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Economic valuation of natural pest control of the summer grain aphid in wheat in South East England

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ABSTRACT

Wheat (*Triticum* spp.) is the most important arable crop grown in the UK, and the grain aphid (*Sitobion avenae*) is one of the key pests of this crop. Natural enemies could help suppress grain aphid and reduce unnecessary insecticide inputs, but few studies have estimated the economic value of natural pest control in this crop-pest system, which could help inform effective integrated pest management strategies. Based on a natural enemy exclusion experiment carried out in South East England, this study used an economic surplus model to estimate the value of predators and parasitoids to control summer grain aphid in wheat in this region. Incorporating three levels of spray intensity and three levels of pest infestation, the annual economic value of natural pest control service was conservatively estimated to be £0-2.3 Million. Under the medium pest infestation level, a 10% increase in the proportion of wheat fields using economic threshold-based spray method would increase this value by 23% (£0.4 Million). 71% of the value would benefit wheat growers. A potential rise in insecticide costs due to resistance development would also enhance the value of natural pest control. These findings support growing efforts from policy-makers to promote this ecosystem service in agriculture.

1. Introduction

Wheat (*Triticum* spp.) is the most widely cultivated crop in the UK, with ~2 million ha planted annually from 2010 to 2014, representing 42% of the total national arable cropping area and generating £2 billion in sales annually (DEFRA, 2014, 2016a). The grain aphid, *Sitobion avenae* Fabricius (Hemiptera: Aphididae), is one of the main insect pests in UK wheat production (Foster et al., 2014), acting as a potential vector of the barley yellow dwarf virus to the young seedlings sown during the autumn period and causing direct feeding damage through leaves and ears in the summer (Dewar et al., 2016). Indirect crop damage caused by the summer grain aphid is the secretion of honeydew during feeding, which provides a medium for sooty moulds that reduce the photosynthetic rate (Larsson, 2005).

The dominant insecticides applied in wheat to control summer grain aphid are pyrethroid sprays. From 2010 to 2014, an average of 1.6 million ha of UK wheat was treated with pyrethroids annually, representing 92% of total insecticidal spray area for this crop (Garthwaite et al., 2010, 2012, 2014). However, since 2011, pyrethroid resistance has developed in the UK grain aphid (AHDB, 2015; Foster et al., 2014). An alternative spray for aphid control has been pirimicarb (1.5% of total insecticidal spray area for wheat) (Garthwaite et al., 2010, 2012, 2014), however, its authorisations are set to end in July 2017 (AHDB, 2016a; Dewar et al., 2016). These factors have caused concerns for the future of effective grain aphid control in UK wheat.

An alternative control mechanism for grain aphid infestation is provided by natural enemies present in the wheat fields, including predators (e.g., Carabidae), parasitoids (e.g., Aphidiinae), and pathogens (e.g., Entomophthorales). Many studies have demonstrated their importance for suppressing grain aphid damage in wheat production (Plantegenest et al., 2001; Safarzoda et al., 2014; Schmidt et al., 2003; Thies et al., 2011). Beyond direct pest control, the contributions of natural pest control include: reducing the rate of development of insecticide resistance in pests (Lefebvre et al., 2015; Liu et al., 2014), providing consumers with potentially healthier food containing fewer chemical residues (Baker et al., 2002; Florax et al., 2005), and reducing negative effects of insecticides on other ecosystem services (e.g., pollination, see Potts et al., 2016).

The effectiveness of natural pest control is influenced by various factors: for example, farm management (Holland, 2004), landscape

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structure (Martin et al., 2013), weather and climate change (Ewald et al., 2015). Foremost, numerous studies have demonstrated that insecticides negatively affect the development and pest control abilities of natural enemies in croplands by killing or weakening non-target species (Geiger et al., 2010; Roubos et al., 2014). Indeed, there have been policy and research interests in encouraging a reduction in the intensity of insecticide application, particularly by using the economic threshold method pioneered by Stern et al. (1959). This method encourages farmers to use insecticides as a complement to natural pest control, treating crops only when it is necessary to prevent an increasing pest density from reaching the economic injury level (EIL), where the cost of control equals the perceived value of crop damage (Pedigo et al., 1986; Stern et al., 1959).

By monitoring grain aphid densities in summer and comparing the subsequent yield responses in 49 wheat fields across England and Wales, George and Gair (1979) advised that the economic threshold for UK grain aphid in summer is five aphids/tiller. This threshold level was further validated by Oakley and Walters (1994), and is now recommended for UK wheat growers to follow when treating summer grain aphid infestations (Dewar et al., 2016; Ramsden et al., 2017). However, there remains little information on the extent of benefits that this method can have in enhancing natural pest control service for UK wheat production.

