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Article

What is the value of and who values native bee pollination for wild blueberries and cranberries?

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Abstract: Recent pollinator declines have focused efforts on their conservation which require clear estimates of pollination value to agriculture. Our socio-economic producer surveys and agronomic field research data were used to present a new way of estimating ecosystem service value of native pollinators. Using two regionally important U.S.A. crops, Maine wild blueberry and Massachusetts cranberry as models, we present perceived values of native bee pollinators from both consumer and producers. Wild blueberry's Replacement Cost (RC) was greater than Attributable Net Income (ANI), since greater rented honey bee stocking densities are required. Attributable Net Income for native bees were similar for wild blueberry ($613/ha) and cranberry ($689/ha). Marginal Net Farm Income (MNFI) from incrementally adding more hives per ha was greater from stocking a third/fourth hive per ha for cranberry ($6,206) than stocking a ninth/tenth hive per ha for wild blueberry ($556), given greater responsiveness of yield, revenue, and profit to using rented honey bee hives in cranberry compared to wild blueberry. Both crops' producers were only willing to annually invest $140-188/ha in native pollination enhancements on their farms, justifying government support. Consumers are willing to pay ~6.7 times more to support native bees than producers, supporting market-based support for invertebrate conservation.

Keywords: pollination value; native bees; economics; production function; willingness to pay; contingent valuation; stated preference; wild blueberry; cranberry; survey.

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1. Introduction

Recent declines in both managed and native pollinator populations [1] have highlighted the importance of pollination for maintaining the stability of agro-ecosystems [2,3,4]. Honey bees, the predominant managed pollinator used in the U.S., have declined by 62% over the past 60 years owing to agricultural intensification [5] as well as establishment of Varroa mites since the mid-1980s [6] and Colony Collapse Disorder (CCD) since 2006 [7–9]. Better monitoring [10] and stabilization [11] of pollinators have been advocated. Ecosystem service valuation of native pollinators in agricultural systems is paramount to producers' pollination strategy decisions and pollinator conservation efforts. Grower adoption of alternative pollination strategies may be hindered by real or perceived low valuations of native bee contribution to crop pollination.

The ecosystem service value of pollination by native (versus managed) pollinators can be estimated by quantifying 1) their contribution to the value of the crops they pollinate, or 2) their value to consumers. Based upon native bee contribution to pollinated crop value, (12) developed a framework valuing the role of native bees in crop pollination where pollination value can be estimated using Production Value, Replacement Cost, or Attributable Net Income. Production Value, where a pollinator-dependent percentage of total crop value is lost owing to a lack of pollination, assumes catastrophic crop loss from collapse of all pollinators. Although globally native bees contribute more to crop pollination than honey bees [13], in most production systems, including wild blueberry and cranberry, the proportion of pollination contributed by native bees is less than 100%. The remainder is contributed by managed pollinators [14–16]. Thus the market values of these crops exceed the ecosystem service value contributed by native pollinators. Replacement Cost assumes there is adequate time to invest in native pollinator replacements, such as renting or owning managed honey bee hives to substitute for native bees. The Replacement Cost approach may underestimate the value of native pollination if the pollination alternative (e.g., managed honey bees) is not an adequate substitute for native bees [13]. Further, while honey bee rental fee data is robust in the western U.S.A [17] only limited surveys are available for the eastern U.S.A. [18].

Native bees in western Kenya are estimated to contribute \$3.2 million of \$8.5 million total Production Value of eight crops [19]. The crop pollination services contributed by forest ecosystems around Costa Rican coffee plantations can increase crop Production Value by \$382/ha [20]. However, there are wide discrepancies between Replacement Cost and Production Value estimates of the value of native pollinators. Replacement Cost of native bee pollination is 99% less (managed honey bees) to 30% more (hand pollination) than Production Value estimates of the same in South African deciduous fruits [21]. Discrepancies between these two valuations also exist in U.S. watermelon in New Jersey and Pennsylvania [12] and several other crops globally [22]. The Attributable Net Income may be the most realistic way to estimate the value of native pollinators where crop profits are attributed to either managed and/or native pollinators [12]. Unlike Production Value [23,24], Net Farm Income and Attributable Net Income account for yield-dependent costs [25,12] that vary proportionally with yield, such as transportation or labor costs. Excluding these and other production costs from valuation estimates may exaggerate native pollinators' contribution.

Pollination value can be measured using surveys, by assessing the stated preference[1] of both consumers' and producers willingness to pay (WTP), for crops pollinated by native (versus managed) bees, and for investing in native bee pollination strategies, respectively. Studies on consumer WTP for native bee pollinated crops is scant. Consumers are willing to pay \$0.51/dry liter more for native bee pollinated blueberries (both wild and cultivated), enough to cover the annualized cost of planting bee pastures [26]. United Kingdom consumers' WTP was estimated to be \$22/person/year to maintain local agriculture and wildflower esthetics [27]. Studies of farmers' WTP for native pollination services is limited to small-shareholder farmers in western Kenya where average farmer WTP for native bee pollination is \$88/year [28]. Studies quantifying the amount agricultural producers are willing to

[1] Stated preference is for services with no markets such as native bee pollination, while revealed preference can directly be observed from markets such as those for rented honey bee hives.

annually invest in native pollinator friendly practices such as planting bee pastures (a.k.a. pollination reservoirs) have been limited [26].

In Massachusetts, U.S.A., cranberry (*Vaccinium macrocarpon* Aiton) is cultivated primarily in Plymouth (4,681 ha), Barnstable (433 ha), and Bristol (403 ha) counties. Although distributed statewide, wild blueberry (*Vaccinium angustifoilum* Aiton) in Maine is harvested biennially, with a distinct fruiting year and vegetative year. Wild blueberries in Maine are primarily grown in Washington (11,735 ha), Hancock (2,331 ha), Knox (751 ha), Lincoln (222 ha) and Waldo (172 ha) counties (Figure 1; [29(2012)]. Both industries expanded in the 1980s with subsequent decline of harvested fruiting area during 1997 - 2012 of 29% (10,921 ha to 7,329 ha) for Maine blueberry and 5% (5,557 ha to 5,284 ha) for Massachusetts cranberry [29(1997-2012)]. Maine wild blueberry (50% globally) and Massachusetts cranberry (25% globally) are major production areas for both crops [29(1998-2012)].

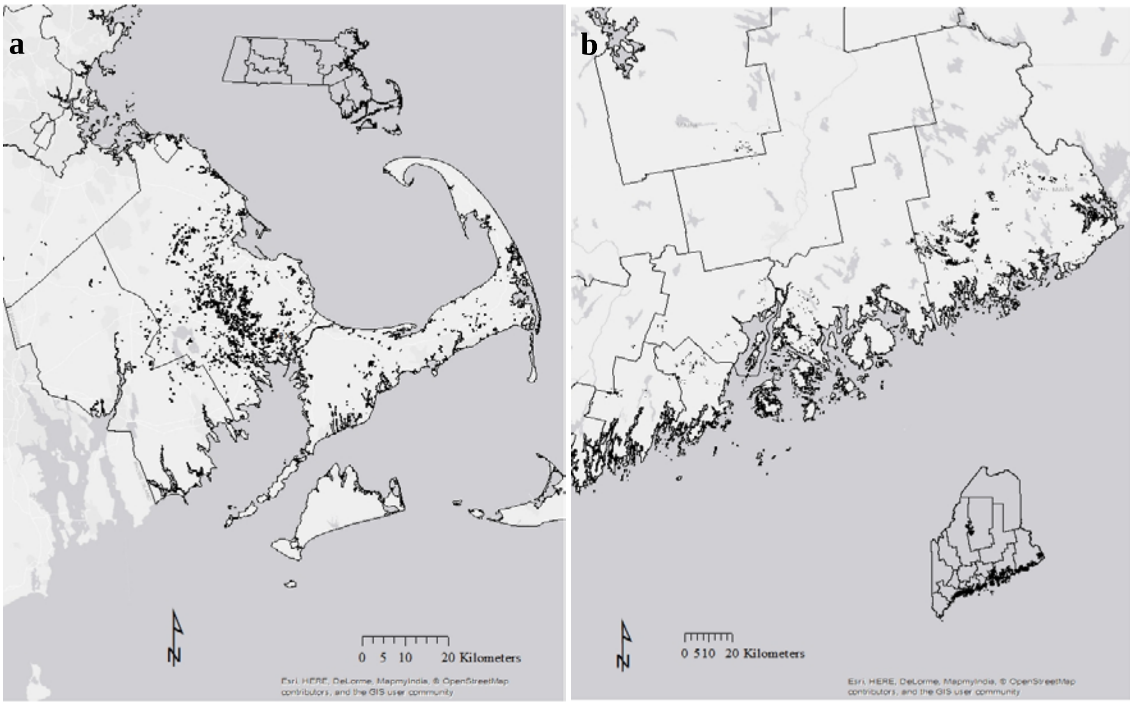

Figure 1. Production areas and regions for a) Massachusetts cranberries and b) Maine wild blueberries, USA.

