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Impacts of COVID-19 on Canadian Beekeeping: Survey Results and a Profitability Analysis

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Abstract

To gauge the impact of COVID-19 on the Canadian beekeeping sector, we conducted a survey of over 200 beekeepers in the fall of 2020. Our survey results show Canadian beekeepers faced two major challenges: 1) disrupted importation of honey bees (Hymenoptera: Apidae) (queen and bulk bees) that maintain populations; and 2) disrupted arrival of temporary foreign workers (TFWs). Disruptions in the arrival of bees and labor resulted in fewer colonies and less colony management, culminating in higher costs and lower productivity. Using the survey data, we develop a profitability analysis to estimate the impact of these disruptions on colony profit. Our results suggest that a disruption in either foreign worker or bee arrival allows beekeepers to compensate and while colony profits are lower, they remain positive. When *both* honey bee and foreign workers arrivals are disrupted for a beekeeper, even when the beekeeper experiences less significant colony health and cost impacts, a colony with a single pollination contract is no longer profitable, and a colony with two pollination contracts has significantly reduced profitability. As COVID-19 disruptions from 2020 and into 2021 become more significant to long-term colony health and more costly to a beekeeping operation, economic losses could threaten the industry's viability as well as the sustainability of pollination-dependent crop sectors across the country. The economic and agricultural impacts from the COVID-19 pandemic have exposed a vulnerability within Canada's beekeeping industry stemming from its dependency on imported labor and bees. Travel disruptions and border closures pose an ongoing threat to Canadian agriculture and apiculture in 2021 and highlight the need for Canada's beekeeping industry to strengthen domestic supply chains to minimize future risks.

Key words: COVID-19, bee importation, temporary foreign worker, colony health, beekeeping profit

The 2020 pandemic revealed economic vulnerabilities inherent in most sectors of the economy, and agriculture was no exception. As COVID-19 caused a worldwide lockdown of businesses in the early spring of 2020, the agriculture sectors in Canada were just beginning their seasons. The arrival of approximately 60,000 agricultural temporary foreign workers (TFWs) into Canada to fulfill their seasonal contracts in the spring of 2020 was affected (Stats Can 2020a) when Canada barred entry to the majority of foreign nationals on March 18, 2020. In apiculture, we estimate that there are between 1800 and 2000 temporary foreign workers who arrive each year (Rod Scarlett, personal communication, April 29, 2021) and according to a 2018 survey of Canadian beekeepers, 41% of beekeeping operations hire foreign workers for their operations (CAHRC 2018). These workers are often highly skilled in beekeeping practices, and are responsible for colony preparation, management, honey production, and other critical operational support (Falconer 2020). Urgent and coordinated efforts on the part of government and industry during the spring and summer of 2020 were successful in creating some exemptions for foreign workers, including right-of-entry and organizing charter flights (CHC 2021). However, ongoing disruptions in countries of origin, such as closed visa offices and evolving regulations in Canada, made it impossible to avoid impacts on the apicultural sector. Many temporary foreign workers were unable to travel to Canada and fulfill their apicultural contracts in 2020 and, for those beekeepers whose workers did eventually arrive, beekeeping operations were disrupted due to workers facing quarantine, social distancing, and personal protective equipment (PPE) requirements. Quarantine requirements in Canada resulted in beekeepers having to pay workers who were unable to work, while in some cases, also hiring local workers to fill the labor gap. Employers and workers were also mandated to follow public health orders regarding mask-wearing and social distancing, limiting operational efficiencies, for example, by reducing the numbers of passengers allowed in work vehicles at one time, quarantining requirements, and isolation in the case of exposures or outbreaks (AAFC 2020).

As commercial flights were canceled or delayed, Canadian beekeepers experienced a second impact of the pandemic: a disruption in the arrival of imported honey bees needed to compensate for high annual colony losses. Canada, like many regions globally, has been experiencing elevated annual honey bee mortality for over a decade due to *Varroa destructor* (Le Conte et al. 2010), pesticides (Johnson et al. 2010, Alburaki et al. 2017), nutrition (Naug 2009, Branchiccela et al. 2019), overwintering losses (Genersch et al. 2010, Spleen et al. 2013), among many other multifaceted causes (Currie et al. 2010, Potts et al. 2010, van Engelsdorp et al. 2013). Over the winter of 2019-2020, the national colony mortality average was 30.2%, more than double the sustainable threshold for winter losses of 15% (Furgala and McCutcheon 1992, van Engelsdorp et al. 2007, Ferland et al. 2020), demonstrating the need for robust stock replacement systems. Canada's cold northern climate has historically limited the scale of domestic queen breeding (Bixby et al. 2020), thus beekeepers in Canada rely on the importation of bees across international borders to support and often replace losses from their roughly 700,000 colonies each year. Certain provinces were affected by COVID-19 disruptions more than others, for example, thirty-three percent of survey respondents manage their bees in Alberta, where in 2020, beekeepers managed 285,000 colonies (38% of Canada's total), producing 36% of the nation's honey that year (Stats Can 2020b). Alberta beekeepers rely on large numbers of both honey bee and foreign worker arrivals each spring to support their colonies. Coinciding with the travel disruptions in the spring of 2020, Alberta beekeepers also suffered unsustainable losses of 40% of their colonies over the winter of 2019/2020, resulting in an extremely difficult economic situation.