Estimating the economic benefits of an ecosystem service has been suggested as a method to quantify its contribution to human welfare, encourage farmers to implement a more sustainable pest management approach, and guide policy makers in supporting relevant conservation programs (Braat and de Groot, 2012; Schaefer et al., 2015). Some attempts have been made to estimate the monetary values of natural pest control service (see Table 1 in Naranjo et al., 2015 as a summary). It is difficult to compare the values among economic studies, because of the often significant differences in study locations, trophic relationships, input costs, data used, and modelling techniques. However, few evaluations have been conducted on the wheat-grain aphid system (Porter et al., 2009), and to our knowledge, none on any crop-pest system within the UK context.

By expanding upon the economic surplus model developed by Letourneau et al. (2015), this study estimates the economic value of natural pest control of the summer grain aphid damage in UK wheat, while accounting for the influence of different intensities of insecticide input and levels of pest infestation. In particular, the potential contribution of the economic threshold-based method towards the value of natural pest control is analysed. By conducting a set of sensitivity analyses, this study also quantifies the potential variation in the value from the uncertainties in the price elasticities of supply and demand, and the insecticide input costs. This study focuses on the summer grain aphid control by the related predators and parasitoids in the South East England. However, the model could potentially be used for other regions and crop-pest systems.

2. Materials and methods

2.1. Overview of economic surplus method

The economic surplus method is commonly used in economics to estimate the change in benefits and costs brought by a change in technology in a market setting (Alston et al., 1998). It is also recognized and widely used to value the economic benefits of various ecosystem services (e.g., wetland: Woodward and Wui, 2001; pollination: Southwick and Southwick, 1992). It is measured as the sum of consumer surplus (ΔCS, benefits that consumers would receive when the market price that they pay for a product is lower than the highest price they are willing to pay) and producer surplus (ΔPS, benefits that producers receive when they sell a product at a higher price than the cost of producing it). Assume Fig. 1 represents the wheat market in South East England. The demand curve (*Demand*) denotes the relationship between wheat price and quantity that consumers are willing and able to purchase. The supply curve (*Supply 1*) is the relationship between product price and quantity that farmers are willing to produce. The intercept between the two curves represents an equilibrium point where the market price is set (P_0), with related wheat quantities produced (Q_0). Consumer surplus is represented by the area (A + B+C), and producer surplus (D + E).

Hypothetically, if there is an absence of natural enemies of the summer grain aphid in the wheat fields in South East England (i.e., natural pest control is at the minimum level), crop damage from grain aphid would be likely to occur (Östman et al., 2003), resulting in lower yields or increased insecticide input. Either of these two changes would increase the incremental cost of crop production, leading to a leftward shift of the supply curve (*Supply 2*), and a higher market price (P_1). Thus the economic surplus will fall (A + B + D) and the difference in economic surplus with and without natural pest control can be identified (C + E), capturing the value of this ecosystem service (Alston et al., 1998; Letourneau et al., 2015).

2.2. Insecticide intensity and pest infestation levels

This study incorporated three levels of insecticidal application intensity of foliar sprays in the model: (i) no-spray, where no foliar sprays are used to control grain aphid in the summer; (ii) economic

Table 1
Estimated peak aphid densities and yield reductions in relation to a change in natural enemies in the wheat fields in South East England.

Peak grain aphid densities (number/tiller)		Percentage yield losses (%)	
Without NE[1]	With NE	Without NE	With NE
2	0	0	0
4	1	0	0
6	2	2	0
8	3	4	0
9	4	5	0[2]
11	5	6	2
13	6	6	3

Note: 1. NE = natural enemies; 2. this value amounts to <1% so is treated as no damage.

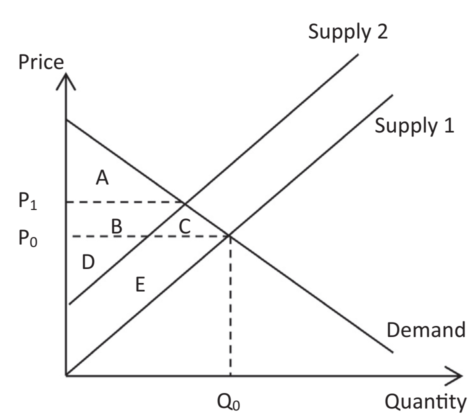

Fig. 1. Framework of wheat market in South East England and the related measurement of economic surplus.