ARTICLE

The humid and thermal impact on distribution of Sea buckthorn fly (*Rhagolethis batava* Hering, 1958) in Mongolia

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Abstract: *A total of 80 species in 1834 types of Tephritidae Newman (fruit flies) were recorded in the Mongolian-Russian comprehensive and joint expedition report, which was organized in 1967-1995. In the course of an itinerary survey conducted in 2019, we have recorded the dispersion of Rhagoletis batava at 223 natural (wild) and planted sea buckthorn points in 22 soums of Bayan-Ulgii, Uvs, Zavkhan, Khovd, Selenge and Govi-Altai aimags (provinces).*

Accordingly, we summarized the spread of sea buckthorn fruit fly relating mostly to territories that have dry and cooler climates, while some areas are humid and cold. Based on the dispersion points, we determined the current and future changes in the distribution of this species of flies, using the MaxEnt Modeling of geographical distribution. Thermal and humidity rates that affect the flies were estimated using data collected from 18 meteorological stations and sentinel posts. These points are located in different natural zones with an average annual air temperature fluctuating from -4.8 to 3.2°C. For example, in Tes soum of Uvs aimag, Bayantes soum of Zavkhan aimag and in Tes along the Tes river basin the average annual temperature is from -3.7 to - 4.8°C; in Baitag Kharuul of Bulgan soum of Khovd aimag, along the Bulgan river basin, the warmest temperature is 3.2°C, and in other soums it is -2.4 ... 1.8°C.

Keywords: Sea buckthorn fly; Rhagolethis batava; dispersion; distribution;

INTRODUCTION

The tribe of *Rhagoletis batava* is a species of fruit fly, whose larvae feed on the flesh of *Hippophae rhamnoides* (Elaeagnaceae) - sea buckthorn fruit. In terms of classification, it belongs to the order of Diptera, family of fruit fly (*Tephritidae*) and genus *Rhagoletis*. As of today, 4350 species in 480 types of *Tephritidae Newman* and around 850 species of *Palearctic* have been recorded in all geographical regions and territories.

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But, 36 types and 98 species from 11 tribes were revealed in the Southeast of Western Siberia.

To date, 62 species in 1863 types of *Rhagoletis Loew* were recorded. Hering was the first to determine the *Rhagoletis batava* in 1958 and later by Rohdendorf in 1961; Kandybina determined it in 1977; White & Elson-Harris in 1992; Merz in 2001; Norrbom et al., in 1999 and Smit determined it in 2010.

It is a *Palearctic* species and is widespread in Central and Western Europe, Central Asia, the Caucasus, Russia, Altai Region, the desert in the Great Lakes Depression, forest steppe, large river valleys of our country; around Uvs Lake, Kharkhiraa, Turgen River, Khovd River, Bulgan River and Zavkhan River basins. The female fly lay their eggs by pricking the surface of the fruit skin, and as soon as the larvae are born, they enter inside the fruit and feed on the soft tissue of the fruit flesh. The number of fruits damaged by one larva varies depending on the size of the fruit. Usually 1-2 fruits are damaged, the color of the damaged fruit begins to change and turns yellowish, shrinks, darkens, warps and then dries.

Sainzaya's (2014) observation of sea buckthorn field in the center of Uvs aimag was similar to that of Chuluunjav's (2014) observation, but differs in the early stages of mating and spawning. According to Sainzaya's research, the flight began when the temperature was higher than plus 18°C, and increased sharply when it was above 22-23°C. It has been also noted that the soil temperature at the time of emergence from the soil has a strong effect on flies. According to Zeynalov (many years in Russia), the fly's flight takes place at a temperature of 252.1-319°C, ovulation 339.5-390.30°C, larval development 428.3-470.00°C and lasts 48-57 days per offspring. (Zeynalov AS 2018).

In this study, we aimed to determine the distribution of sea buckthorn flies on the territory of Mongolia, map them, and determine the time of their development and disappearance. For this purpose, data from the Meteorological stations, in the soums where the flies were prevalent, related to rainfall in Baitag Kharuul of Bulgan soum in Khovd aimag for 1999-2019, air and soil temperature, and average wind speed for 20 years were processed in a series of ten-day average data, including multi-year value (MYV), and the results of 20-year average temperature and precipitation changes in 2050 (2046-2065) and 2080 (2081-2100) were all used to calculate the distribution of sea bucktorn flies.