Both bulk package honey bees and queen bees are imported into Canada on a commercial scale annually. Queen bees are used to make splits or nucleus hives (nucs) by dividing existing colonies and introducing a queen, or simply to replace older, less vigorous queens. Less than 10% of Canadian beekeepers breed queens each year. Some of these queens are sold while others are used to sustain the home operation's colonies. Provincial survey results show that domestic breeders supplied the industry with approximately 100,000 queens in 2017–2018. (BCBPS 2018, QIS 2018). Colony survival in 2019/2020 was 70%, resulting in approximately 490,000 live colonies in the spring of 2020 (Ferland et al. 2020). As a conservative estimate, one half of these colonies (245,000) coming out of winter need to replace their queens each season (Amiri et al. 2017). Including these 245,000 queens used for replacement, plus the 210,000 queens used to support the new colonies from the 30% loss, minus the 100,000 queens supplied domestically, Canadian beekeepers need to source at minimum 355,000 queens each spring to maintain the current number of colonies. Failing to replace a queen in a timely manner can result in major productivity declines and risk of an eventual colony death since the quality of the queen has a direct impact on the colony's health and productivity (Nelson and Smirl 1977, Tarpy et al. 2000, 2012, Rangel et al. 2013, Simeunovic et al. 2014, Ethem et al. 2016, Amiri et al. 2017, Eccles et al. 2017, Guarna et al. 2017). Poor queens are cited by Canadian beekeepers and others worldwide as a leading cause of annual colony mortality (Ferland et al. 2020, Van Engelsdorp et al. 2011). Package honey bees are the other critical source of bee imports each year, consisting of between one to two kilograms of bees shipped in a cardboard container and installed into a hive in early spring to rapidly replace or expand the number of colonies in an operation. Packages have the advantage of not diminishing existing stocks as they do not rely on division methods to create new colonies. For many commercial beekeepers, importing and installing package bees is an annual practice, particularly as winter loss rates continue to be high.

As the ability to transport goods across borders became constrained in the spring of 2020, there were significant disruptions to the scheduled importation of queen and package bees that are transported on commercial passenger flights. In 2019, 235,928 queens and 41,339 kilograms of package bees were imported into Canada (Stats Can 2018). In 2020, due to COVID-19 related travel disruptions resulting in canceled and delayed commercial flights, there was a 10% reduction in queen imports and a 67% reduction in the number of imported packages from 2019 (Fig. 1). Package imports had been increasing yearly since 2017 (Stats Can 2018) and due to COVID-19, 2020 numbers showed a significant change in this importation pattern. Although queen bee imports were nearly equivalent to 2019 by the end of 2020, there was a delay in their arrival over the spring months of March, April, and May when comparing 2019 and 2020 (Fig. 2). The average queen importation into Canada between the start of March and the end of May for three seasons, 2017-2019, was nearly 65,000, compared to 54,000 in 2020, a 15% decrease (Stats Can 2018, Page 2021). These spring months are a critical period in the beekeeping season to build up colonies for pollination contracts (particularly for early season crops such as blueberries and tree fruits) and honey production (Seeley et al. 1985). Colonies need sufficient time to build up populations to achieve maximum efficacy in crop pollination and foraging during summer nectar flows (Smirl and Jay 1972, Harris 2008). Furthermore, shipping live honey bees is a sensitive process necessitating timeliness in production and shipping/receiving. Recent studies confirm that sperm viability in queens can be affected by temperature fluctuations in transit when delayed and overheated (McAfee et al. 2020, Rousseau et al. 2020, Pettis et al. 2016).

The Canadian beekeeping industry produced over 80 million pounds of honey in 2019, worth over 173 million dollars, and honey bees contributed pollination services worth between 4 and 5.5 billion dollars to the Canadian economy annually (AAFC 2019). It is therefore important to understand the economic impact of the disrupted supply of bees and labor on the beekeeping sector. Towards this goal, in the fall and early winter of 2020 we conducted a survey of Canadian beekeepers asking about their experiences with COVID-19-related disruptions during the 2020 beekeeping season. The results are presented here along with a profitability analysis of the economic impact of these disruptions and a discussion of the

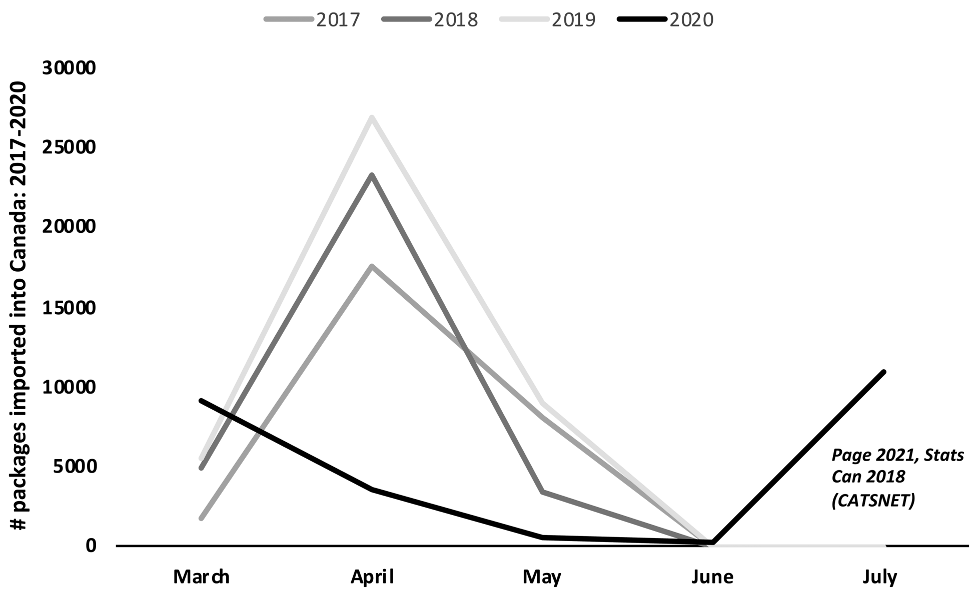

Fig. 1. Package honey bee imports into Canada: 2017 through 2020.

