fields. Laser leveling potentially boosts winter invertebrate activity due to higher soil temperatures on these fields. The practice also increases soil penetrability, which in turn also effects invertebrate activity and makes soil "similar to the mud encountered in…marine feeding habitat" facilitating shorebird foraging accessibility (p. 115). More research is needed to determine the extent to which and the exact reasons that laser leveling favours shorebirds, the place of laser leveling in mosaic design, and which species it favours most.

Create landscape mosaics

While individual practices will undoubtedly benefit shorebird species, research strongly suggests that a large-scale diversity of landscapes, or 'mosaic,' can maximize the benefits of other efforts. The mosaic approach, routinely identified and recommended in studies cited in this report, aim for a mix of landscape types to balance the needs of shorebirds with other birds while providing all wildlife with a full array of their habitat needs. Evans-Ogden et al. (2008) write that "[a]lthough field preferences are species-specific," Dunlin, Black-bellied Plover, and Killdeer "show an affinity for co-occurrence" of "bare fields, grasslands, winter vegetables, and cover crops" (p. 257). A mosaic approach, moreover, responds to Shuford et al.'s (2015) findings, which "highlight[] the challenges associated with managing for multiple waterbird species on an individual farm," leading them to suggest that "setting conservation priorities across a broader landscape" can be very effective (p. 503).

Challenges to this approach include the need for large amounts of information, the capacity for farmers and conservationists to coordinate efforts, and the need for more precise research on optimum mosaic patterns for shorebird support. Detailed local research such as that conducted by Hawey (2022) and Kulikowski (2023) can provide excellent information to this end, while GIS mapping efforts could also scaffold future mosaic planning. Whether based on existing conditions, plans based on complex data sets, or decisions based on general principles, a diverse landscape is favourable to shorebirds.

Mitigate Human Disturbance

With variations between species, many shorebirds are sensitive to anthropogenic sources of disturbance (Pfister et al., 1992, p. 123). The *Atlantic Flyway Shorebird Initiative* and the *Pacific Americas Shorebird Conservation Strategy* both identify human disturbance as among the most serious threats to shorebirds (Atlantic Flyway, 2015, p. 5; Senner et al., 2017, p. 2). Sources of disturbance include agriculture, human recreationists (especially dog owners), motorized vehicles, avian predators (see description above) and many others (Senner et al., 2017, pp. 24-27).

Disturbance, especially when chronic, can have serious impacts on shorebirds. Citing previous studies, Drever et al. (2016) write that "[h]uman recreational disturbance can reduce foraging opportunities and energy stores if disturbed birds spend more time vigilant and fleeing or shifting habitats rather than foraging" (p. 125). Such energy store depletion can be especially significant for migrating shorebirds like Western Sandpiper, who use the FRD to build up energy stores to effect long-distance migrations (Butler et al., 2021, pp. 29-30).

Mitigating this disturbance can thus help shorebirds conserve energy, and agricultural fields adjacent to tidal flats can play an important role in doing so by providing refuge areas. Milsom et al. (1998) write that "[t]he attractiveness of fields to waders will be enhanced if they are situated away from sources of frequent human disturbance, particularly roads" (p. 128). To achieve optimum placement of shorebird conservation projects, farmers and conservationists should take known disturbance levels into account. For instance, a field near a road, heavily used farm site, or popular recreation area may not be the best place for a potential shorebird roosting site, but could be considered for a feeding site, as some shorebirds (Dunlin, for example) will feed at night when avian predator threat and human disturbance is reduced (Evans-Ogden et al., 2008a, p. 77; Shepherd at al., 2003, p. 41).

Western Sandpipers in flight. Photo by Matt Tillett

Improve Roosting Sites

During high tides, many shorebirds roost on land. Some shorebirds, like Dunlin and Black-bellied Plover, will spend some high tides feeding on terrestrial vertebrates in nearby fields, often at night (Shepherd & Lank, 2004). They also rest on farmland "within 2 km of the beach from October to May" (Butler et al., 1992, p. 82). Other species , like Western Sandpiper, roost "along the shore," or, under certain conditions will "fly offshore in large flocks," usually to avoid predators or because of disturbance (Butler et al., 2002, p. 488). Dekker (1998) writes that "Dunlin at Boundary Bay had to resort to high-tide flocking because they could not locate suitable, bare ground for roosting after all of the intertidal zone had been inundated by the high tides" (p. 696). Frequent disturbance at such sites results in energy expenditures that can impact survival rates of shorebird species and "could be more damaging than permanent habitat loss" (West et al., 2002, p. 319). For migrating birds and resident non-breeders alike, a range of relatively safe roosting sites is crucial for long term health and, in some cases, short term survival. Agricultural areas near shorelines on the FRD can play a role in providing or denying suitable roosting sites for shorebirds and thus significantly impact survival rates.

