Potential of unmanned aerial sampling for monitoring insect populations in rice fields

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Recently, remote-controlled unmanned aerial vehicles have gained popularity as a new platform to monitor and manage agricultural threat agents in various crop fields (Schmale III et al. 2008). Previous studies have demonstrated successful use of unmanned aerial vehicles to detect and control weeds and insect pests (Rasmussen et al. 2013; Shields & Testa 1999; Zhang & Kovacs 2012; Lopez-Granados 2010; Tan & Yoon 2013; Tahir & Brooker 2009). For example, Park et al. (2017) developed unmanned aerial vehicles equipped with an aerial release system to disseminate a biological control agent, Rhinoncomimus latipes Korotyaev (Coleoptera: Curculionidae), to control an invasive weed, Persicaria perfoliata L. (Polygonaceae), in the United States. The aerial delivery system makes it possible to conduct spatial targeting and precision release of the biological control agents, overcoming challenges with the current visit-and-hand-release approach. Shields and Testa (1999) demonstrated the value of using a remotely piloted vehicle to study the role of weather fronts and changes in barometric pressure on fall migratory flight initiation of the potato leafhopper, Empoasca fabae Harris (Hemiptera: Cicadellidae). In addition, a recent civilian application for autonomous unmanned aerial vehicles allows aerobiological sampling up to 300 m above crop fields (Schmale III et al. 2008), and the release of new operational rules for unmanned aerial vehicles by the National Airspace System has opened up the possibility of large-scale deployment of unmanned systems for pest management (Park et al. 2017).

Despite progress in aerial sampling with unmanned aerial vehicles in the past decade, the use of unmanned aerial vehicles in agricultural fields or forests has been limited to a few countries including the United States, China, and Japan (Keller & Shields 2014; Ivošević et al. 2015; Xiongkui et al. 2017). Indeed, very few attempts have been made in other countries, including South Korea, to develop and apply unmanned aerial vehicles for aerial sampling in agricultural fields. Recently in South Korea, Ivošević et al. (2015) used unmanned aerial vehicles to acquire photographs and videos for monitoring birds as well as landscapes in areas that are difficult to access. In South Korea, unmanned aerial vehicles have promising potential for monitoring and management of insect pests, especially in rice fields. The arcage (or, in Chinese, the “rice paddies”) are the largest and most diverse land use type in South Korea’s agricultural sector. The rice season is typically divided into two periods: the spring and fall, with each period consisting of multiple stages. During the fall period, the rice crop is harvested, leaving behind large, wide-open fields that are ideal for aerial sampling.

In this study, we developed a rotary-wing unmanned aerial system (Fig. 1a) with 2 remote-controlled insect nets (28 × 32 cm [diameter × length]) (Fig. 1b) that allows aerial sampling exclusively at designated altitudes. The unmanned aerial vehicle and insect net system were developed and assembled by Korea Aero Models Association, Seoul, South Korea. The main body (1.45 × 1.45 × 0.6 m [L × W × H], 7.1 Kg without battery) was made with a carbon fiber frame, carbon-30 (Artcopter, Paju, South Korea). It had 8 motors (MT3520 kv400, T-motor, Nanchang, China) with a flight controller (DJI A2, DJI, Shenzhen, China). With a separate remote controller, the insect nets were switched from the default position (facing downward) to the collecting position (facing the upwind direction) once the unmanned aerial vehicle reached its designated altitude. Then, the position of the net opening was reversed (facing downward) after the unmanned aerial vehicle had completed a 5 min sampling flight. The target altitudes for sampling were 5, 10, 50, and 100 m above the ground. We conducted a total of 21 sampling flights at a rice field (ca. 80 × 240 m) at Chungcheongnam-do, South Korea (36.3866°N, 126.5702°E) in June, July, and August 2017 to evaluate the potential of using the unmanned aerial vehicle to survey an aerial insect complex. All flights were manually operated by a remote pilot with an instructor’s license, and who attempted to maintain a designated altitude with consistent flight speed. The flight altitude and speed were recorded using a GPS system on board (Garmin Edge...
A total of 235, 7, 6, and 3 insects were captured from 1 sampling event during a 5 m high flight on Aug 30. Among them, 205 individuals were Diptera, including Chironomidae and Phoridae. A recent survey in South Korea found 41 species of Chironomidae (Na et al. 2010), but only 2 chironomid midges, Cricotopus oryzae and C. sylvestris, have been reported to damage rice during the germination and young plant stages (Ree & Kim 1998). To our knowledge, there have been no reports of significant damage by Phoridae in rice fields in South Korea, whereas the phorid fly, Megaselia sp., is known to attack eumenid wasps near rice in Japan (Itino 1986). Hemiptera was the second-most abundant group, yielding 12 individuals, mostly in the family Aphididae. Yano et al. (1983) reviewed the biology and economic importance of rice aphids (Hemiptera: Aphididae) addressing 37 species and indicated that 3 species (Aphis craccivora, Myzus persicae, and A. gossypii) are found sporadically on rice. Also, in our sample a specimen of Hemiptera was identified as a planthopper (Delphacidae). In South Korea, 3 migratory planthopper species (N. luteus, L. striatellus, and S. furcifera) are major rice pests, causing serious economic losses in rice fields (Son et al. 2014; Otuka et al. 2012). Among Hymenoptera, 3 individuals in the families Eulophidae, Aphelinidae, and Figitidae were collected. Eulophidae and Aphelinidae include beneficial parasitic wasps, and some species have been found in rice fields in South Korea and Iran (Bayegan et al. 2015; Kim et al. 2015). From the order Coleoptera, 4 individuals in families Ptiliidae and Staphylinidae were identified. Both families belong to Staphylinoidea, which are generally known as facultative predators or as scavengers, though only limited information is available for Ptiliidae. In addition, several members in Ptiliidae and Staphylinidae are facultative or obligatory fungal spore or pollen feeders (Betz et al. 2003). Lastly, 1 insect in the order Thysanoptera was captured, but damaged, making it impossible to identify to the family level. Thysanoptera are known as a serious pest complex in diverse crops and include rice thrips such as Stenchaetothrips hifarmis Bagnall (Thysanoptera: Thripidae) (Ve-lusamy & Saxena 1991).