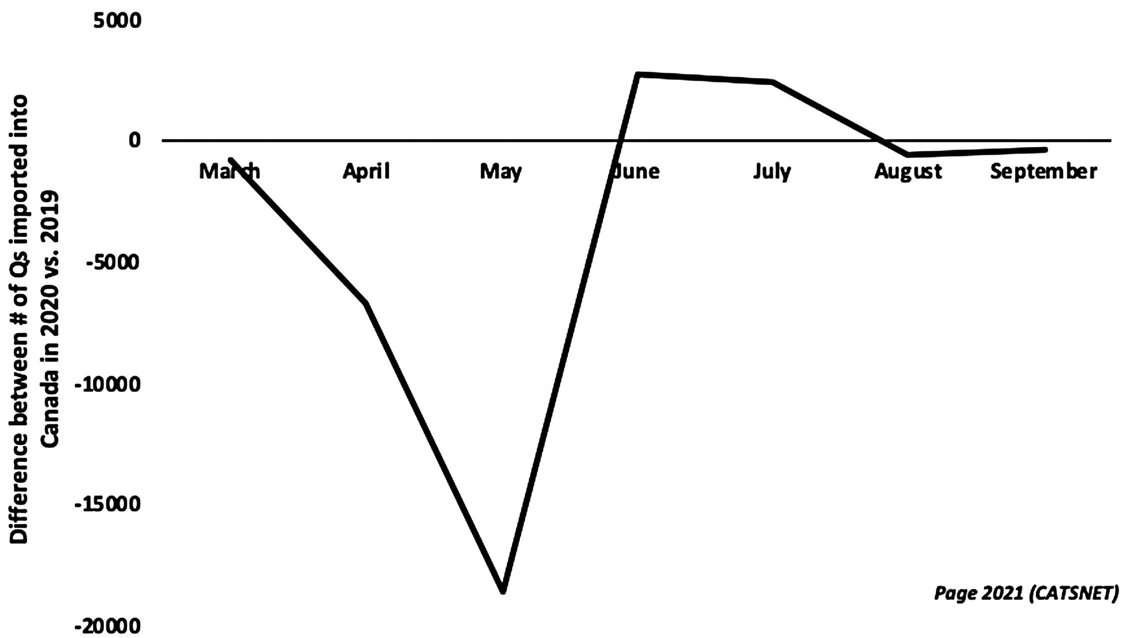

Fig. 2. Queen importation differential by month (2020 minus 2019).

immediate and longer-term effects of COVID-19 on the Canadian beekeeping industry.

Methods and Materials

To ascertain the impact of COVID-19 on apiculture in Canada, we surveyed a sample of Canadian beekeepers through the fall and winter of 2020/2021. The survey was sent out by the Canadian Honey Council (CHC) to their mailing list and was also sent to all provincial apiculture specialists to disseminate within their regions. The survey consisted of twelve questions ranging in focus from demographics to specific colony management during the spring and summer of 2020 (Bee CSI COVID-19 2020). The questions were designed to capture information about operational and colony management changes due to COVID-19 disruptions. Our objective was to reach all types of beekeeper from backyard hobbyists to commercial operators. Two hundred and five responses were received between October 29, 2020 and March 15, 2021. There were 186 responses to the English language survey and 19 responses to the French language version of the survey. These 205 responses represent approximately 1.7% of Canada's nearly 12,000 Canadian beekeepers (Stats Can 2020b). Thirty-six percent of the survey respondents' operations are located in Western Canada (B.C. and Alberta), 36% in the prairies (Saskatchewan and Manitoba), 12% in Ontario and Quebec, and 16% in Atlantic Canada (New Brunswick and

Nova Scotia). Recent survey data of Canadian beekeepers found that the mean number of full-time employees in an operation predicted 55% of the variance in the mean number of colonies within an operation with each additional full-time employee accounting for several hundred additional colonies ($R^2 = 0.5543$, $P < 0.001$) (Bee CSI 2020). Of the beekeepers in our COVID-19 survey, 62% hired five or more foreign full-time workers to support their operations, suggesting that the majority of operations in the survey (who hired 5 or more full-time foreign employees) are likely larger operations, defined as having more than 500 colonies (Kulhanek et al. 2017). To test the statistical equality of the survey responses across categories, we used the chi-squared test of goodness of fit for all multiple-choice questions (select one) and Cochran's Q test (West et al. 2010) for all multiple response questions (select all that apply). Beekeepers were asked about several key beekeeping activities (and how these were affected by COVID-19 in 2020) including: the employment of both local workers and temporary foreign workers; importation practices with regards to queens and packages; effects to colony interventions; and impacts on colony numbers and revenue sources as a result of COVID-19 disruptions.

To develop preliminary estimates of the economic impact of COVID-19 on beekeeping in Canada, we take the experience of a representative commercial beekeeper who typically relies on honey bee imports and/or temporary foreign workers to maximize profit from their beekeeping operation. Each year, the representative beekeeper receives revenue from his/her colonies from both honey sales and pollination rental fees. Using survey data to parameterize the colony profit functions, we estimate a range of impacts that this representative Canadian beekeeper incurred as a result of COVID-19. Specifically, we focus on two particular areas of concern highlighted in the survey responses: honey bee and foreign worker arrival interruptions, and we calculate the economic effects of these disruptions on per colony profit. This study explores the impact of COVID-19 related disruptions for a beekeeper on a colony level. This estimation can be scaled up to explore the impact at an apiary and ultimately industry level, however, for the purposes of this study, we will focus on the colony level effects for a single representative beekeeper. Each beekeeping operation is inherently unique in the number of colonies, regional impacts and operational structure, lending itself to a colony-level analysis.