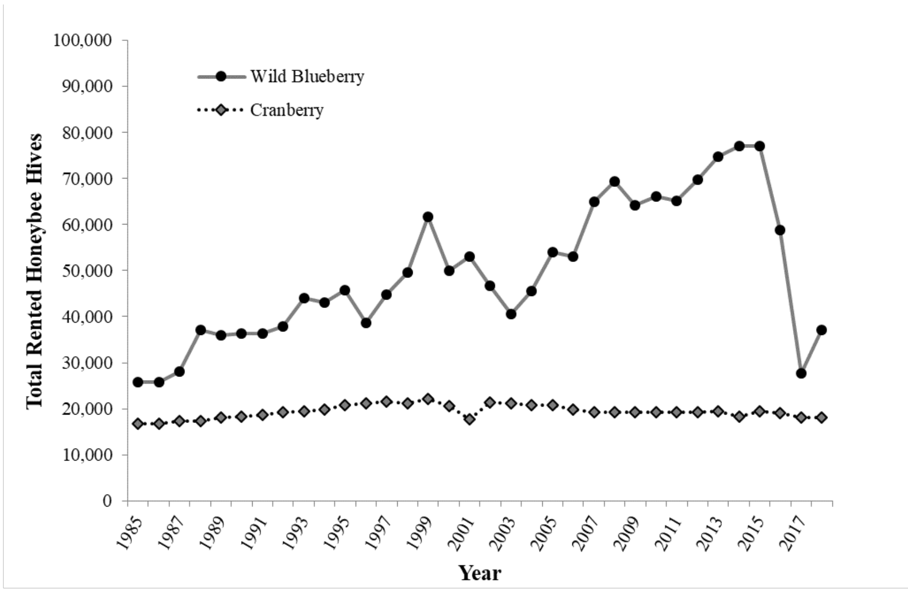

Figure 2. Annual rented honey bee hive use during 1985-2018 for ME wild blueberries and MA cranberries.

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During 1985 - 2013 Maine wild blueberry hive rental increased 191% (25,700 - 74,800), while wild blueberry crop area remained relatively stable [29, 30]. Hive stocking density for blueberries increased 197% from 3.2 hives/ha in 1983 to 9 hives/ha in 2013. However from 2013-2018, rented hives plummeted 50% as producers cut costs after price declines from successive years of high production (Figure 2). Cranberry industry hive use increased 17% during 1985 (16,678) to 2013 (19,482), with stocking density increasing from 2.35 to 3.66 hives/ha. The rental cost of honey bees is greater for blueberry producers than cranberry producers by about $20 per hive. This reflects the time of year hives are needed, with spring being a much more competitive hive rental market than summer [17].

This study uses consumer and producer survey data to quantify the value of native bee pollination, and compare these perceived values to estimates that are based on crop production data. We use crop production data from a single year, 2012. These crops are somewhat unique. Both are native to northeastern North American, and their native bee fauna is evolutionarily adapted to their floral morphologies and life history strategies [3]. However, both systems rely heavily on honey bees for supplemental pollination, especially since the 1970s [31,32]. Therefore, we consider these crops to be ideal models for economic analysis of pollination value. Our objectives were: 1) to compare Maine wild blueberry and Massachusetts cranberry producers' sources of pollination and 2) to improve native bee pollination value estimates for both crops using data from both producer and consumer economic surveys as both a complement to and substitute for native pollinators' directly measured contribution to fruit set and yield in entomological field studies.

2. Materials and Methods

2.1. Mapping Study Area

Maine wild blueberry fields were identified from a composite land cover map [33], and Massachusetts cranberry bogs were identified from the 2005 Massachusetts Land Use Dataset [34] with ArcGIS® version 10.2 (Environmental Systems Research Institute, Redlands, CA, United States, 2014).

2.2. Producer Surveys

Surveys of Maine wild blueberry producers in 2012 and 2013 (n=80, 20% of 400 commercial producers) informed pollination value estimates for the crop. We surveyed 46 respondents predominantly from Washington County at the Maine Wild Blueberry Industry's Annual Field Day on 18 July 2012, in Jonesboro, Maine. We surveyed an additional 34 producers from Hancock, Knox, Waldo, and Lincoln counties on-farm or over the phone during 19 July 2012 to 1 July 2013. More detailed crop budget in-person interviews were conducted with 35 producers on farm from 2012-15. From these data we created an enterprise budget model representative of the cropping system. This enterprise budget was used for Net Farm Income (NFI) calculations.

Using the same survey format, we surveyed Massachusetts' cranberry producers (n=66, 22% of 300 commercial producers) at the University of Massachusetts Cranberry Station Pesticide Safety Training meeting in East Wareham on 9 April 2013. In a supplemental survey on 15 April 2014, we asked cranberry producers (n=40) about their historical rented honey bee hive stocking densities as well as their production practices. Additional on-farm interviews to document pollination practices and economics of five cranberry producers occurred during 2012 - 2013. For cranberry, five sit-down interviews were conducted from 2013-14 to construct a representative crop enterprise budget to calculate NFI.

For both crops, producer surveys collected data on rented honey bee hive use and rental prices. Producers also were asked about the amount of money they were willing to invest in native bee enhancement on their farms as well as the practices they use to conserve and enhance native bee populations. Farmer socio-demographic data such as age, education, and attendance at Extension meetings were also documented.

Our blueberry and cranberry surveys were administered to larger, commercial farmers, producers most likely to have resources for financing pollination alternatives. Many producers in

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Maine own land containing wild blueberry fields but do not actively manage the crop [35]. In Massachusetts, 42% of 205 cranberry producers (48% response rate) surveyed in 2005 managed 0.4 - 3.6 ha [36]; only 15% of cranberry farmers we surveyed during April 2013 managed bogs of this size. Statistical analyses of survey data were done with the software packages JMP (SAS, 2012) and SPSS (2013).

2.3. Rented Honey Bee Hive Use

Rented honey bee hive use during 1985-2013 was compared for both crops. For Maine wild blueberries, hive imports were based on 1985-2013 bee keeper records [37], while Massachusetts cranberry hive imports were estimated from producer surveys. We estimated annual hive stocking densities (hives/ha) by dividing annual hive rental by estimated Maine wild blueberry harvested crop area linearly interpolated among Census of Agriculture years [29(1982-2012)] owing to a lack of reported annual harvested area. Unlike wild blueberry, cranberry harvested area is tracked annually. We estimated cranberry hive use by multiplying hives per ha interpolated from producer hive use data surveyed on 15 April 2014 by Massachusetts' crop area [29(1985-2012)]. Rented honey bee hive stocking densities in 2012 for both crops were calculated by averaging 2012 stocking densities from surveyed producers that were share-weighted by their farm's crop area. Honey bee hive stocking densities were multiplied by similarly share-weighted rented hive prices from our surveys to derive pollination costs per ha.

2.4. Value of Native Pollination

We estimated the 2012 pollination Replacement Cost (RC) for both crops by multiplying total hives used by the average surveyed cost per hive to estimate the total cost of rented honey bee hives (TC_{hb}) that serve as a substitute or replacement from relying on native bees:

$$RC = TC_{hb} \tag{1}$$

Production value (PV) of pollination for both crops was based on 1998 - 2012 crop total value (TV) calculated as the real (inflation adjusted) price multiplied by total crop production for each year [29] (USDA NASS, 1998-2012), which was then multiplied by a pollination dependency factor (d) = 1 [24], indicating complete dependency on animal-mediated pollination:

$$PV = TV \times d \tag{2}$$

Recent research suggests $d < 1$ for Wisconsin cranberry due to abiotic factors such as wind and agitation [38]. Since biotic contribution to pollination from other insects aside from honey bees was not quantified in their study to determine total animal mediated dependency (d), d = 1 was used [24].

Valuing pollination using Attributable Net Income requires first calculating Net Farm Income (profit) for both crops, which is crop total revenue (TR) minus total costs (TC) where TC equals both variable and fixed production costs. Net Farm Income (NFI) was calculated using detailed representative budgets based on individual budgets from 32 wild blueberry and 5 cranberry farmers surveyed on-farm from July 2012 to July 2013. While surveyed producers were fewer in cranberry (5) than in wild blueberry (32), cranberry has less variability in producer management in addition to more detailed crop management and cost of production data [39]. The wild blueberry budget was checked with summary budgets from farmers [40]. Budgets were constructed to have yield dependent costs such as crop taxes and harvest transport vary with yield changes (Supplementary Materials, Tables S1 & S2).

Attributable Net Income (ANI) equals NFI times the percent (P) of NFI attributable to native bees (nb) versus managed honey bees:

$$ANI_{nb} = NFI \times P_{nb} \tag{3}$$

Estimation of P_{nb}=39.89% for wild blueberry was based on our 2012-13 producer survey and consistent with historical field studies [13,14], while P_{nb}=34.3% for cranberry was solely from our 2013-14 producer survey, owing to a lack of available entomological field data measuring this.

ANI_{nb} in addition to RC and PV were calculated as 1998 - 2012 average values. To estimate ANI on a per bee basis for both crops, ANI was divided by typical numbers of foraging rented honey bees (Q_{hb}) or typical observed native bee (Q_{nb}) densities for wild blueberry [14,41] and cranberry [42,43].

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Each rented honey bee hive for wild blueberry was assumed to have 8,000 foraging workers (20% of an average colony population of 40,000 bees [44]; whereas for Massachusetts cranberry this was half as much owing to smaller colony size (20,000 bees) for most hives [45].