MATERIALS AND METHODS

We processed the 20-year's average ten-day data series of meteorological stations and security point's precipitation, air and soil temperature, and average wind speed for 1999-2019 and calculated the multi-year mean (MYM) values in Bayannuur, Bulgan, Nogoonnuur, Tsengel, Ulaankhus and Sagsai soums of Bayan-Ulgii aimag, Tes, Khovd and Ulaangom soums of Uvs aimag, Aldarkhaan, Durvuljin and Tes soums of Zavkhan aimage, Bulgan and Erdeneburen soums of Khovd aimag, Zuunburen station of Selenge aimag and Choir soum of Govisumber aimag. Using the future climate change scenario (Gomboluudev, 2018), which estimated greenhouse gas (GHG) emissions at RCP8.5 using the HadGEM atmospheric general circulation model, we calculated the results of twenty-year average temperature and precipitation changes in 2050 (2046-2065) and 2080 (2081-2100), and made 1999-2019 as the base year (precipitation, temperature).

The time for flies to emerge (appear) and disappear is calculated as the period of warming and cooling of the air at a constant temperature of 10°C and its mapping was developed using "Natural Zones and Belts", 2009 shapefile, geographic information ARCGIS-10.2, and digital processing using Microsoft Excel 2013 software. The "MaxEnt-Geographical spread and distribution" model was used to calculate the change in the spread of flies. The following information was used for model input. These include: biological data or coordinates of Sea buckthorn flies' distribution points (Excel*.CSV file), environmental data or

climate (precipitation, present and future changes in temperature), forest, soil, and environmental area maps which were prepared in ArcGIS *. asc. Also, we calculated profitability and active temperature at which flies develop. Insect development does not take place at any temperature, but above a certain temperature range (10°C), and this is called effective temperature, and it is the temperature that is above the lower limit of development.

$$t_a = t - C$$

t_a – effective temperature,
C – temperature limit,
t – ambient temperature of insects.

Sum of effective or profitability temperature:

This parameter is a continuous (integral) indicator which presents the rhythm (rate) of insect development at ambient temperature.

$$K_1 = n \cdot t_a \; ; \quad K_1 = n \cdot (t - C)$$

K_1 – sum of effective temperature.
n, C, t – similar to previous.

RESULTS AND DISCUSSIONS

In the research work, our team selected meteorological stations and security points in soums along the major rivers such as Khovd, Buyant, Bulgan in the Uvs Lake basins, Tes and Zavkhan rivers south of the Khangai Mountains, and we marked a total 223 locations, which recorded the spread of flies on the map (Figure 1).

Under normal living conditions, the sum of effective temperatures (above a certain limit) and the duration of development are constant.
Sum of active temperature:

We calculated the sum of active temperatures by crossing a certain limit (10°C) of the average air temperature and adding the temperature between the stable transition periods.

Humidity and thermal coefficient (Insect life expectancy) (Druzhelyubova, Makarova, 1972).

Humidity and heat coefficients affecting the flies are considered to be 1.0-1.5 suitable, over 1.6-excess, 1.0-insufficient and 0.5-less humidity.