The beekeeper's profit equation is given by total revenues minus total costs (Eq. 1). Revenues are accrued for honey where the first expression on the right-hand side of the equation, (P_h*Q_h), refers to the price of honey (P_h per pound multiplied by the quantity of pounds sold (Q_h). Revenue for this colony is also accrued through the rental fee for commercial pollination for blueberries and cranberries (*RFbl*, *RFcr*). Colony strength and size determine pollination grade and associated rental price (Sagili and Burgett 2011). We assume that the colony can have one or two pollination rental contracts per season. Total costs include an operation and maintenance cost (C_{op}) to keep the colony fed, treated, transported, and overwintered, including all associated labor costs. In the case of the representative beekeeper facing operational disruptions due to COVID-19, we have another cost parameter, β, which takes into account the effect of additional COVID-19 related material costs and COVID-19 risks incurred by the beekeeper. These additional costs include: personal protective equipment (PPE) and cleaning supplies required; social distancing of workers requiring more vehicles and/or more trips to the apiaries per vehicle, as well as fewer workers in the field at a time; the potential for reduced work efficiency due to mask-wearing, cleaning requirements, and illnesses requiring paid or unpaid isolation; as well as any additional labor costs associated with quarantining and risks of exposures and outbreaks. α is a health variable used to determine the level of disruption that COVID-19 effects had on the colony's health and ability to thrive longer term. α will play a role later in the analysis when looking at how significant interruptions in management could impact colony health going into the winter of 2020-2021 and then into the following beekeeping season.

Profit equation for the representative beekeeper's colony:

$$\Pi_{\ h} = [\alpha(P_h * Q_h + \ RFbl + RFcr) - (1+\beta)(C_{op})] \quad \text{where } \alpha\ (0,1),\ \ \beta(0,1) \tag{1}$$

The honey price of \$4.10/lb used in this analysis is an average of Statistics Canada's average honey price for the 2020 season (Stats Can 2020b) and the average honey price accrued to a sample of 112 Canadian beekeepers over the 2019-2020 beekeeping seasons selling at a variety of outlets including farmer's markets, wholesale and retail (Bee CSI 2020). The quantity of honey produced by the colony in the absence of COVID-19 disruptions is 100 lbs/colony, which is an average of the sampled Canadian beekeepers' honey output over the 2019/2020 seasons of 88.5lbs/colony (Bee CSI 2020), Statistics Canada's average output for Canadian colonies in 2020 of 111lbs/colony (Stats Can 2020b) and an average of the Alberta provincial beekeepers' survey in 2019 of 100lbs/colony (AAF 2020). When a colony is unable to adequately build-up in the spring due to a lack of bees or inadequate management, such as fewer necessary *Varroa* treatments, there is a decrease in honey production (Smirl and Jay 1972, Currie and Gatien 2006, Gabka 2014, Maucourt 2020). Honey impact estimates from lack of effective treatment range from a decrease of 20kg of honey for untreated *Varroa* in a colony (Currie and Gatien 2006) to a decrease of 30 kg of honey with two fewer healthy frames of brood per colony (Gabka 2014), an average decrease of 25% due to reduced colony strength. When COVID-19 travel disruptions affected the colony's management and spring build-up, due to either labor or honey bee disparities, we initially set the quantity of honey produced at 75lbs, a 25% decrease. As COVID-19 impacts become more significant, the amount of honey produced decreases further, to capture the impact from multiple causes such as reduced build up, reduced treatment, and unmitigated queen issues (important variables raised in the survey). The rental fee/pollination price in the absence of COVID-19 disruptions for the healthy commercial pollinating honey bee colony to pollinate blueberries is \$124/colony. This price is the average of the Canadian Honey Council's average pollination price of \$110/colony (CHC 2020) and the average rental fee of \$137.5/colony paid to a sample of over 100 Canadian beekeepers in 2019/2020 (Bee CSI 2020). Some beekeepers, primarily in British Columbia, are able to secure two pollination contracts per season. Typically, due to the timing of the blooms, a colony will pollinate blueberries in May and June and then be moved to cranberries. The rental fee earned for cranberry pollination varied among a group of sampled B.C. beekeepers in 2019/2020, with an average of \$112.50 per colony (Bee CSI 2020). Studies have shown that there is a correlation between colony strength (often proxied by size) and pollination rental fees (Cheung 1973, Goodrich 2019). When the representative beekeeper is unable to receive honey bees or foreign workers and the colony is underprepared (in size and strength) for pollination season, the colony will typically earn a lower pollination grade (e.g. grade B is at most 25% less strong than grade A) (Sagili and Burgett 2011) and thus a lower pollination rental price. Future economic studies are necessary to determine the specific mathematical relationship between these variables (Goodrich 2019). In this study, to capture the impacts on pollination rental fees from a weaker colony, we set the disrupted rental fee for blueberries at \$93, a 25% decrease, and disrupted rental fee for cranberries is set at \$84.375, a 25% decrease. When the COVID-19 disruptions cannot be effectively mitigated by the beekeepers, we assume that colonies are too weak to pollinate, and there is no rental fee paid to the beekeeper. The operation and maintenance cost for one colony is \$248, which is the most recent cost estimate to maintain a colony in Alberta, Canada (Laate 2017). Surveyed beekeepers indicated reduced colony interventions due to fewer colonies and fewer workers, as a result, when the representative beekeeper has fewer active workers and/or insufficient numbers of honey bees to manage, the basic operating colony cost will decrease by half, to \$124. β is the additional cost variable that reflects the increase in costs to the beekeeper due to the COVID-19 disruptions of timely worker and honey bee arrivals. In the absence of COVID-19 disruptions, $\beta = 0$ (no additional costs). Survey results indicated significant cost increases for Canadian beekeepers due to COVID-19. This is one of the first and only studies exploring the impacts on beekeeping operations from COVID-19. Further economic studies are needed to ascertain the explicit economic impact of COVID-19 on beekeeper costs, however, for this study, we use a range of cost increases to estimate profit effects. For the scenarios that involve hiring local workers instead of foreign workers and/or paying for foreign workers while in quarantine, we set $\beta = 0.25$, which means that costs have increased by 25% due to temporary foreign worker arrival disruptions. When the beekeeper has sufficient labor but must purchase local or supply in-house honey bees instead of importing bees, we set $\beta = 0.10$, a cost increase of 10% due to added costs associated with bee arrival disruptions, as indicated by the survey results. Survey results suggest that these cost increases likely represent a lower bound as foreign workers play a very important role in Canadian beekeeping and COVID-19 disruptions to labor were significant. In scenario 3, we explore the effect on colony profit from more disruptive COVID-19 requirements through an increased value of β. The colony health parameter, α, reflects the impact that COVID-19 disruptions have on the colony's health and ability to thrive beyond this season due to a lack of adequate colony management and bees. Studies show a correlation between weak fall colonies and winter mortality (van Engelsdorp et al. 2010, 2011). This study is one of the first to draw a link between COVID-19 disruptions, colony management, and ultimately long-term colony health and productivity. As α decreases from 1 (no long-term health impact) towards 0 (colony unable to accrue any revenue due to mortality or extreme morbidity), the colony deterioration from the disruptions increases as well. For scenarios 1 and 2, $\alpha = 1$, to reflect no long-term impact on colony health from the disruptions beyond the changes in honey output and pollination rental price in 2020. In scenario 3, α is decreased to between 25% and 75% of its full value to reflect a range of more long-term colony health risks from reduced colony management resulting in weaker fall colonies. A sensitivity analysis further explores the impact of a broad range of parameter values on colony profit (Table 2).