The incremental (marginal) change in farm profits NFI as rented honey bee hives (H_{hb}) are added to the farm system is a way to value managed pollination which can be used as a proxy for pollination from native bees. Such marginal profit (MP) was calculated with nonlinear asymptotic sigmoidal production functions fit for both crops based on our producer surveys:

$$MP = \Delta NFI / \Delta H_{hb} \quad (4)$$

Crop enterprise budgets were used to calculate profit (NFI) at each scenario using incrementally more managed honey bee hives. Calculating the difference in NFI between these scenarios derives MP.

Production functions are defined as crop output (kg yield/ha) as a function of input (hives/ha) and commonly have diminishing returns to input use, at least at the upper end of the input range [46]. A sigmoidal relationship is both theoretically expected and empirically observed between pollination input and fruit set or yield [13,47]. Production function data from our producer surveys were graphed with wild blueberry field study data for yield/ha versus hives/ha collected on producer's farms in 2013 [48], while for cranberry similar field study data were not available.

Production functions were estimated using non-linear asymptotic (NLAS) models explaining crop yield (kg/ha) as a non-linear function of rented honey bee hive density (hives/ha) plus other farm production characteristics. NLAS production function models improved marginal output estimates over initial univariate models using just hives/ha. Linear multivariate (LMV) production function models were used for greater ease of interpretation of parameter estimates of marginal impacts compared to non-linear asymptotic model runs. All production function models were run in SPSS (2013).

The fitted production function models were then used to estimate marginal outputs with increasing hive use. These incremental changes in crop output were then used in representative crop budgets to estimate marginal revenues (value of marginal product or VMP) and MP (marginal NFI) with increasing hive use. Like NFI and ANI, MP was adjusted for 100% dependency (d=1) on animal-mediated pollination. Calculating marginal profit used average crop prices. This marginal measure is driven by incremental changes in yield that is predominantly independent of crop price. Thus we did not run sensitivity analyses for MP based on crop price.

2.5. Consumer Surveys

Methods for assessing consumer WTP for native pollination of cranberries was similar to contingent valuation (CV) survey methods used for blueberries (n=498) [26]. An online Qualtrics survey (n=771 viable observations) was administered to United States citizens (≥18 years old) online through Amazon Mechanical Turk (AMT) marketplace for researchers and workers as a human intelligence task completed in return for a $0.45 payment. Each respondent was able to see the payment amount and read a short description of the survey prior to participation. Participants entered a code from the Qualtrics survey back into AMT, allowing us to match survey responses with AMT's anonymous worker identification numbers.

The online survey had two versions. Both versions began with a short introduction summarizing the study's objective to determine consumer WTP for native pollination of cranberry, along with verifying age requirements of participants. Unlike the first survey, the second survey asked respondents to sign an oath promising to give honest, accurate answers. Our oath may not be as effective as an oath administered in-person since respondents were not required to show any form of identification. Survey results improve once people sign an oath with their name or initials. Using surveys with and without an oath allowed us to analyze hypothetical bias where survey respondents hypothetical WTP can be double or triple their actual WTP [49].

Consumer survey respondents were then provided a brief summary of Colony Collapse Disorder, a list of products containing cranberries, and possible benefits and costs of native pollination. Surveyed consumers were then asked their WTP as well as their percent WTP more (0%, 5%, 10%, 15%, >15%) for hypothetical sustainable native pollinated cranberry products priced $2, $5, or $10. No specific cranberry product was listed due to the diversity of products containing cranberries. Forcing consumers to complete the survey with only one specific cranberry product in mind could bias results. For example, survey participants disliking fresh cranberries may not be willing to pay any more for native pollination of the crop, while this answer may be positive for products containing cranberries that they enjoy more (e.g. juice, Craisins®, etc.). The choices of $2, $5, and $10 represent common prices for cranberry products sold in grocery stores.

Next survey respondents were asked for their level of certainty (0% to 100% in 10% increments) of their WTP responses. Past research suggest that people with 70% to 80% or more certainty tend to provide more accurate CV responses [50], so this can be used to mitigate hypothetical bias. Respondents were asked to specify their reasons if they were not willing to pay any price increase for native pollinated cranberries. The survey concluded with socio-demographic questions including if they read product labels when shopping, prior knowledge of CCD and commercial honey bee (CHB) keeping, viewing climate change (CC) as a problem, having at least one child, as well as their gender, ethnicity, age, and annual income. These socio-demographic variables were regressed against WTP using Ordinary Least Squares (OLS) with associated parameters (β_n) and random error (ε):

$$WTP = \beta_0 + \beta_1 Price + \beta_2 Oath + \beta_3 Certainty + \beta_4 Labels + \beta_5 CCD + \beta_6 CHB + \beta_7 CC + \beta_8 Child + \beta_9 Gender + \beta_{10} Ethnicity + \beta_{11} Age + \beta_{12} Income + \varepsilon \quad (5)$$

to test for factors significantly influencing respondents' stated preferences. An ordered logit regression was also run to compare to the OLS model.

3. Results

3.1. Producers' Pollination Practices

Although Maine wild blueberry producers manage slightly more cropland per farm than Massachusetts cranberry producers (see Table 1), wild blueberry producers are more reliant on pollination services of native bees ($F_{(1,142)} = 5.731$, $P = 0.018$) and are 3.7 times more likely to not use honey bees than cranberry producers ($\chi^2_{(1)} = 7.161$, $P = 0.007$). For those wild blueberry producers who do rent honey bee hives, stocking densities are greater than densities used in cranberry ($F_{(1,103)} = 12.516$, $P = 0.006$). Honey bee hive density is positively associated with yield for both industries (Slope = 8.923, $F_{(1,84)} = 8.473$, $P = 0.005$). Percent of available crop blossoms pollinated by native bees (fruit set) was estimated by cranberry farmers to be 34.3% and by wild blueberry farmers to be 39.9% (Table 1). Wild blueberry and cranberry producers who did not rent honey bee hives attributed more pollination (83.8%) to native bees than did producers who rented hives (30%). A greater percentage of wild blueberry (36%) than cranberry (18%) producers reported monitoring native bees.

3.2. Pollination Value

Replacement cost (RC) for Maine wild blueberry rented honey bee hives at stocking densities weighted by farm size is $7,272,851 or 13% of the 1998 - 2012 crops' average production value ($55,622,419). The RC for Massachusetts cranberry ($1,508,454) is 2% of the 1998 - 2012 crops' average production value ($76,835,455). The difference in RC is attributed to lower stocking densities and prices of rented honey bees for cranberry (3.66 hives/ha at $78.62/hive) versus wild blueberry (9.46 hives/ha at $104.20/hive). Greater cranberry production value is attributable to greater average cranberry yield (14,996 kg/ha) compared to wild blueberry yield (3,704 kg/ha), despite cranberry's lower (42%) average price per kg (Table 2).

Pollination valuation estimations of Net Farm Income (NFI) and Attributable Net Income (ANI) subtract production costs from total revenue reflecting farmers' realized returns. NFI and ANI may be more accurate estimations of pollination value that are between the value of short-run catastrophic crop loss (PV) from pollinator collapse and the long-run perfect substitutability of

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managed pollinator rentals (RC). Estimated total NFI for Maine's wild blueberry industry ($12,852,054) exceeds total NFI for Massachusetts' cranberry ($10,226,073), owing to 71% more harvested average (1998 - 2012) crop area for wild blueberry (9,384 ha) compared to cranberry (5,501 ha). Cranberry NFI per ha ($2,009) exceeded that for wild blueberry ($1,536). This difference is attributable to the greater cranberry yield per ha (305%) that resulted in greater crop total revenues ($14,119 for cranberry vs. $6,340 for wild blueberry).

Table 1. Use and characteristics of pollinators by Maine wild blueberry (BB) and Massachusetts cranberry (CB) growers.

Dependent Variable	Crop / Effect	Mean (Standard Error)	Test	Statistic	P-value
1) Hectares (ha) Managed[a]	Crop: BB	184.17 (59.50)	ANOVA	$F_{(1,143)} = 2.691$	0.103
	Crop: CB	39.55 (66.01)			
2) Hectares Pollinated by Native Bees	Crop: BB	3.05 (0.72)	ANOVA	$F_{(1,142)} = 5.731$	0.018
	Crop: CB	0.51 (0.80)			
	Hectares managed^{NS}				
	Hectares x crop^{NS}				
3) Use of Honey Bee (HB) Hives by Growers (predicts probability not to use hives)	Crop	Odds: BB 3.74 X likely not use HB than CB	Logistic regression	$\chi^2_{(1)} = 7.161$	0.007
	Hectares managed			$\chi^2_{(1)} = 24.757$	< 0.0001
	Hectares x crop^{NS}	Slope = -0.508			
4) Hives / ha of Those Renting Hives	Crop: BB	5.31 (0.42)	ANOVA	$F_{(1,103)} = 12.516$	0.006
	Crop: CB	2.92 (0.40)			
	Hectares managed			$F_{(1,103)} = 11.618$	0.0009
	Hectares x crop^{NS}				
5) Rental Cost of Honey Bee Colonies	Crop: BB	$98.44 ($2.40)	ANOVA	$F_{(1,77)} = 22.261$	<0.0001
	Crop: CB	$77.90 ($3.11)			
	Hectares managed^{NS}				
	Hectares x crop^{NS}				
6) Expected Fruit Set by Native Bees	Crop^{NS}; Crop: BB	39.89% (3.34%)	ANOVA		
	Crop: CB	34.30% (4.04%)			
	Hectares managed	-0.511 X (sqrt hectares)		$F_{(1,124)} = 8.125$	0.005
	Hectares x crop^{NS}				
	Use of HB			$F_{(1,124)} = 127.707$	<0.0001
	Use of HB x crop^{NS}	no HB = 83.81% (5.02%) HB= 26.96% (1.97%)			

[a] Square root (SQRT) transformed, but means are untransformed.