$$GTC = \frac{RR \cdot 10}{\sum T u}$$

GTC – humidity and heat coefficient (HHC):
RR – insect generation (stage) whole precipitation,
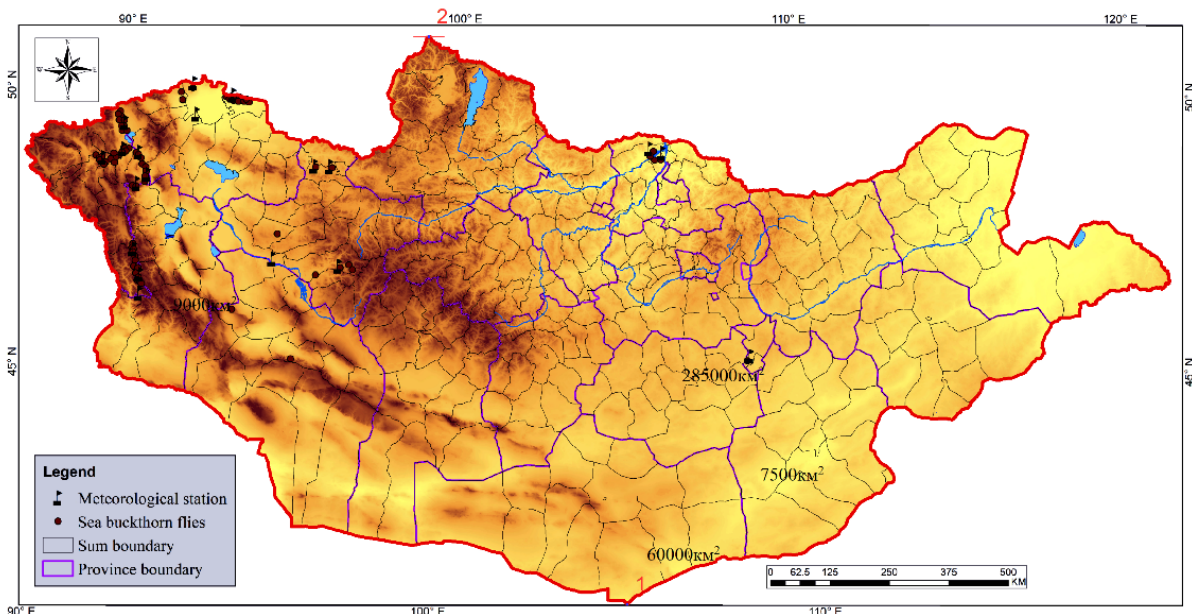$\sum T u$ – sum of active temperature.

Figure 1. Distribution map of Sea buckthorn flies in Mongolia. 2019 (Marked the distribution of flies along Khovd, Buyant, Bulgan rivers originating from the Altai mountain ranges, Tes river along the Uvs lake basin, and Zavkhan river along the Khangai mountain range. 223 points)

These points are located in different natural zones and the average annual air temperature is from -4.8 to 3.2°C and Tes in Uvs aimag and Bayantes and Tes in Zavkhan aimag along the Tes river basin is from -3.7 to - 4.8°C, Baitag security point of Bulgan soum of Khovd aimag along the Bulgan river basin is the warmest or measures at 3.2°C and in other soums, the average annual air temperature is from -2.4 to 1.8°C. The average soil temperature has a significant effect on the growth and development of an insect, wintering, emerging in the spring, and disappearing in the fall.

The average soil temperature is from -5.2 to 5.5°C, which is significantly different from the average air temperature (-0.4...2.3). The volume and distribution of precipitation is not very similar, as Sea buckthorn flies covered areas with a unique and comprehensive system of mountains and deserts. As of the total annual precipitation, it is 266.7-273.9 mm in Tsagaannuur and Zuunburen soums of Selenge aimag, 83.6 mm in Nogoonnuur soum of

Bayan-Ulgii aimag and only 84.0 mm in Durvuljin soum of Zavkhan aimag. Also, Tsagaannuur and Zuunburen soums have the highest annual precipitation in August, while Nogoonnuur soum has the highest precipitation in July. During the warm season or active time of insect development, 208.1-237.2 mm of precipitation fall in Tsagaannuur and Zuunburen soums, and 69.6-72.5 mm in Nogoonnuur and Durvuljin soums. The average wind speed is 1.1-3.0 m/s.

Humidity and heat influence the present and future spread of Sea buckthorn fly

As of multi-year mean (1999-2019), the flies start appearing in Bayan-Ulgii aimag, from April 24 to May 16, in Zavkhan from April 26 to June 5, in Uvs from April 28 to May 3, in Khovd April 16 -19, in Selenge from April 28, May 1, and in Choir April 29, but in 2050, flies are expected to appear earlier by 13-18 days in Bayan-Ulgii, 11-14 days in Uvs and Khovd, 46 days in Zavkhan (46 in Aldarkhaan), 11-16 days in Selenge and 12 days in Choir.