For this analysis, we will develop profit equations for the colony in three different COVID-19 disruption scenarios:

COVID Disruption Scenario 1

The commercial beekeeper normally imports honey bees from abroad to compensate for winter mortality. The survey data indicates that 40% of all surveyed beekeepers were impacted by a delay or cancellation in their orders of package and queen bees. As a result, due to COVID-19 travel restrictions, in this scenario the beekeeper's honey bee orders do not arrive at all or within the typical timeframe required to build up strong colonies this season. For simplicity, in this scenario the beekeeper has a sufficient and skilled local labor force and does **not** hire temporary foreign workers. The beekeeper has two options to manage this disruption to honey bee imports for his one pollinating and honey-producing colony, including:

Good Outcome Scenario 1

The beekeeper makes a split from within the operation and uses either an in-house or domestically produced queen to support this colony. We assume the beekeeper has sufficient stock in early spring to split existing colonies. Using the beekeeper's own honey bees to make replacements is feasible if, and only if, the operation has an in-house breeding program set-up, as approximately 5-10% of the 8,500 Canadian beekeepers do (Bixby et al. 2019). In most regions, the infrastructure to produce early season queens in Canada's northern climate (e.g., by overwintering queens/queen banks) is in its infancy and not adequately developed to support the demand, particularly when faced with COVID-19 import delays (Bixby et al. 2019). There is a risk that these early spring domestic colonies will not build up in time for early pollination (e.g., blueberry crops) with success largely dependent on the extent of regional winter losses that year, local bee supply availability, and advance notice, allowing beekeepers to plan accordingly. In this good outcome scenario, by splitting an existing colony and using an in-house or local queen, the beekeeper will not lose their pollination contract(s). However, due to a timing lag (in-house/local queens not available for use as early as imported queens), the colony does not have sufficient time to build up adequately for a high pollination grade, and thus earns lower pollination rental fees. Honey production is also lower than average due to reduced time to grow the population adequately. There is a small increase in COVID-19-related costs for this beekeeper to adhere to COVID-19 related industry health protocols within the operation.

Poor Outcome Scenario 1

The beekeeper does not have sufficient honey bees to split an existing colony and/or is unable to access a domestic queen in time to support this colony. As a result, the colony in this scenario is unable to build up for any commercial pollination and produces only a fraction of the typical honey output. Operations costs go down due to less colony management, however, there is again an increase in COVID-19 related costs for this beekeeper to adhere to industry health protocols within the operation.

COVID Disruption Scenario 2

The commercial beekeeper has timely access to bulk and queen honey bees from within the operation and/or from local beekeepers to build up their colony, however, the representative beekeeper hired foreign workers for the spring and summer bee season and experienced a delay or cancellation in their arrival in 2020. As well, if/when the workers arrived, they were required to quarantine and follow strict health protocols, thus causing additional productivity/timing gaps and costs. The beekeeper has two options to manage this disruption to their colony, including:

Good Outcome Scenario 2

The beekeeper hires local workers to compensate for foreign worker arrival disruptions. Due to a labor productivity and timing gap between foreign and local workers, as reported in the survey, only a portion of the colony preparation is complete for the same labor cost as with foreign workers. The colony is not adequately built up for early pollination and earns a lower pollination grade and consequently lower rental fees. In addition to this loss of pollination revenue, the colony is not managed effectively (e.g., lack of treatment, feed, and other necessary interventions resulting in insufficient preparation) and thus produces less honey. Related to the productivity gap is the requirement for even stricter COVID-safety protocols to be in place in the case of foreign workers. Beekeepers have to pay for foreign worker quarantine as well as local worker wages during the timing gap and the risks of COVID-19 exposures and outbreaks increase with workers arriving from abroad and living together in close quarters. The beekeeper has increased additional labor costs.