Maine Cooperative Extension recommendations (personal communication, David Yarborough) for honey bee hive rental for wild blueberry (9.88 hives/ha) is a greater portion of variable costs for wild blueberry production (35%), whereas recommended [51] hive rental (4.94 hives/ha) comprises

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only 7% of the variable costs for cranberry producers. Therefore, Replacement Cost (or hypothetical expenditures on additional rentals to replace failed hives) for wild blueberry ($7,272,851 or $992/ha) is greater than its Attributable Net Income from native bees (ANI_{nb}=$5,126,684 or $613/ha). Cranberry ANI_{nb} was estimated at $3,507,543 or $689/ha. Decreasing values for PV, NFI and ANI_{nb} were consistent for both crops across the full range of 1998 - 2012 crop prices (Table 2).

Table 2. 1998-2012 Maine wild blueberry (BB) and Massachusetts cranberry (CB) crop production values of pollination.

		------ 2012 Rented Hives[a] ------			------------------------ Average for 1998-2012 Crop Years ------------------------					
Crop	Measure	Amount	Cost ($/hive or $/ha)	Replace-ment Cost ($ or $/ha)	Attributable Net Income for Native Bees[a] ($ or $/ha)	Net Farm Income[a] ($ or $/ha)	Prod-uction Value[b] ($ or $/ha)	Price[b] ($/kg)	Prod-uction[b] (kg or kg/ha)	Harv-ested Hect-ares[b] (ha)
ME	Total	69,800	104.20	7,272,851	5,126,684	12,852,054	55,622,419	1.607	34,718,655	9,384
BB	Per ha	9.46	984.91	992[c]	613	1,536	6,340	-	3,704	-
MA	Total	19,048	78.62	1,508,454	3,507,543	10,226,073	76,835,455	0.933	82,063,932	5,501
CB	Per ha	3.66	286.72	287	689	2,009	14,119	-	14,996	-

[a] From 2012-2013 wild blueberry (n=80) and 2013-14 cranberry (n=66) grower surveys.
[b] From USDA NASS (1998-2012) and Census of Agriculture [29(1997,2002,2007,2012)].
[c] Estimated by dividing 2012 rented hive value from Maine beekeepers (personal communication, Tony Jadczak, Maine Department of Agriculture) by 2012 harvested wild blueberry cropland from Census of Agriculture [29,(2012)].

Total NFI ($12,852,054) for Maine wild blueberry is split between rented honey bees ($7,725,369) and native bees ($5,126,684). ANI per ha for wild blueberry is similarly divided between rented honey bees (ANI_{hb} = $923) and native bees ($ANI_{nb}$ = $613). For Massachusetts cranberry, total ANI and ANI per ha are both greater for rented honey bees ($6,718,530 and $1,320/ha) compared to native bees ($3,507,543 and $689/ha). ANI on a per bee basis is greater for rented honey bees for cranberry ($0.09/bee) compared to wild blueberry ($0.012/bee). Native bee densities in cranberry are slightly greater than in wild blueberries [43,14,41], so native bee pollination value per bee is less ($0.26/bee) than for wild blueberry ($0.31/bee). ANI values per native bee are greater than those for rented honey bees due to natives' greater pollination efficiency [52,53].

Production functions for wild blueberry indicate lower marginal impact of hive use on yield compared to cranberry, with diminishing returns to rented honey bee hive use for cranberry after 4.94 hives per ha compared to 9.88 hives per ha for wild blueberry (Figure 3). Cranberry's greater marginal output is a result of average 1998 - 2012 crop yields that are more than three times larger than that of wild blueberry, harvested into 18-wheel tractor trailers compared to 10-wheeler flatbeds or smaller trucks typically used to transport wild blueberries out of field. Fewer cranberry pollen grains per flower are required for cranberry pollination compared with that required for blueberry pollination, and therefore, hive use per ha for Massachusetts cranberry is less than that for Maine wild blueberry, even though cranberry floral density (61.8 - 98.8 million/ha) exceeds that for wild blueberry (19.8 million/ha) [54,51]. Despite lower cranberry prices, the greater marginal impacts on crop yield for cranberry relative to wild blueberry result in not only greater marginal

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changes in total revenue per ha but also greater marginal changes in NFI per ha for cranberry ($2,440 - $6,206) compared to wild blueberry ($797 - $1,102) when using 2 to 8 hives per ha (Table 3).

Table 3. Total and marginal output, revenue, and profit per hectare for adding more rented hives for Maine wild blueberry and Massachusetts cranberry.

Crop	Hives/ha	Crop Yield (kg/ha)	Marginal Yield[a] (kg/ha /hives)	Crop Price[b] ($/kg)	Total Revenue ($/ha)	Value of Marginal Product ($/ha)	Variable Costs (VC) ($/ha)	Rented Hive % of VC	Fixed Costs ($/ha)	Net Farm Income (NFI) or Profit ($/ha)	Marginal NFI[a] ($/ha)
Wild	0	2,396	-	1.607	3,851	-	1,565	0	1,655	631	-
Blue-	2	3,236	840	1.607	5,201	1,350	1,856	11.23	1,655	1,690	1,059
Berry	4	4,105	869	1.607	6,597	1,396	2,150	19.39	1,655	2,792	1,102
	6	4,907	802	1.607	7,886	1,289	2,438	25.64	1,655	3,793	1,002
	8	5,575	668	1.607	8,960	1,074	2,714	30.71	1,655	4,591	797
	10	6,085	510	1.607	9,779	819	2,977	35.00	1,655	5,147	556
Cran-	0	10,790	-	0.933	10,070	-	5,089	0	6,583	-1,602	-
berry	2	17,694	6,904	0.933	16,515	6,445	5,327	2.95	6,583	4,605	6,206
	4	24,520	6,826	0.933	22,885	6,370	5,565	5.65	6,583	10,737	6,133
	6	29,454	4,934	0.933	27,491	4,605	5,780	8.16	6,583	15,128	4,390
	8[c]	32,272	2,818	0.933	30,121	2,631	5,971	10.53	6,583	17,567	2,440
	10[c]	33,670	1,398	0.933	31,426	1,305	6,145	12.79	6,583	18,698	1,131

[a] Marginal yield is the incremental change in yield from adding additional rented hives calculated from estimated production function equations in Figure 3. Marginal NFI is the change in NFI for native bees from incrementally adding hives.
[b] Crop prices are 1998-2012 average real prices adjusted for inflation using crop specific producer price index.
[c] Only one surveyed cranberry grower on April 9, 2013 (n=66) in East Wareham, Massachusetts stocked 7.41 hives per hectare. University of Massachusetts Cooperative Extension recommendation is to not exceed stocking density of 4.94 hives per hectare owing to diminishing marginal returns.

Linear multivariate (LMV) regressions for production functions (Table 4) explained more of the variation in crop yield for both wild blueberry (r^2= 0.555) and cranberry (r^2= 0.508) compared to univariate non-linear asymptotic (NLAS) models for these same crops (r^2= 0.263 and 0.141 respectively, Figure 3). For both crops, larger farms had significantly larger yields. For wild blueberry, Midcoast producers in Waldo, Knox, and Lincoln counties had significantly smaller yields compared to those in Washington County (Figure 3) likely due to the lower intensity systems and smaller fields typically found in this area. Wild blueberry pollination management did not significantly affect yields. Cranberry farmers managing the improved Stevens variety had greater yields than farmers producing traditional Early Blacks and Howes. Cranberry producers tended to have significantly greater yields if they altered pesticide use for bees, left standing dead wood around their bogs, and if they did not change hive stocking densities when they perceived spillover pollination from other producers' rented honey bees.

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3.3. Consumer and Producer Surveys

There were no significant differences in WTP values between cranberry consumer survey respondents who took the oath versus those that did not, nor OLS and ordered logit models.

Table 4. Linear multivariate regression estimates for Maine wild blueberry (BB) and Massachusetts cranberry (CB) production functions.

Dependent Variable F-test & Significance[a]	Independent Variables	Coefficient	Standard Error	t-Statistic & Significance[a]	Model Fit (r^2)
BB Crop yield (hg/ha)	Constant	1,822.76	242.08	7.529***	0.555
$F_{(5,72)}$ = 16.683***	Hives/acre	2,038.37	434.49	4.691***	
	Hives/acre^2	-651.27	190.09	-3.429***	
	Hives/acre^3	59.51	18.10	3.287***	
	Acres pollinated	0.25	0.09	2.674***	
	Mid-coast growers	-869.89	402.86	-2.159**	
CB Crop yield (kg/ha)	Constant	12,273.21	2,720.75	4.511***	0.508
$F_{(9,60)}$ = 5.863***	Hives/acre	6,632.64	6,089.58	1.089	
	Hives/acre^2	-4,598.85	5,469.64	-0.846	
	Hives/acre^3	817.55	1,274.30	0.642	
	Acres pollinated	10.09	2.47	4.176***	
	Early Blacks/Howes	-3,187.48	1,475.82	-2.160**	
	Stevens	4,016.68	1,584.32	2.535**	
	Alter pesticide use	4,531.26	1,832.48	2.473**	
	Leave dead wood	3,519.36	1,283.49	2.742***	
	Rent fewer hives (spillover)	-5,399.92	1,653.48	-3.266***	

[a] Significance at p=0.10 (*), p=0.05 (**), and p=0.01 (***).