The results of this study indicate that aerial sampling using unmanned aerial vehicles can serve as an alternative to conventional sampling methods such as stationary 10-m-high insect nets in rice fields. Indeed, 21 aerial sampling flights captured a total of 251 insects in 22 families, most of which include major pest and beneficial species reported in rice fields in South Korea. Aerial sampling of insects over 10 m in height in South Korea rice fields was conducted for the first time in this study and revealed that both potential pests and beneficiales were present in the air up to 100 m from the ground. It is noteworthy that the aerial sampling captured delphacids and thysanopterans, some of which are listed as major pests on rice in South Korea (RDA 2016). Although the pest complex was not monitored directly from rice in the current study, further study should address relationships between aerial samples and actual pest pressure on the crop. Then, given that the use of unmanned aerial vehicles is portable, this approach would provide a great predictive tool for early detection of the migratory planthopper complex emigrating from China to the west coast of the Korean Peninsula. Lastly, it is also noteworthy that 29 out of 251 insects were damaged during the aerial collecting making it difficult to identify them to the level of insect family.

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Table 1. Environmental conditions, flight information, and results of aerial sampling using a rotary-wing unmanned aerial vehicle with remotely controlled insect nets.

| Date       | Flight number | Flight time  | Temperature (°C) | Relative humidity (%) | Designated flight altitude (m) | Actual flight altitude (m) (Mean ± SE) | Flight distance (km) | No. of samples | Arthropod sample                  | Remark               |
|------------|---------------|--------------|------------------|-----------------------|-------------------------------|----------------------------------------|----------------------|----------------|-----------------------------------|----------------------|
| 24 Jun 2017 | 1             | 5:58–6:05 PM | 23.8             | 67                    | 10                            | 6.3 ± 1.6                             | 1.30                 | 1             | Diptera Ephydridae                |                      |
|            | 2             | 6:18–6:25 PM | 24.4             | 71                    | 100                           | 98.1 ± 0.7                            | 1.36                 | 0             | -                                | -                    |
|            | 3             | 6:36–6:43 PM | 24.2             | 76                    | 50                            | 43.5 ± 2.8                            | 1.40                 | 1             | Diptera Ephydridae                | Sample damaged       |
| 25 Jun 2017 | 4             | 8:26–8:33 AM | 26.3             | 63                    | 100                           | 100.1 ± 1.9                           | 2.38                 | 1             | Hemiptera Aphididae               |                      |
|            | 5             | 8:42–8:50 AM | 25.9             | 65                    | 50                            | 62.7 ± 11.5                           | 2.45                 | 1             | Diptera Unknown                   | Sample damaged       |
|            | 6             | 9:01–9:07 AM | 26.2             | 65                    | 10                            | 10.5 ± 1.5                            | 1.44                 | 4             | Hemiptera Delphacidae             |                      |
|            | 7             | 9:24–9:30 AM | 28.1             | 65                    | 5                             | 3.4 ± 1.6                             | 1.30                 | 1             | Diptera Chironomidae sp.1         |                      |
|            | 8             | 5:20–5:26 PM | 31.5             | 63                    | 50                            | 56.2 ± 3.5                            | 2.26                 | 0             | -                                | -                    |
|            | 9             | 5:43–5:49 PM | 31.6             | 66                    | 10                            | 13.4 ± 1.9                            | 1.37                 | 0             | -                                | -                    |
|            | 10            | 6:13–6:20 PM | 31.6             | 66                    | 100                           | 98.5 ± 2.0                            | 2.35                 | 0             | -                                | -                    |
| 27 Jul 2017 | 11            | 8:16–8:23 AM | 30.4             | 67                    | 50                            | 35.5 ± 1.5                            | 1.47                 | 1             | Araneae                           |                      |
|            | 12            | 8:39–8:46 AM | 29.7             | 68                    | 100                           | 98.1 ± 0.8                            | 2.05                 | 0             | -                                | -                    |
|            | 13            | 8:58–9:05 AM | 30.0             | 68                    | 10                            | 7.4 ± 0.8                             | 1.29                 | 0             | -                                | -                    |
| 30 Aug 2017 | 14            | 5:11–5:17 PM | 24.9             | 48                    | 10                            | n/a*                                  | n/a*                 | 1             | Diptera Chironomidae sp.2         |                      |
|            | 15            | 5:29–5:35 PM | 25.2             | 51                    | 50                            | 37.1 ± 1.7                            | 1.96                 | 0             | -                                | -                    |
|            | 16            | 5:51–5:59 PM | 23.6             | 54                    | 100                           | 96.4 ± 1.0                            | 1.66                 | 1             | Hymenoptera Eulophidae            |                      |
|            | 17            | 6:09–6:16 PM | 23.2             | 57                    | 5                             | 1.7 ± 0.7                             | 1.50                 | 1             | Diptera Unknown                   | Sample damaged       |