Several factors should be considered when identifying agricultural lands for potential roosting site development. In addition to determining where shorebirds currently roost, factors such as aspect, distance to benthic and terrestrial feeding sites, and disturbance levels are noted in the literature. Peters and Otis (2007) note that conservation-oriented "land acquisition procedures and mitigation projects... should include a wide range of potential roosts that could be used under different wind conditions. The roosts should provide variability in aspect and sheltering capabilities, with open, sandy beaches available for some species such as sanderling" (p. 207). They add that "[t]hese roosts should also be within reasonable travelling distance of preferred feeding areas…, which may change within and among years" (p. 207). On the question of proximity to shore, Neima et al. (2020) write that there is a "need for maintenance of a range of relatively closely connected foraging and roosting sites within each region" of a large stopover site (Discussion). Pfister et al. (1992) add that "[p]roximity of the resting area to the feeding area could… increase feeding efficiency by maximizing feeding time through the ability to detect when intertidal feeding areas become available as the tide falls" (p. 124). These observations suggest that fields closest to mudflats are prime areas of interest for creating and supporting shorebird roosting sites.

Consideration of potential roosting sites for shorebirds is an important element in mosaic design as described above. By ensuring a variety of suitable sites, agricultural lands near the tidal flats can play a key role in supporting many of the shorebird species who visit the Fraser River Delta.

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Appendix A: Projected Benefits of Farming Practices by Species

This spreadsheet collates shorebird ecology by species with proposed farming practices, predicting the level of benefit each practice will have to each species. Each species is assigned a number—0, 1, or 2—per practice to indicate the predicted benefit that a farming practice would have on the species.

"0" indicates that a given farming practice is unlikely to benefit a particular species based on known ecology, including usage of landscapes for roosting or foraging, seasonal timing, and anticipated anthropogenic habitat pressures. "Prevent future Greenhouses/Berry Crops" is unlikely to benefit Sanderling, for example, for this species is not known to visit upland fields during its stay on the FRD.

"1" indicates that a given farming practice will provide some benefit or will potentially provide benefit to a given species. "Mow cover crops" will possibly provide some benefit to Whimbrel, but as this species forages in short to medium height vegetation, and because its migration is usually over by the end of September, any benefit is unlikely to be significant.

"2" indicates that a practice will provide significant benefit to a species. "Mitigate Human Disturbance" is likely to provide significant benefit to nearly all shorebirds who visit the FRD, as most species are to some degree sensitive to anthropogenic disturbance. Additionally, anthropogenic disturbance is so widespread across the FRD, any mitigation measures are sure to provide needed respite and benefit to shorebirds and other wildlife. A few species, such as Ruddy Turnstone, tend to stay offshore and in rocky areas of the coastline, and so are less likely to benefit from low-disturbance zones on or near agricultural lands. Others, such as Black-bellied Plover have been found to be possibly less sensitive and/or more adaptable to disturbance than other species, and so received a "1" (Drever et al., 2016).

Predictions are made as follows:

a) When possible, predictions are based on direct research on a particular species in the FRD.
Example: Evans Ogden et al. (2008) found that Killdeer, unlike other shorebirds, are found in or near berry crops. For this reason, the prevention of berry crops is marked (0) for Killdeer. As greenhouses do not provide any benefit to Killdeer, the prevention of more greenhouses on ALR land would provide significant benefit (2) to killdeer.

b) Some predictions are based on research on a species carried out elsewhere.
Example: Research on the benefits of lime applications to shorebirds who feed

terrestrially was carried out in the UK, but the benefits of liming as a pH regulator to soil invertebrates is very likely to apply to the acidic soils of the FRD and so a (2) is applied to species known to feed on terrestrial invertebrates and a (1) for species whose benefits are reasonable speculations based on known feeding behavior on the FRD or elsewhere.

c) Otherwise, predictions are inferred based on species ecology as pertains to the farming practice.
Example: The impact of human disturbance has not been studied systematically across all shorebirds listed. However, as shorebirds are generally sensitive to disturbance, it is assumed here, unless otherwise observed, that mitigating the high and increasing level of disturbance would significantly benefit (2) most shorebirds—with the exception of those who are known to be adaptable (Black-bellied Plover) or who do not frequent areas of human disturbance (Black Turnstone) and so receive (1).

Occurrence – Occurrence numbers and ecology are from Butler et al. (1987) except where updated by other sources (as indicated in the third column). Occurrence of most species varies widely by season. Here, a given species' highest seasonal occurrence is listed. Note that for species rare in the FRD, impacts of farming practices may not be well understood and are here speculated based on known ecology. In other cases, more research is needed to understand particular species' ecology in the FRD. Endangered status information is from COSEWIC (2022).