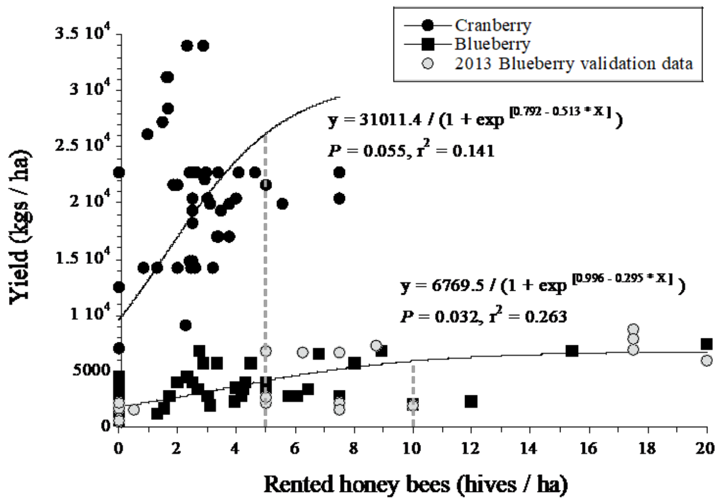

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Figure 3. Production function of crop yield versus hive density for Maine wild blueberries and Massachusetts cranberries.

Higher consumer WTP for native pollinated cranberries were significantly associated with higher certainty, reading product labels, knowledge about CCD, belief that climate change is a problem, women versus men, non-African Americans, and higher income. The price premium that survey respondents were willing to pay for native bee pollinated cranberries as a percentage of product price declined for $2 (12%), $5 (8.6%), and $10 (7.5%) cranberry products with an average price premium of 8.4%. Cranberry native pollination price premiums were slightly less than the 14% premium [26] found for blueberries. Applying these price premium percentages to the production value of both crops, consumers' value of native bee pollination are quantified for both Maine wild blueberry ($888/ha) and Massachusetts cranberry ($1,179/ha) in Table 5, close to covering the $974/ha annual cost of establishing pastures (a.k.a. pollination reservoirs) for native bees [55]. For both crops, consumer WTP per ha exceed Attributable Net Income for native bees (ANI_{nb}) per ha. The amount that surveyed wild blueberry ($140/ha) and cranberry ($188/ha) producers are willing to invest annually on their farms to enhance native pollinators are only ~15% of what consumers are WTP for native bee pollination and ~25% of ANI_{nb} (Table 5).

Table 5. Maine wild blueberry and Massachusetts cranberry pollination valuation comparisons.

	------------------- Crop Production Valuations ($/ha) -------------------					-- Willing to Pay ($/ha) --	
Crop	Production Value[a]	Net Farm Income[a]	Attributable Net Income (ANI) for Native Bees[b]	Replacement Cost[b]	Marginal NFI at 4 hives/ha[b]	Consumer[c]	Producer[b]
ME Wild Blueberry	6,340	1,536	613	992[d]	1,102	888	140
MA Cranberry	14,119	2,009	689	287	6,133	1,179	188

[a] From [29{1998-2012)] and Census of Agriculture [29,(1997,2002,2007,2012)].
[b] From 2012-2013 wild blueberry (n=80) and cranberry (n=66) grower surveys of crop production, native bee pollination, hive use, and amount willing to annually invest in native bee habitat on-farm.
[c] From 2013 blueberry (n=498) [26] and 2016 cranberry (n=771) consumer willingness to pay surveys with 14% (wild blueberry) and 8.4% (cranberry) price premium paid over production value.
[d] Estimated by dividing 2012 rented hive value from Maine beekeepers [38] by 2012 harvested wild blueberry cropland from Census of Agriculture [29,(2012)].

4. Discussion

4.1. Improving Valuation Metrics of Native Bee Pollination

Replacement cost (RC) as a percent of production value (PV) is low for both Maine wild blueberry (13.08%) and Massachusetts cranberry (1.96%) although greater than the national average of 0.56% [29]. The estimated rental (replacement) cost of U.S. honey bee hives was about $91.3 million (2,599,000 honey producing hives x $35.14/hive) in 2003 [29(2005),17] or about 1/180 = 0.56% of total U.S. crop value dependent on bee pollination [24]. Thus RC of native pollinators may underestimate the value of obtaining pollination ecosystem services owing to the time lag for ordering rented honey bee hives (6 - 12 months) for wild blueberry and cranberry producers, where hive prices and thus RC may increase as beekeeper regeneration costs go up prior to the following year's order of rented hives placed by producers.

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Increasing rented honey bee hive prices may be more of a challenge for wild blueberry compared to cranberry. Hive prices are higher for earlier-blooming wild blueberry (May) compared to cranberry (June) (Table 2), consistent with past research where hive prices were more for crops that bloom closer to winter hive regeneration. Beekeepers typically undertake hive regeneration in February due to CCD or other off-season mortality [17]. Although producers of pollinator-dependent crops may be able to absorb recent price increases [56], persistent increases in pollination fees may encourage adoption of alternative pollinators. For example, increased use of an alternative almond pollinator, the blue orchard bee (*Osmia lignaria* Say) could decrease real hive prices for almonds by 40% assuming a 15% reduction in rented hives [57].

The lower U.S. RC/PV percentage (0.56%) may be due to U.S. crop PV being inflated due to inclusion of soybeans. Soybeans have questionable dependence on pollination by bees combined with constituting a disproportionate percentage of U.S. pollinator-dependent crop production value [58]. Another reason PV and subsequently Net Farm Income (NFI) may over-estimate the ecosystem service value of native pollination for certain crop areas like southeastern Massachusetts cranberry and Maine's Downeast (rather than Midcoast) wild blueberry barrens is lack of sufficient quantity of surrounding habitat to support enough native bees to reliably pollinate each crop. For cranberry in our study, thin forest strips and suburbs surrounding bogs have limited floral resources for native pollinators. The wild blueberry barrens of Maine have large fields surrounded by more extensive patches of forest [59] than Massachusetts cranberry but the forest is predominantly softwood, which is generally poor habitat for crop pollinators. Since PV and NFI for these areas are so dependent on rented honey bees, it is important to determine the amount of NFI that is "attributable" to native (versus managed) bees.

Current Attributable Net Income (ANI) calculations do not differentiate between farm profits attributable to pollination versus other factors (i.e., irrigation risk or weather conditions) affecting crop yields, revenues, and profits. Prior research on other crops [60,22,21] do not make this distinction, potentially inflating pollination value. While NFI has been attributed to both native (ANI_{nb}) and managed honey bees (ANI_{hb}) [12], NFI has not been attributed to factors other than pollination (e.g. weather) [61]. For Massachusetts cranberry, pollination was sufficient in 2013, however, unusually hot summer weather stressed vines and contributed to aborted fruit, which disproportionately reduced crop yield and profits. While our ANI_{nb} estimates use average fruit set from native bees estimated by wild blueberry and cranberry producers at approximately 1/3 of their crop, native bee fruit set on farms can be variable. For example, larger producers who operate the majority of production area for both crops have a higher crop field to natural habitat ratio, less abundant native bee populations, and proportionally less (~5%) of their pollination services are provided by native bees [48].

ANI_{nb} reflects the total contribution to farm profitability from native bee (nb) pollination; however, it also has limits as an aggregate measure of pollination value because it does not show incremental (marginal) impacts from adding pollinators. The additional units for managed bees are standardized and quantifiable, facilitating estimation of marginal NFI from incrementally adding hives. Determining such marginal impacts of native bees is challenging, however, because few surveyed producers monitor native bees (cranberry, 18%; wild blueberry, 36%). This may be attributed to time management rather than difficulty with pollinator monitoring and identification [62]. The use of producer surveys to derive marginal ANI_{nb} from marginal NFI (marginal NFI x % fruit set from native bees = marginal ANI_{nb}) would be enhanced by measuring the marginal impact of native versus managed pollinators in field studies.

The three pollination valuation methods (RC, PV, and ANI) used in the literature do not measure the incremental contribution of a pollination unit such as a honey bee hive, which can be used as a proxy for the ecosystem service value of native bees. By fitting a crop production function (yield/ha as a function of hives/ha) to producer survey data, such incremental (marginal) impacts of rented honey bee hives can be estimated as the marginal output (yield) associated with adding each hive/ha. The subsequent pollination valuations derived using such marginal output (marginal product, value of marginal product, and marginal NFI) measure the marginal increases in crop

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yield, revenue and profits from adding incrementally more rented honey bee hives (or potentially native bee hive equivalents) per hectare. Marginal NFI/ha derived from production functions is more reflective of the degree of diminishing returns to using 2 to 10 rented honey bee hives/ha for both wild blueberry ($1,059 → $556) and cranberry ($6,206 → $1,131) in Table 3, compared to average surveyed NFI/ha estimates for wild blueberry ($1,536) and cranberry ($2,009) in Table 2. The degree of these diminishing returns does not reflect risk due to years with bad weather that reduces the number of days pollinators are available to set the crop. For hives that are split going from wild blueberry to cranberry, marginal output and profit per "hive equivalent" rather than per hive may be greater.