*n/a: flight information was not recorded due to technical problems with GPS system.
### Table 1.
Environmental conditions, flight information, and results of aerial sampling using a rotary-wing unmanned aerial vehicle with remotely controlled insect nets.

| Date       | Flight number | Flight time          | Temperature (°C) | Relative humidity (%) | Designated altitude (m) | Actual flight altitude (Mean ± SE) | No. of samples | Arthropod sample | Order | Family | Remark                  |
|------------|---------------|---------------------|------------------|-----------------------|------------------------|-----------------------------------|----------------|------------------|-------|--------|------------------------|
| 31 Aug 2017 | 18            | 8:27–8:34 AM        | 22.4             | 69                    | 10                     | 9.1 ± 0.4                        | 0              | -                | Hymenoptera | Eulophidae | Sample damaged          |
|            | 31 Aug 2017   | 19                 | 8:45–8:53 AM      | 22.9                  | 70                     | 9.6 ± 0.5                        | 50             | -                | Hymenoptera | Figitidae | Sample damaged          |
|            | 18            | 18                 | 9:15–9:23 AM      | 24.3                  | 65                     | 9.7 ± 1.1                        | 100            | -                | Diptera    | Chironomidae | Sample damaged          |
|            | 20            | 19                 | 9:45–9:57 AM      | 29.0                  | 50                     | 3.0 ± 0.8                        | 50             | -                | Diptera    | Chironomidae | Sample damaged          |
|            | 21            | 11                 | 9:50–9:57 AM      | 36.1 ± 1.5            | 50                     | 3.0 ± 0.8                        | 50             | -                | Diptera    | Chironomidae | Sample damaged          |

*Note: Flight information was not recorded due to technical problems with GPS system.

**Summary**

Conventionally, sampling for insects has been limited to the ground level or low altitudes. Recent progress in unmanned aerial vehicles has made it more feasible to use this technique for aerial sampling of insect populations. In this study, we developed a rotary-wing unmanned aerial vehicle with remote-controlled insect net openings that allows serial sampling at designated altitudes. A total of 21 flights using the unmanned aerial vehicle system captured 251 insects in 6 orders and 22 families at 5, 10, 50, and 100 m above rice fields in South Korea. The results of this study demonstrate that the aerial sampling can collect diverse pest and beneficial insects above rice fields and demonstrate a promising alternative to conventional sampling methods.

**Key Words:** insect sampling; unmanned aerial vehicle; drone

**Sumario**

Convencionalmente, el muestreo de insectos se ha limitado al nivel del suelo o a bajas altitudes. El progreso reciente en vehículos aéreos no tripulados ha hecho que sea más factible utilizar esta técnica para el muestreo aéreo de poblaciones de insectos. En este estudio, desarrollamos un vehículo aéreo no tripulado de ala giratoria con aberturas de red de insectos controladas a distancia que permite el muestreo en serie a altitudes designadas. Un total de 21 vuelos que utilizan el sistema de vehículo aéreo no tripulado capturaron 251 insectos en 6 órdenes y 22 familias a 5, 10, 50 y 100 m sobre el campo de arroz en Corea del Sur. Los resultados de este estudio demuestran que el muestreo aéreo puede recolectar diversas plagas e insectos beneficiosos por encima del campo de arroz y demuestra una alternativa prometedora a los métodos de muestreo convencionales.

**Palabras Clave:** muestreo de insectos; vehículo aéreo no tripulado (VANT); dron; arroz; monitoreo

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