Table 2: Projected Benefits of Farming Practices by Species

Species / Common Name	Species / Scientific Name	Source (other than or in addition to Butler et al. 1987)	Occurence in Fraser Delta, 2021 Conservation Status	Prevent future Greenhouses/Berry Crops	Mow Cover Crops
Baird's Sandpiper	*Calidris bairdrii*	Iglecia and Winn 2021, Weber et al. 2018	Rare	1	1
Buff-breasted Sandpiper	*Tryngites subruficollis*	Lanctot et al. 2009, Butler et al. 2021	Rare, *Special Concern*	2	2
Long-billed Curlew	*Numenius americanus*	Shuford et al., 2013, Butler et al. 2021	Rare, *Special Concern*	2	1
Marbled Godwit	*Limosa fedoa*	Colwell and Dodd 1997	Rare	2	0
Red Knot	*Calidris canutus roselaari*	Butler et al. 2021	Rare, *Threatened*	1	0
Red-necked Phalarope	*Phalaropus lobatus*	Butler et al. 2021	Rare, *Special Concern*	0	0
Ruddy Turnstone	*Arenaria interpres*	Iglecia and Winn 2021	Rare	0	0
Sharp-tailed Sandpiper	*Calidris acuminata*		Rare	2	2
Solitary Sandpiper	*Tringa solitaria*		Rare	1	0
Willet	*Tringa semipalmata*		Rare	1	1
Bar-tailed Godwit	*Limosa lapponica*	Iglecia and Winn 2021	Rare	0	0
Hudsonian Godwit	*Limosa haemastica*	Iglecia and Winn 2021	Rare	0	0
Ruff	*Calidris pugnax*	Weber et al. 2018	Rare	1	1
Rock Sandpiper	*Calidris ptilocnemis*	Iglecia and Winn 2021	Rare	0	0
Wandering Tattler	*Tringa incana*	Iglecia and Winn 2021	Rare	0	0
American Avocet	*Recurvirostra americana*	Weber 2018	Rare	0	0
Pacific Golden-plover	*Pluvialis fulva*	Butler et al. 1987*, Iglecia and Winn 2021	Rare	2	2
Wilson's Phalarope	*Phalaropus tricolor*	Iglecia and Winn 2021	Uncommon	0	0
Stilt Sandpiper	*Calidris himantopus*		Uncommon	0	0
Black Oystercatcher	*Haematopus bachmani*	Weber et al. 2018	Uncommon	0	0
Semipalmated Sandpiper	*Calidris pusilla*	Sprague et al. 2008	Fairly common	1	0
American Golden-plover	*Pluvialis dominica*	Butler et al. 1987*	Fairly common	2	2
Black Turnstone	*Arenaria melanocephala*		Fairly common	0	0
Least Sandpiper	*Calidris minutilla*		Fairly common	1	1
Lesser Yellowlegs	*Tringa flavipes*	Weber et al. 2018	Fairly common, *Threatened*	1	1
Semipalmated Plover	*Charadius semipalmatus*	Iglecia and Winn 2021	Fairly common	1	1
Spotted Sandpiper	*Actitis macularius*	Iglecia and Winn 2021	Fairly common	1	1
Whimbrel	*Numenius phaeopus*		Fairly common	2	1
Pectoral Sandpiper	*Calidris melanotos*		Fairly common	2	2
Greater Yellowlegs	*Tringa Melanoleuca*	Weber et al. 2018	Fairly common	2	2
Surfbird	*Calidris virgata*	Weber et al. 2018, Iglecia and Winn 2021	Fairly common	0	0
Killdeer	*Charadrius vociferus*	Evans-Ogden 2008	Common	G=2; B=0	2
Long-billed Dowitcher	*Limnodromus scolopaceus*	Butler et al. 2021	Common	0	0
Short-billed Dowitcher	*Limnodromus griseus*		Common	0	0
Wilson's Snipe	*Gallinago delicata*	Butler et al. 1987*	Common to very common	2	2
Sanderling	*Calidris alba*	Butler et al. 2021	Very abundant	0	0
Black-bellied Plover	*Pluvialis squatarola*	Evans-Ogden 2008 & 2002; Pfister et al. 1992;	Very abundant	2	2
Dunlin	*Calidris alpina pacifica*	Evans-Ogden 2008, Butler et al. 2021	Very abundant	2	2
Western Sandpiper	*Calidris mauri*	Pomeroy 2008, Butler et al. 2002	Very abundant	1	1