Commercial cranberry producers may place greater emphasis on the importance of stocking the Cooperative Extension recommended number of honey bee hives per ha (4.94) on their farms compared to wild blueberry (9.88) owing to cranberry's greater initial responsiveness of crop yield and profit (steeper initial slope of production function, Figure 3) with incremental rented honey bee hive use. If pollination options are less effective, cranberry producers are more immediately threatened with greater loss of yield, revenue, and profit at the margin compared to wild blueberry producers. This is not to say that using pollination alternatives are not important to Maine's wild blueberry industry, given at least two hives per ha insures adequate profits (Table 3). Rather, the economics of pollination driven by the production functions for both crops create an incentive for cranberry producers to emphasize managed pollination and potentially pollination alternatives more than wild blueberry producers. This also is reflected in the greater percentage of pollination value (ANI/bee) of one honey bee compared to one native bee for cranberry ($0.09 / $0.255 = 35.5%) versus wild blueberry ($0.012 / $0.306 = 4%).

Estimating production functions from producer surveys can enhance understanding of incremental impacts of rented honey bees on crop yield and may be better suited for crops that are more reliant on rented honey bees rather than native bees due to the afore mentioned challenges of standardizing and measuring native bee hive equivalents. Accurate calculation of NFI and ANI requires robust economic budgets with specification of yield-dependent variable costs as well as fixed costs such as depreciation. In this analysis, the pollination value of native bees was estimated based on allocating ANI between rented honey and native bees based on producers' estimates of percent fruit set from native bees. While for wild blueberry these estimates were consistent with measured field data [63,64], cranberry in our study did not have field data that could be used to validate producers' estimates of percent fruit set from native bees (Figure 3).

4.2. Recent Policy and Marketing Incentives to Promote Native Bee Conservation

Our survey has found that many cranberry and wild blueberry growers in the northeastern United States are not yet willing to invest in pollination alternatives to honey bees. In both crops berry prices are currently following a steep downward tradjectory and producers may have only limited capital from variable profits [63] to make an investment in native bee pollination. However, these decreasing profit margins, U.S. government cost share programs, regulatory predictability of U.S. Endangered Species Act for listed pollinators, and the possibility of adding value through the new U.S. Bee Better Certified program [65] all may bring growers closer to adoption.

In Maine, growers and other "eligible producers" are increasingly taking advantage of USDA-NRCS (United States Department of Agriculture – Natural Resources Conservation Service) cost-share programs. Similar to Europe's Agri-Environmental schemes [66], these U.S. government assistance programs provide technical and financial assistance to growers to manage farm habitats to support greater populations of native bee pollinators. In theory, this will increase the abundance and diversity of native crop pollinators, and decrease growers' expenditures for honey bee hive rentals as more abundant native bee populations supplant honey bees. In practice, research supports the idea that creating habitats for pollinators on farm can increase pollinator diversity [67], abundance [68,69], population stability [70], and measures of pollination service that include fruit quality, fruit set, and yield [71,72].

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In 2018, U.S. government support for pollinator focused USDA-NRCS practices (e.g., pollinator hedgerows, pollinator conservation cover) increased significantly. Cost-share payments are made to growers as a percentage (appx. 60-75%) of the total estimated cost of the practice. In 2017, the estimated cost of planting one hectare of wildflowers through government cost-share programs ranged between $1,119 and $1,989; Across the U.S. in 2018 this rate increased by 174-221% to $1,945-4,411/acre [73]. In the state of Maine, as a direct result of this increased payment rate, an initiative program (the Maine Pollinator Initiative), and increased outreach and capacity for technical support, the number of producers planting habitat for pollinators increased by approximately 600% [74]; however, this estimate is across sectors and includes mixed vegetable growers, forestry producers, apple growers, and blueberry growers.

On 21 March 2017, the United States Fish and Wildlife Service (USFWS) declared the rusty-patched bumble bee a Federally Endangered Species. Listing as a U.S. endangered species comes with stringent protections for the species [75]. The rusty-patched bumble bee was once common in both Maine's wild blueberry fields and also in Massachusetts cranberry bogs. The USFWS is set to make a determination on a second species, the yellow banded bumble bee, in September of 2018. These listings have growers concerned that changes in management could be prescribed by the USFWS to help recover these species. To alleviate concern, and to protect the species, the Maine USDA-NRCS has spearheaded a regional proposal across 6 northeastern U.S. states to create a Working Lands for Wildlife program. This program would further incentivize pollinator conservation by producers, provide guidance to protect pollinators on farmland, and in turn, provide participating producers with some level of liability protection from take. This program, if enacted, could provide growers with an additional justification for creating pollinator habitat on farmland.

Market prices for both cranberry and wild blueberries have declined sharply in the last several years. Some Maine blueberry growers are leaving fields unharvested because their return from the product no longer pays for the cost of harvesting. Cranberry producers are exploring options to restore commercial cranberry bogs back to native bogs; in some cases the cost of harvesting is no longer economically justified. These drops in processed berry prices on one hand make cash-strapped growers less likely to invest the capital required to shift from honey bee to native bee pollination systems. On the other hand, honey bee hive rental can comprise a significant part (37% for wild blueberry compared to 7% for cranberry) of growers' variable costs. Once growers do make the shift to a native bee centric crop pollination model, annual honey bee rental numbers should decline, saving growers' money and time.

Finally, the Xerces Society for Invertebrate Conservation's new Bee Better Certified program offers those growers that conserve pollinators through adaptive management and habitat creation an opportunity to increase the value of their product through labeling. As this certification standard grows in popularity, it will add one more factor entering into growers' decisions on whether or not to adopt a native bee centric pollination model. According to this study, consumers are willing to pay a ~10% premium for blueberries and cranberries pollinated by native bees – a premium that may be realized through eco-labeling.

5. Conclusions

Pollination valuation metrics each have limitations but when evaluated together can be insightful. Pollination hive rental data is available to calculate Replacement Cost, however perfect substitutability of rented honey bees for native bees is not always valid. Production Value and Net Farm Income capture catastrophic pollinator collapse and subsequent crop losses, however both indicators may not be attributable exclusively to native pollinators. The Attributable Net Income from native bees can be calculated from the contribution to crop pollination from native bees versus managed honey bees using both entomological field surveys in addition to producer surveys, however the responsiveness of a crop to native bee pollination is not distinguished. Marginal Net Farm Income using production functions can be used to determine the optimal level of pollination services, however when estimated from producer surveys rented honey bee hives serve as a proxy

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for native pollination. We propose also using Marginal Net Farm Income to distinguish the higher value of optimal pollinator input use from diminishing returns from higher pollinator densities.

About 83% to 93% of Massachusetts cranberry and Maine wild blueberry producers rated native bees as being very important or important in our surveys. Despite this recognition of the critical role of native pollinators in their crop's production, surveyed producers were less able to invest in native bee conservation practices on their farms. Producers' level of investment of $140-188/ha was only ~15% of what consumers of these crops were willing to pay for native bee pollination and only ~25% of the Attributable Net Income from native bees per hectare. Government cost share and federal protection of endangered pollinators can continue to encourage more agricultural producers to install native pollinator habitat on their farms. Additional support can come from higher prices consumers pay for eco-labelled native bee pollinated crops.

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References

1. NRC (National Resource Council) of the National Academies. *Status of pollinators in North America*. Committee on the Status of Pollinators in North America, Board of Life Sciences, Board of Agriculture and Natural Resources, Division on Earth and Life Studies, National Research Council of the National Academies, National Academies Press, Washington D.C., USA, 2007; pp. 1-307, IBSN-13 978-0-309-10289-6.
2. Allen-Wardell, G., Bernhardt, P., Bitner, R., Burquez, A., Buchmann, S., Cane, J., Cox, P.A., Dalton, V., Feinsinger, P., Ingram, M., Inouye, D., Jones, C.E., Kennedy, K., Kevan, P., Koopowitz, H., Medellin, R., Medellin-Morales, S., Nabhan, G.P., Pavlik, B., Tepedino, V., Torchio, P., Walker, S. The potential consequences of pollinator declines on the conservation of biodiversity and stability of food crop yields. *Conserv Biol* **1998**, Volume 12 (1), 8-17, DOI: 10.1111/j.1523-1739.1998.97154.x.
3. Jones, M.S., Vanhanen, H., Peltola, R., Drummond, F.A. A global review of arthropod-mediated ecosystem-services in *Vaccinium* berry agroecosystems. *Terrestrial Arthopod Rev* **2014**, Volume 7, 41-78, DOI: 10.1163/18749836-06041074.
4. Aizen, M.A., Garibaldi, L.A., Cunningham, S.A., Klein, A.-M. How much does agriculture depend on pollinators? Lessons from long-term trends in crop production. *Ann of Botany* **2009**, Volume 103, 1579-1588, DOI: 10.1093/aob/mcp076.