Poor Outcome Scenario 2

Foreign workers are unable or unavailable to work and no local workers are hired to compensate. In this case, the beekeeper did not hire local workers either because of a lack of supply, a belief that foreign workers would eventually arrive but did not, or the case where foreign workers arrived well into the season and were required to quarantine or experienced an outbreak in the operation requiring isolation. Survey results indicate that with the availability of Canada's Emergency Response Benefit (CERB) for COVID 19-impacted unemployed Canadians during the spring and summer of 2020, there was a reduced incentive for Canadians to seek local employment. Due to a lack of labor, the representative beekeeper was unable to adequately prepare their colony and as a result, is not able to rent out the colony for pollination. The colony is also not managed effectively and as a result has decreased honey output. Additional COVID-19 related costs increase due to health protocols for industry workers while general colony operations costs decrease due to less colony intervention.

COVID Disruption Scenario 3

This scenario is a combination of scenarios 1 and 2, in which the beekeeper relies on both foreign workers and honey bee imports to operate his business. Like the earlier scenarios, scenario 3 has a good outcome in which the beekeeper is able to compensate for foreign workers and honey bee losses and a poor outcome in which the beekeeper cannot compensate.

Results

Survey Results

Over half of respondents indicated that they hire foreign workers annually. In 75% of these cases, these workers make up more than 50% of respondents' labor workforce and in 46% of cases, they make up more than 75% of their workforce. Ninety-two percent of beekeepers who hire foreign workers annually experienced cancellation or delays in their arrivals, with 46% of these respondents reporting over 80% of their foreign workforce was delayed and 19% reporting 80% of their workforce did not arrive at all. Of employers with foreign workers who eventually arrived, 86% reported that their workers quarantined for two weeks as per federal health orders, creating a lag between foreign worker arrival and inputs. Twenty-five percent of these employers also reported that they had to manage and pay for the two-week quarantine period for their foreign workers. Cochrane's Q test showed that survey responses for operational impacts from worker arrival disruptions were not selected in equal proportions X^2 (6, N = 112) = 59.25, $P < 0.001$. In the survey, 19% of responses indicated that beekeepers experienced increased personal protective equipment (PPE) costs, while 17% experienced increased vehicle costs (Supp. Fig. S1 [online only]). Beekeepers also dealt with decreased efficiencies due to COVID-19 disruptions, including 16% who had less colony output due to fewer workers and 13% who reported a decrease in efficiencies due to social distancing. In 58% of responses, beekeepers reported a timing gap of between two and six weeks between when foreign workers were scheduled to begin work and when those who did arrive were able to work or when local workers were hired. Fifty-six percent of beekeepers who hire foreign workers house them in accommodations with five or more individuals living together in close quarters, further increasing the risk of viral transmission and an outbreak in the operation. The chi-square goodness-of-fit test was used to determine that survey responses indicating the productivity impact from arrival disruptions for beekeepers whose foreign worker arrivals were compromised were not equally distributed X^2 (3, N = 89) = 207.04, $P < 0.001$. Seventy-seven percent of respondents hired local laborers, with 91% of these beekeepers indicating that there was a productivity gap between local workers and foreign workers, where local workers were less productive (Supp. Fig. S2 [online only]).

Beekeepers believed that this productivity gap was due to both local workers being less skilled and local workers prematurely leaving their employment (Supp. Fig. S3 [online only]). Cochrane's Q test was performed, and the results show that the proportion of responses indicating the reasons for a labor productivity gap were not equally distributed between categories X^2 (3, N = 90) = 133.59, $P < 0.001$. Seventy percent of local workers hired were between the ages of 15 and 24 years old. This younger demographic would be less likely to have acquired the skills necessary to perform at a high level compared to the foreign workers and more likely to be of student age. Employers indicated that local workers left their apiculture positions for both unknown reasons (possibly returning to in-person learning for student workers) and, in some cases, to qualify for assistance through Canada's Emergency Response Benefit, which provides easily accessible relief funds for Canadians 15 years and older who are experiencing unemployment due to COVID-19. Due to the COVID-19-related arrival disruptions for foreign workers, many beekeepers elected to (or were forced to) operate fewer colonies, with 30% of beekeepers reporting a reduction in the number of colonies in their operation. Cochrane's Q test results determined that the proportion of beekeepers' responses to types of impacts from worker disruptions differed by category X^2 (4, N = 97) = 141.18, $P < 0.001$. In addition, these beekeepers impacted by foreign worker disruptions experienced reduced colony management with 35% of beekeepers reporting fewer necessary interventions such as treatment applications and hive checks, while 25% had to postpone re-queening their surviving colonies (Supp. Fig. S4 [online only]).

Cochrane's Q test results show that the proportion of responses indicating the impacts from bee disruptions on beekeeping operations were not equally distributed in the categories X^2 (7, N = 150) = 156.78, $P < 0.001$. Operations faced significant delays or cancellations of their anticipated honey bee imports, affecting 40% of respondents who normally import bees each spring. Twenty-eight percent of those with disrupted bee imports indicated that general operations were affected, while 23% reported lost income, 22% had decreased colony management and in 17% of cases, the disrupted bee arrivals affected labor (Supp. Fig. S5 [online only]). Cochrane's Q test results show that the proportion of responses for types of disruptions to colony management were not equally distributed between categories X^2 (7, N = 93) = 107.12, $P < 0.001$. Twenty-nine percent of beekeepers who had disrupted honey bee arrivals reported less active colony interventions such as treatment and hive checks, 23% experienced a reduction in the number of colonies, while 29% focused more on local breeding or honey bee sourcing than pre-COVID-19 (Supp. Fig. S6 [online only]). In the case of COVID-19-caused delays or cancellations of imported bees in 2020, beekeepers had little to no advance notice, leaving them short colonies. Nearly a quarter of surveyed beekeepers reporting fewer colonies in 2020 due to these bee disruptions and were unable to build up any new colonies in a timely manner. Only 5% of surveyed beekeepers reported a reduction in the number of colonies rented for pollination due to a delay or cancellation in their honey bee imports, however, this represents 25% of the surveyed beekeepers who pollinate commercially.