Species / Common Name	Incorporate crop Residues postharvest	Apply Manure	Apply Fertilizer	Apply Lime	Control Vegetation For Avian Predators	Maximize FIeld Area/ Limit Habitat Fragmentation
Baird’s Sandpiper	1	1	0	1	2	1
Buff-breasted Sandpiper	2	2	1	2	2	2
Long-billed Curlew	2	2	1	2	2	2
Marbled Godwit	1	2	1	2	2	1
Red Knot	0	1	0	1	1	1
Red-necked Phalarope	0	0	0	0	1	0
Ruddy Turnstone	0	0	0	0	1	0
Sharp-tailed Sandpiper	1	2	1	2	2	2
Solitary Sandpiper	0	0	0	0	2	1
Willet	1	1	0	1	2	1
Bar-tailed Godwit	0	0	0	0	0	0
Hudsonian Godwit	0	0	0	0	0	0
Ruff	1	1	0	1	1	1
Rock Sandpiper	0	0	0	0	0	0
Wandering Tattler	0	0	0	0	0	0
American Avocet	0	0	0	0	1	0
Pacific Golden-plover	2	2	1	2	2	2
Wilson’s Phalarope	0	0	0	0	2	0
Stilt Sandpiper	0	0	0	0	1	0
Black Oystercatcher	0	0	0	0	1	0
Semipalmated Sandpiper	0	0	0	0	2	0
American Golden-plover	2	2	1	2	2	2
Black Turnstone	0	0	0	0	1	0
Least Sandpiper	1	1	0	1	2	1
Lesser Yellowlegs	1	1	0	1	2	1
Semipalmated Plover	1	1	0	1	2	1
Spotted Sandpiper	1	1	0	1	2	1
Whimbrel	2	2	1	2	2	2
Pectoral Sandpiper	2	2	1	2	2	2
Greater Yellowlegs	2	2	1	2	2	2
Surfbird	0	0	0	0	0	0
Killdeer	2	2	1	2	2	1
Long-billed Dowitcher	0	0	0	0	2	0
Short-billed Dowitcher	0	0	0	0	2	0
Wilson's Snipe	2	2	1	1	2	1
Sanderling	0	0	0	0	1	0
Black-bellied Plover	2	2	1	2	2	2
Dunlin	2	2	1	2	2	2
Western Sandpiper	0	1	0	1	2	1

Species / Common Name	Laser Level Fields	Create Landscape Mosaics	Mitigate Human Disturbance	Improve Roosting Sites	Comments
Baird's Sandpiper	1	2	2	2	
Buff-breasted Sandpiper	2	2	2	2	
Long-billed Curlew	1	2	2	1	
Marbled Godwit	1	1	2	2	
Red Knot	1	2	2	2	Butler et al. (1987) note they are "frequently seen in fields near sewage lagoons, on upper beaches, and on mud flats
Red-necked Phalarope	0	1	2	1	
Ruddy Turnstone	0	1	1	1	
Sharp-tailed Sandpiper	2	2	2	2	
Solitary Sandpiper	0	2	2	1	
Willet	1	2	2	2	
Bar-tailed Godwit	0	1	2	1	
Hudsonian Godwit	0	1	2	1	
Ruff	1	1	2	1	
Rock Sandpiper	0	1	2	1	
Wandering Tattler	0	1	2	1	
American Avocet	0	1	2	1	
Pacific Golden-plover	2	2	2	2	Butler et al. list *P. fulva* and *P. dominica* as *P. dominica* together, as they were then considered one species, "Lesser Golden-plover."
Wilson's Phalarope	0	2	2	1	
Stilt Sandpiper	0	2	2	1	
Black Oystercatcher	0	1	1	1	
Semipalmated Sandpiper	0	2	2	2	
American Golden-plover	2	2	2	2	
Black Turnstone	0	1	1	1	
Least Sandpiper	2	2	2	2	
Lesser Yellowlegs	2	2	2	2	
Semipalmated Plover	2	2	1	2	
Spotted Sandpiper	2	2	2	1	
Whimbrel	2	2	2	2	
Pectoral Sandpiper	2	2	2	2	
Greater Yellowlegs	2	2	2	2	
Surfbird	0	0	2	1	
Killdeer	2	2	2	1	
Long-billed Dowitcher	1	2	2	2	More research needed for *L. scolopaceus* ecology.
Short-billed Dowitcher	1	2	2	2	
Wilson's Snipe	2	2	2	2	Butler et al. list Common Snipe.
Sanderling	0	1	2	1	More research is needed on *C. alba* ecology in the FRD.
Black-bellied Plover	2	2	1	1	
Dunlin	1	2	2	2	
Western Sandpiper	1	2	2	1	