Peer-reviewed version available at Environments 2018, 5, 98; doi:10.3390/environments5090098

5. van Engelsdorp, D., Meixner, M.D. A historical review of managed honey bee populations in Europe and the United States and the factors that may affect them. *J. Inverteb Path* **2010**, Volume 103, Supplement, S80-S95, DOI: 10.1016/j.jip.2009.06.011.
6. De Guzman L.I. de, Rinderer, T.E., Stelzer, J.A. DNA evidence of the origin of *Varroa jacobsoni* Oudemans in the Americas. *Biochem Genetics* **1997**, Volume 35, 327-335, DOI: 10.1023/A:1021821821728.
7. Johnson, Renée. Recent honey bee declines. CRS Report for Congress, Library of Congress, Washington, D.C., USA, 2007; pp. 1-17.
8. Cox-Foster, D., Conlan, S., Holmes, E.C., Palacios, G., Evans, J.D., Moran, N.A., Quan, P.-L., Briese, T., Hornig, M., Geiser, D.M., Martinson, V., vanEngelsdorp, D., Kalkstein, A.L., Drysdale, A., Hui, J., Zhai, J., Cui, L., Hutchison, S.K., Simons, J.F., Egholm, M., Pettis, J.S., Lipkin, W.I. A metagenomic survey of microbes in honey bee Colony Collapse Disorder. *Science* **2007**, Volume 318, 283-287, DOI: 10.1126/science.1146498.
9. vanEngelsdorp, D., Speybroeck, N., Evans, J.D., Nguyen, B.K., Mullin, C., Frazer, M., Frazier, J., Cox-Foster, D., Chen, Y., Tarpy, D.R., Haubruge, E., Pettis, J.S., Saegerman, C. Weighing risk factors associated with bee Colony Collapse Disorder by classification and regression tree analysis. *Journ of Econ Entomology* **2010**, Volume 103 (5), 1517-1523, DOI: 10.1603/EC09429.
10. Lebuhn, G., Droege, S., Connor, E.F., Gemmill-Herren, B., Potts, S.G., Minckley, R.L., Griswold, T., Jean, R., Kula, E., Roubik, D.W., Cane, J., Wright, K.W., Frankie, G., Parker, F. Detecting insect pollinator declines on regional and global scales. *Conserv Bio* **2013**, Volume 27 (1), 113-120, DOI: 10.1111/j.1523-1739.2012.01962.x.
11. Obama, B. Presidential memorandum -- creating a federal strategy to promote the health of honey bees and other pollinators. The White House, Washington, DC, USA, 2014.
12. Winfree, R., Gross, B.J., Kremen, C. Valuing pollination services to agriculture. *Ecol Econ* **2011**, Volume 71, 80-88, DOI: 10.1016/j.ecolecon.2011.08.001.
13. Garibaldi, L.A., Stefan-Dewenter, I., Winfree, R., Marcelo A. Aizen, M.A., Bommarco, R., Cunningham, S.A., Kremen, C., Carvalheiro, L.G., Harder, L.D., Afik, O., Bartomeus, I., Benjamin, F., Boreux, V., Cariveau, D., Chacoff, N.P., Dudenhöffer, J.H., Freitas, B.M., Ghazoul, J., Greenleaf, S., Hipólito, J., Holzschuh, A., Howlett, B., Isaacs, R., Javorek, S.K., Kennedy, C.M., Krewenka, K.M., Krishnan, S., Mandelik, Y., Mayfield, M.M., Motzke, I., Munyuli, T., Nault, B.A., Otieno, M., Petersen, J., Pisanty, G., Potts, S.G., Rader, R., Ricketts, T.H., Rundlöf, M., Seymour, C.L., Schüepp, C., Szentgyörgyi, H., Taki, H., Tscharntke, T., Vergara, C.H., Viana, B.F., Wanger, T.C., Westphal, C., Williams, N., Klein, A.M. Wild pollinators enhance fruit set of crops regardless of honey bee abundance. *Sci.* **2013**, Volume 339, 1608-1611, DOI: 10.1126/science.1230200.
14. Stubbs, C.S., Drummond, F.A. Management of the alfalfa leafcutter bee, Megachile rotundata (Hymenoptera: Megachilidae), for pollination of wild lowbush blueberry. Journal of the Kansas *Entomological Society* **1997**, Volume 70 (2), 81-93.
15. Drummond, F.A. Commercial bumble bee pollination of lowbush blueberry. *Int. J. Fruit Sci* **2012**, Volume 12 (1-3), 54-64, DOI: 10.1080/15538362.2011.619120.
16. Bushmann, S.L. Wild Bee (*Hymenoptera: Apoidea*) Communities Associated with the Lowbush Blueberry Agroecosystem of Maine. PhD Dissertation, University of Maine, Orono, Maine, USA, 2013, 146 pp.
17. Rucker, R.R., Thurman, W.N., Burgett, M. Honey bee pollination markets and the internalization of reciprocal benefits. *Am. J. Agric. Econ.* **2012**, Volume 94 (4), 956-977, DOI: 10.1093/ajae/aas031.
18. Caron, D.M. Bee colony pollination rental prices, eastern US with comparison to West Coast. University of Delaware, Newark, DE 19716, USA, 2011, 4 p.
19. Kasina, J.M, Mburu, J., Kraemer, M., Holm-Mueller, K. Economic benefit of crop pollination by bees: a case of Kakamega small-holder farming in western Kenya. *J. Econ. Entomol.* **2009**, Volume 102 (2), 467-473, DOI: 10.1603/029.102.0201.
20. Ricketts, T.H., Daily, G.C., Ehrlich, P.R., Michener, C.D. Economic value of tropical forest to coffee production. *PNAS* **2004**, Volume 101 (34), 12,579-12,582, DOI: 10.1073/pnas.0405147101.
21. Allsopp, M.H., de Lange, W.J., Veldtman, R. Valuing insect pollination services with cost of replacement. *PLoS One* **2008**, Volume 3 (9), 1-8, DOI: 10.1371/journal.pone.0003128.
22. Mburu, J., Hein, L.G., Gemmill, B., Collette, L. Economic valuation of pollination services: review of methods. Food and Agriculture Organization of the United Nations, Rome, Italy, 2006, 43 p.

Peer-reviewed version available at *Environments* **2018**, *5*, 98; doi:10.3390/environments5090098

23. Southwick, E.E., Southwick Jr., L. Estimating the economic value of honey bees (Hymenoptera: Apidae) as agricultural pollinators in the United States. *J. Econ. Entomol.* **1992**, Volume 85 (3), 621-633, DOI: 10.1093/jee/85.3.621.
24. Morse, R.A., Calderone, N.W. The value of honey bees as pollinators of U.S. crops. Pollination 2000, Cornell University, Ithaca, NY, USA, 2000, 15 p.
25. Olschewski, R., Tscharntke, T., Benitez, P.C., Schwarze, S., Klein, A.-M. Economic evaluation of pollination services comparing coffee landscapes in Ecuador and Indonesia. *Ecol. Soc.* **2006**, Volume 11 (1, A7), Issue 1, Article 7, 14 p., DOI: 10.5751/ES-01629-110107.
26. Stevens, T.H., Hoshide, A.K., Drummond, F.A. Willingness to pay for native pollination of blueberries: A conjoint analysis. *Int. J. Agric. Marketing* **2015**, Volume 2 (4), 068-077.
27. Breeze, T.D., Bailey, A., Potts, S.G., Balcombe, K. A stated preference valuation of the non-market benefits of pollination services in the UK. *Ecol. Econ.* **2015**, Volume 111, 76-85, DOI: 10.1016/j.ecolecon.2014.12.022.
28. Kasina, John Muo. Bee Pollinators and Economic Importance of Pollination in Crop Production: Case of Kakamega, Western Kenya. PhD Dissertation, University of Bonn, 2007, 152 p.
29. USDA NASS (U.S. Department of Agriculture, National Agricultural Statistics Service). 1982-2012. Statistics by state; Census of Agriculture; Honey. NASS, Agricultural Statistics Board, USDA.
30. Yarborough, D.E. (University of Maine, Orono, ME, USA). Personal communication, 2015.
31. Loose, J.L., Drummond, F.A., Stubbs, C., Woods, S., Hoffmann, S. Conservation and management of native bees in cranberry. MAFES Technical Bulletin 191, University of Maine, Orono, ME, USA, 2005, 43 p.
32. Bushmann, S.L., Drummond, F.A., Beers, L.A., Groden, E. Wild bumblebee (*Bombus*) diversity and *Nosema* (Microsporidia: Nosematidae) infection levels associated with lowbush blueberry (*Vaccinium angustifolium*) production and commercial bumblebee pollinators. *Psyche* **2012**, p. 1-11, DOI: 10.1155/2012/429398.
33. Chapin, S. The application of spatial modeling tools to predict native bee abundance in Maine's lowbush blueberries. Master of Science, Ecology and Environmental Science, The University of Maine, Orono, ME, USA, 2014, 44 p.
34. Massachusetts Land Use Dataset. Available online: www.mass.gov/ (accessed on 15 March 2015).
35. Rose, A., Drummond, F.A., Yarborough, D.E., Asare, E. Maine wild blueberry growers: A 2010 economic and sociological analysis of a traditional Downeast crop in transition. Maine Agricultural & Forest Experiment Station Miscellaneous Report 445, University of Maine, Orono, ME, USA, 2013.
36. Constantine, P., Faidell, K., Pereira, D. The grower study II: innovations, viability, and the future of the Massachusetts cranberry bogs. University of Massachusetts Dartmouth Center for Marketing Research, Dartmouth, MA, USA, 2006, 109 p.
37. Jadczak, T. (Maine Department of Agriculture, Augusta, ME, USA). Personal communication, 2014.
38. Gaines-Day, H.R., Gratton, C. Biotic and abiotic factors contribute to cranberry pollination. Journal of *Poll. Ecol.* **2015**, Volume 15 (3), 15-22.
39. FCE (Farm Credit East). Massachusetts cranberry cost of production study: 2010 crop year. Farm Credit East, 2010, 22 p.
40. Yarborough, D.E., DeGomez, T., Hoelper, A.L. Marketing and business management – 260 – Blueberry enterprise budget. Fact Sheet No. 260, University of Maine Extension No. 201, University of Maine, Orono, ME, USA, 2011.
41. Asare, E. The economic impacts of bee pollination on the profitability of the lowbush blueberry industry in Maine. Master of Science, School of Economics, The University of Maine, Orono, ME, USA, 2013, 84 p.
42. MacKenzie, K.E., Averill, A.L. Bee (*Hymenoptera: Apoidea*) diversity and abundance on cranberry in southeastern Massachusetts. Annals of the *Entomol. Soc. Amer.* **1995**, Volume 88 (3), 334–341, DOI: 10.1093/aesa/88.3.334.
43. Notestine, M.M. Pollinator population in Massachusetts cranberry, 1990 to 2009: changes in diversity and abundance, effects of agricultural intensification, and a contribution to the North American population survey. Master of Science, Plant and Soil Science, University of Massachusetts, Amherst, MA, USA, 2010, 63 p.
44. Drummond, F.A. Honeybees and lowbush blueberry pollination. Fact Sheet No. 629, University of Maine Extension No. 2079, University of Maine, Orono, ME, USA, 2002.
45. Averill, A. (University of Massachusetts, Amherst, MA, USA). Personal communication, 2015.
46. Beattie, B.R., Taylor, C.R. The economics of production. Krieger Publishing Company, Malabar, Florida, USA, 1985, IBSN 0-89464-534-X.