Profit Results

Table 1 shows the parameter values and profit calculations without any COVID-19 disruptions and with temporary foreign worker and honey bee arrival disruptions as described in scenarios 1, 2, and 3. In the absence of any COVID-19 disruptions, the representative beekeeper would have accrued $286.00 in profit with one pollination contract and $398.50 with two contracts from this colony in 2020 (A). When bee imports do not arrive and the representative beekeeper has a timing and productivity lag in colony build-up but is eventually able to compensate with their own honey bees or locally sourced bees, colony profit falls by 55% to $127.70 with one pollination contract and $212.08 with two pollination contracts (1a). When the beekeeper is unable to compensate for honey bee losses and cannot adequately build up the colony for pollination, colony profit falls to $68.60 (1b). For the beekeeper whose foreign worker arrival is disrupted, and local workers are hired, higher COVID-related health and labor costs and less colony management results in lower output and a corresponding profit of $90.50 with one pollination contract and $128.00 with two contracts (2a). When COVID-19 related worker arrival disruptions result in even less efficient colony management with additional COVID-19 related costs and a colony too weak to pollinate, colony profit falls to $50.

Table 1 also shows the profit outcomes in scenario 3 for a beekeeper who is impacted by both honey bee and foreign worker arrival disruptions simultaneously. In this case, we modify the parameter values for both the longer-term health variable, α and the additional cost variable, β, to reflect further COVID-19 disruption impacts. As long-term colony health deteriorates and COVID-19 related risks and costs increase for the beekeeper when both honey bee and foreign worker arrivals are disrupted, it is no longer profitable to operate this honey bee colony with only one pollination contract, however, with two contracts for pollination, the colony is able to generate positive profits. In the good outcome case for a colony that is still able to commercially pollinate, albeit at a lower rental price and produce 75% of the typical amount of honey, profits fall to –$9.62 with one pollination contract and $52.66 with two contracts. When there is a poor outcome for this colony that is impacted by both TFW and bee arrival disruptions and there is no longer revenue from pollination, the colony generates negative profits of –$217.00. Fig. 3 shows the profit effects from foreign worker and bee disruptions alone for both good and poor outcomes, as well as colony profit effects when a beekeeper is impacted by both foreign worker *and* honey bee arrival disruptions. To identify any disproportionate or unanticipated effect of the parameters in our profit equation, we have conducted a sensitivity analysis of the key parameters. Table 2 shows the results of the sensitivity analysis when each variable is given a range of values, ceteris paribus. As the revenue (honey and rental fees) parameter values increased, so too did profit. As the expenditure (operations and other costs) parameter values increased, profits fell. As our COVID-19 related costs variable, β, increased in value from 0 to 1, we see profits falling, similarly as our health parameter, α, decreased in value from 1 to 0, profits also fell.

Discussion

The survey results suggest that Canadian beekeepers were significantly impacted by COVID-19-related disruptions in honey bee and foreign worker arrivals into Canada in the spring of 2020. The importance of skilled labor and honey bee availability to effectively manage colony health and productivity is highlighted in our economic analysis as we estimate the impact of COVID-19 disruptions on beekeeping profit. Additional industry health measures and practices also imposed greater costs on beekeepers, further impacting colony profits. Our estimates of the economic impact of these COVID-19 related disruptions show a range of profit effects from scenarios 1 and 2 where beekeepers were able to compensate for honey bee or foreign worker disruptions and maintain some profit. However, given the tight margins of beekeeping and critical roles of foreign workers and stock replacement, in scenario 3 when both honey bee and foreign worker arrivals are disrupted, even a 25% change to both the colony health parameter and the additional COVID-19 cost parameter result in a net economic loss for a colony with a single pollination contract. When the beekeeper cannot compensate for these simultaneous disruptions and no commercial pollination is possible, profits are negative. The additive and straightforward structure of our profit equation by design resulted in no unanticipated results from our sensitivity analysis.

As we consider the long-term effect of less healthy colonies going into winter and increasing COVID-19 costs and risks, we would anticipate even larger economic consequences of disruptions caused by COVID-19 in 2021. Over a third of survey respondents indicated that they expected to be impacted by COVID-19 during the spring and summer of 2021. While pre-travel processes and on-arrival regulations appeared to stabilize by the end of 2020, in early 2021 concern over the spread of new COVID-19 variants resulted in the implementation of a

Table 1. Total revenue, cost variables and colony profit for COVID-19 disruption scenarios 1, 2 and 3

Variables→ Scenario↓	α (0,1)	β (0,1)	P_h ($/lb)	Q_h (lbs)	RF(bl)($)	RF(cr)($)	C_{op} ($)	π ($/col) 1 rental	π ($/col) 2 rentals
A) No COVID-19 disruptions	1	0	4.10	100	124	112.50	248	$286.00	$398.50
1a) No imports: Good outcome	1	0.10	4.10	75	93	84.375	248	$127.70	$212.075
1b) No imports: Poor outcome	1	0.10	4.10	50	0	0	124	$68.60	$68.60
2a) No TFWs: Good outcome	1	0.25	4.10	75	93	84.375	248	$90.50	$128.00
2b) No TFWs: Poor outcome	1	0.25	4.10	50	0	0	124	$50.00	$50.00
3a) No TFW/Bee: Good outcome	0.75	0.25	4.10	75	93	84.375	248	–$9.63	$53.66
3b)No TFW/Bee: Poor outcome	0.25	0.75	4.10	0	0	0	124	–$217.00	–$217.00

number of new border measures. As foreign workers began traveling to Canada in early 2021, these new measures were gradually introduced, including pre-departure and arrival polymerase chain reaction (PCR) COVID-19 tests to identify the presence of COVID-19 in passengers. Increased testing protocols, new variants, and fourth wave outbreaks threaten to further affect travel to and from both source countries and Canada. We are also currently seeing a disruption in flights transporting bees to Canada, in particular the cancellation of Air Canada flights arriving from New Zealand with Arataki bee Packages. As well, throughout the first few months of 2021 with ongoing COVID-19 related delays and travel complications, commercial Canadian Beekeepers have anecdotally reported significant bee mortality rates on flights arriving into Canada, in some cases thousands of dead bees on arrival (Jonathan Jakes, personal communication, April 26th, 2021). As we progress through the 2021 beekeeping season, there remains a great deal of uncertainty with regards to the ongoing impact of COVID-19's travel and health restrictions on beekeeping. Canada's apiculture and agricultural industries will likely continue to feel some effects from COVID-19 disruptions, particularly as we consider the additional burden of deteriorating longer-term colony health.