Table 1. Estimation of the time of emergence and disappear of Sea buckthorn fly (Rhagoletis batava) in spring and autumn

№	Province	Soum	Emergence (appear)			Disappear			Living period, days		
			MYM	2050	2080	MYM	2050	2080	MYM	2050	2080
1	Bayan-Ulgii	Bayan-nuur	24-Apr	6-Apr	1-Apr	11-Sep	21-Sep	29-Sep	140	168	181
2	Bayan-Ulgii	Duchinjil	14-May	29-Apr	11-Apr	29-Aug	13-Sep	23-Sep	107	137	165
3	Bayan-Ulgii	Nogoonnuur	2-May	15-Apr	4-Apr	7-Sep	17-Sep	26-Sep	128	155	175
4	Bayan-Ulgii	Sagsai	9-May	24-Apr	11-Apr	29-Aug	11-Sep	21-Sep	112	140	163
5	Bayan-Ulgii	Ulaankhus	11-May	26-Apr	12-Apr	29-Aug	11-Sep	20-Sep	110	138	161
6	Bayan-Ulgii	Tsengel	16-May	3-May	20-Apr	25-Aug	9-Sep	18-Sep	101	129	151
7	Gobi-Sumber	Choir	29-Apr	17-Apr	8-Apr	13-Sep	23-Sep	30-Sep	137	159	175
8	Zavkhan	Aldarkhaan	5-Jun	20-Apr	6-Apr	4-Sep	14-Sep	24-Sep	91	147	171
9	Zavkhan	Bayantes	13-May	30-Apr	19-Apr	27-Aug	9-Sep	17-Sep	106	132	151
10	Zavkhan	Durbuljin	26-Apr	9-Apr	2-Apr	12-Sep	22-Sep	1-Oct	139	166	182
11	Zavkhan	Tes	6-May	25-Apr	16-Apr	31-Aug	11-Sep	19-Sep	117	139	156
12	Selenge	Zuunburen	28-Apr	13-Apr	6-Apr	6-Sep	16-Sep	23-Sep	131	156	170
13	Selenge	Tsagaannuur	1-May	15-Apr	6-Apr	8-Sep	20-Sep	28-Sep	130	158	175
14	Ubs	Davst	28-Apr	17-Apr	7-Apr	11-Sep	20-Sep	28-Sep	136	156	174
15	Ubs	Tes	3-May	21-Apr	12-Apr	6-Sep	16-Sep	23-Sep	126	148	164
16	Ubs	Ulaangom	29-Apr	17-Apr	7-Apr	9-Sep	19-Sep	28-Sep	133	155	174
17	Khovd	Baitag	16-Apr	3-Apr	27-Mar	18-Sep	28-Sep	6-Oct	155	178	193
18	Khovd	Erdeneburen	19-Apr	5-Apr	30-Mar	14-Sep	24-Sep	2-Oct	148	172	186

As of multi-year mean, in 2080 the flies are expected to appear one month earlier in soums of Bayan-Ulgii aimag and 20-24 days in other aimags, while they are expected to appear earlier or by 60 days earlier in Aldarkhaan soum

of Zavkhan aimag (Table 1). In Aldarkhaan soum of Zavkhan, the minimum generation period for flies is 91 days, while in Bulgan soum (Baitag station) of Khovd, it is 155 days.

The generation period is estimated to be extended by 20 to 30 days in these soums by 2050 (Figure 2). By 2080, this period is expected to increase by 25-88 percent.
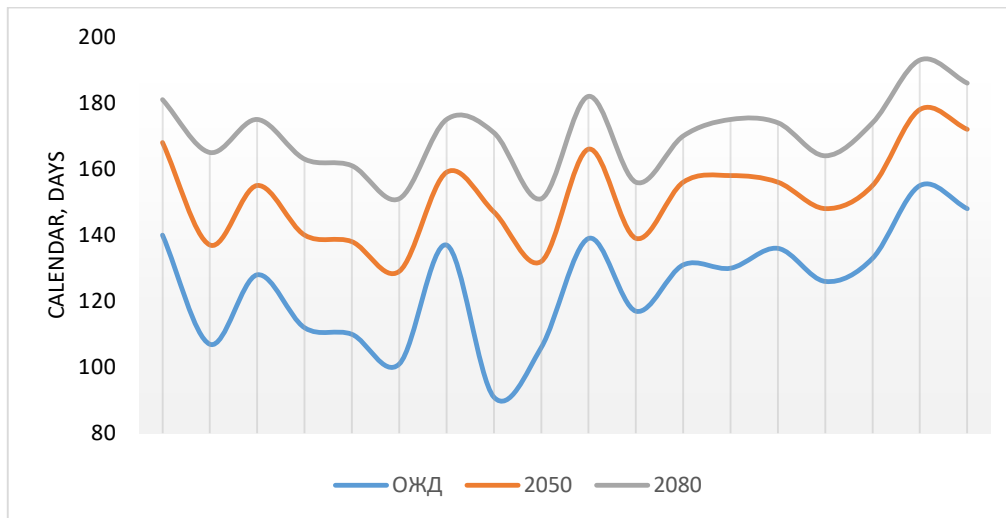