47. Eaton, L.J., Nams, V.O. Honey bee stocking numbers and wild blueberry production in Nova Scotia. *Can. J. Plant Sci.* **2012**, Volume 92 (7), 1305-1310, DOI: 10.4141/cjps2012-045.
48. Drummond, F.A. (unpublished data), 2018.
49. Stevens, T.H., Tabatabaei, M., Lass, D. Oaths and hypothetical bias. *J. Environ. Manage.* **2013**, Volume 127, 135-141.
50. Poe, G.L., Clark, J.E., Rondeau, D., Schulze, W.D. Provision point mechanisms and field validity tests of contingent valuation. *Environ. Res. Econ.* **2002**, Volume 23, 105-131, DOI: 10.1023/A:1020242907259.
51. DeMoranville, C. (UMass Cranberry Station, East Wareham, MA, USA). Personal communication, 2015.
52. Javoreck, S.K., Mackenzie, K.E., Vander Kloet, S.P. Comparative pollination effectiveness among bees (Hymenoptera: Apoidea) on lowbush blueberry (Ericaeae: *Vaccinium angustifolium*). *Ann. Entomol. Soc. Amer.* **2002**, Volume 95(3), 345-351, DOI: 10.1603/0013-8746(2002)095[0345:CPEABH]2.0.CO;2.
53. Drummond, F.A. Behavior of Bees Associated with the Wild Blueberry Agro-ecosystem in the USA. *Int. Entomol. Nematol.* **2016**, Volume 2(2), 27-41.
54. Bell, D.J. Spatial and genetic factors influencing yield in lowbush blueberry (*Vaccinium angustifolium* Ait.) in Maine. Ph.D. dissertation, School of Biological Sciences, University of Maine, Orono, ME, USA, 2009.
55. Venturini, E.M., Drummond, F.A., Hoshide, A.K. Organic establishment of pollination reservoirs in lowbush blueberry (Ericales: Ericaceae). *Open Agric.* (under review).
56. Rucker, R.R., Thurman, W.N., Burgett, M. Colony Collapse: the economic consequences of bee disease. Working Paper, Montana State University, Bozeman, MT, USA, 2011, 57 p.
57. Ward, R., Whyte, A., James, R.R.. A tale of two bees: looking at pollination fees for almonds and sweet cherries. *Amer. Entomol.* **2010**, Volume 56 (3), 172-179, DOI: 10.1093/ae/56.3.170.
58. Melathopoulos, A.P., Cutler, G.C., Tyedmers, P. Where is the value in valuing pollination ecosystem services to agriculture? *Ecol. Econ.* **2015**, Volume 109, 59-70, DOI: 10.1016/j.ecolecon.2014.11.007.
59. Groff, S.C., Loftin, C.S., Drummond, F.A., Bushmann, S., McGill, B. Spatial prediction of lowbush blueberry native bee pollinators in Maine, USA. *Environ. Modell. Softw.* **2016**, Volume 79, 1-9, DOI: 10.1016/j.envsoft.2016.01.003.
60. Losey, J.E., Vaughan, M. The economic value of ecological services provided by insects. *BioSci.* **2006**, Volume 56 (4), 311-323, DOI: 10.1641/0006-3568(2006)56[311:TEVOES]2.0.CO;2.
61. Winfree, R. The conservation and restoration of wild bees. *Ann. N.Y. Acad. Sci.* **2010**, Volume 1195, 169-197, DOI: 10.1111/j.1749-6632.2010.05449.x.
62. Hanes, S.P., Collum, K., Hoshide, A.K., Asare, E. Grower perceptions of native pollinators and pollination strategies in the lowbush blueberry industry. *Renew. Agric. Food Sys.* **2013**, Volume 28 (4), 1-8, DOI: 10.1017/S1742170513000331.
63. Asare, E., Hoshide, A.K., Drummond, F.A., Criner, G.K., Chen, X. Economic risks of bee pollination in Maine wild blueberry, *Vaccinium angustifolium* Aiton. *J. Econ. Entomol.* **2017**, Volume 110 (5), 1980-1992, DOI: 10.1093/jee/tox191.
64. Drummond, F.A., Dibble, A.C., Stubbs, C., Bushmann, S., Ascher, J., Ryan, J. A Natural History of Change in Native Bees Associated with Lowbush Blueberry in Maine. *Northeast. Nat.* **2017**, Volume 24 (15), 49-68, DOI: 10.1656/045.024.m1502.
65. U.S. Bee Better Certified program. Available online: www.beebettercertified.org/ (accessed on 17 June 2018).
66. Carvell, C., Meek, W.R., Pywell, R.F., Goulson, D., Nowakowski, M. Comparing the efficacy of agri-environmental schemes to enhance bumble bee abundance and diversity on arable field margins. *J. Appl. Ecol.* **2007**, Volume 44 (1), 29-40, DOI: 10.1111/j.1365-2664.2006.01249.x.
67. Williams, N.M., Ward, K.L., Pope, N. Isaacs, R., Wilson, J., May, E.A., Ellis, J., Daniels, J., Pence, A., Ullmann, K., and Peters, J. Native wildflower plantings support wild bee abundance and diversity in agricultural landscapes across the United States. *Ecol. Appl.* **2015**, Volume 25 (8), 2119-2131, DOI: 10.1890/14-1748.1.
68. Morandin, L.A., Kremen, C. Hedgerow restoration promotes pollinator populations and exports native bees to adjacent fields. *Ecol. Appl.* **2013**, Volume 23 (4), 829-839, DOI: 10.1890/12-1051.1.
69. Wood, T.J., Holland, J.M., Hughes, W.O., and Goulson, D. Targeted agri-environmental schemes significantly improve the populations size of common farmland bumblebee species. *Mol. Ecol.* **2015**, Volume 24 (8), 1668-1680, DOI: 10.1111/mec.13144.

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Peer-reviewed version available at *Environments* **2018**, *5*, 98; doi:10.3390/environments5090098

70. M'Gonigle, L.K., Ponisio, L.C., Cutler, K. and Kremen, C. Habitat restoration promotes pollinator persistence and colonization in intensively managed agriculture. *Ecol. Appl.* **2015**, Volume 25 (6), 1557-1565, DOI: 10.1890/14-1863.1.
71. Venturini, E.M., Drummond, F.A., Hoshide, A.K., Dibble, A.C., and Stack, L.B. Pollination reservoirs in lowbush blueberry (Ericales: Ericaceae). *J. Econ. Entomol.* **2017**a, Volume 110 (2), 333-346, DOI: 10.1093/jee/tow285.
72. Venturini, E.M. Drummond, F.A., Hoshide, A.K., Dibble, A.C., and Stack, L.B. Pollination reservoirs for wild bee habitat enhancement in cropping systems: a review. *Agroecol. Sust. Food Sys.* **2017**b, Volume 41 (2), 101-142, DOI: 10.1080/21683565.2016.1258377.
73. United States Department of Agriculture – Natural Resources Conservation Service. Available online: www.usda.nrcs.gov/ (accessed on 16 June 2018).
74. Venturini, E. (The Xerces Society for Invertebrate Conservation, Bangor, ME, USA). Personal communication, 2018.
75. USFWS DOI (United States Fish and Wildlife Service, Department of the Interior). Endangered Species Act of 1973, as amended through the 108th Congress. Department of the Interior, U.S. Fish and Wildlife Service. Washington, D.C. 20240, USA, 1973.