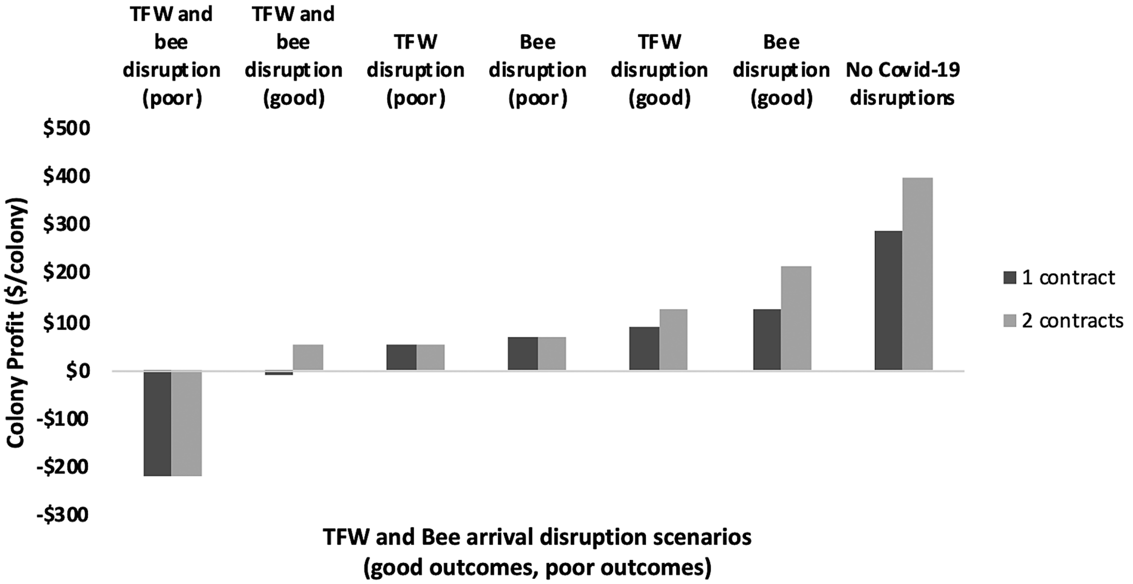

Fig. 3. Estimated colony profit with and without COVID-19 disruptions to TFW and honey bee arrivals in 2020.

Table 2. Sensitivity analysis: changing profit parameter values and the effect on profit (using baseline profit with no COVID-19 disruptions and only one pollination contract)

%Δ in parameter values					
	%Δ	10%	25%	50%	75%
Parameters	↓↑	Colony profit with parameter value changes			
Baseline profit (no COVID-19 disruptions)	$286.00				
α(0,1) Colony health	↓	$232.60	$152.50	$19.00	-$114.50
ß (0,1) COVID-19 Costs	↑	$261.20	$224.00	$162.00	$100
*Ph** Price honey ($/lb)	↓	$245.00	$183.50	$81.00	-$21.50
*Qh** Quantity honey (lb/colony)	↑	$327.00	$388.50	$491.00	$593.50
RF (bl) Rental fee ($/col)	↑	$298.40	$317.00	$348.00	$379.00
RF (bl) Rental fee ($/col)	↓	$273.60	$255.00	$224.00	$193.00
Cop Operation cost ($/col)	↑	$261.20	$224.00	$162.00	$100.00
Cop Operation cost ($/col)	↓	$310.70	$348.00	$410.00	$472.00

**Note the impact on profit from a decrease in honey price is equivalent to the impact from a decrease in honey quantity and vice versa, so we have included only one of each calculation.*

The industry-level result of colony-level unprofitability is that beekeeping operations eventually become unsustainable and individual beekeepers leave the industry. A reduced number of viable beekeepers and colonies would have devastating effects for the Canadian beekeeping industry and potentially even greater consequences on Canadian agricultural outcomes. A decrease in the effectiveness of honey bee pollination services for Canada's pollination-dependent crops due to a lack of strong honey bee colonies would be catastrophic for the agricultural sector and food security. COVID-19 has highlighted the potential impact of a precarious dependency on the migration of people and importation of goods. Canadian beekeepers are susceptible to not only pandemics, but also border closures due to pests and pathogen importation risks, such as the movement of Africanized bees or *Tropilaelaps* mites, natural disasters, and unpredictable politics in foreign worker source countries. COVID-19 has highlighted the urgent need for the Canadian beekeeping industry to expand its domestic bee and labor supply and work towards achieving long-term sustainability. There are opportunities for Canadian policy makers to incentivize beekeepers to expand domestic honey bee supply and Canadian residents to engage in apicultural skill acquisition in order to help mitigate future economic consequences within the industry. A further and ongoing analysis exploring the industry-wide effects of COVID-19 on apiculture in 2020 and 2021 would benefit beekeepers and pollination-dependent crop producers as we move through an unpredictable future in these critically important industries.

Supplementary Data

Supplementary data is available at *Journal of Economic Entomology* online.

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