Figure 2. Changes in the lifetime of Seabuckthorn fly, days
Remarks: 1. Bayannuur. 2. Duchinjil. 3.Nogoonnuur. 4.Sagsai. 5.Ulaankhus. 6.Tsengel. 7.Choir.
8. Aldarkhaan. 9. Bayantes. 10. Durvuljin. 11. Tes (Zavkhan). 12. Zuunburen.13. Tsagaannuur.
14. Davst. 15. Tes. 16. Ulaangom. 17. Erdeneburen. ОЖД- multi-year mean

Insect-friendly temperatures are expected to exceed 100°C in Choir and Durvuljin soums of Zavkhan, Davst soum of Uvs, Bulgan soum and Erdeneburen of Khovd and to increase by 50 percent in 2050 and 100 percent in 2080. In Bulgan (Duchinjil station) soum of Bayan-Ulgii, the heat supply is low or less than 500°C. It is also expected to increase by 50-100% in the future. As the lifetime of flies increases, the heat supply increases as well. According to a multi-year mean, HHC was not enough for flies (suitable for Selenge), it is expected to be less surrounded and less humid in the future.

Sea buckthorn flies were first identified in the Netherlands (Hering, 1958) and were known in a few European countries, but they did not cause significant harm. However, *Rhagoletis batava* caused harm to the sea buckthorn cultivation in western Siberia and the Altai region (Kolomiec, 1970; Shamanskaya, 2006). Since 2001, it has rapidly spread in Russia and areas of Europe and the damage they have done have being observed. Soon in 2014, it began to cause severe damages to crops in several countries such as Belarus, Latvia, Lithuania, Germany and Poland. In 2015, *Rhagoletis batava* were recorded in the sea buckthorn fields in Estonia and Finland, and in the same year, a monitoring study in Hungary found adult flies. This became the basis for confirming that *Rhagoletis batava* had spread from Siberia to Europe, which posed a number of question before researchers, as to why the Siberian population is more destructive than the European population?

In 1970, Kolomyetz considered the Siberian Sea Buckthorn flies as a new subspecies, in other words, he identified it as ***RHAGOLETHIS BATAVA OBSCURIOSA*** (KOLOMIEC, 1970). Kolomyetz identified the Siberian Sea buckthorn fly as a subspecies because he believed that it was symptomatically different from the European species. Russian researchers and sea buckthorn growers have widely used the name of this species. However, since it has not been proven to be a subspecies spread in Siberia, it is considered to be a species that spread from Siberia to Europe. Thus, in Europe, the native species of sea buckthorn flies occur in both alien species from Siberia.

The Siberian species is more adaptable and more aggressive, and several factors influenced it to spread to Europe. These include, climate change, or the humid and warm climate has provided a positive effect on its reproduction. It is also related to the increase in fodder reservoir or sea buckthorn cultivation. The study of the flight dynamics of sea

buckthorn flies is relatively well studied. According to a study in Lithuania, the flight of flies lasted from last ten days of June to August, with a peak of activity in the first ten days of mid-July. According to a study in 2016, flies were recorded in traps between June 30 and August 8, and the number of flies caught in traps between July 14 and 18 was high, but flies were trapped between July 21 and August 22. The peak of the flight was not clearly visible at this time, and statistical estimates suggest that it took place between July 28 and August 18. In 2018, flies were trapped between June 26 and July 9, and the peak of the flight took place between July 20 and 24.

During the years of observations, the dynamics of fly populations fluctuated greatly, which was directly related to the climatic conditions of those years. This study was similar to the observations in Germany, but according to Shamanskaya (2014) and Zhao (2017) (Dominykas Aleknavicius. 2019) it began 2-3 weeks before the flight of flies in Siberia and the Asian part of Mongolia and Russia. In conclusion, the flight of flies in Europe lasts for 6 weeks, starting in late June and ending in August, culminating in ten days in mid-July to ten days in mid-August. Also, the start time of the flight and the start of the flight lasts about 20 days each year.

Sea buckthorn flies are species which are well adapted to warm environments. According to a research by M. A. Prokofieva, the sum of the useful temperatures for the development of the worms is 312°C and the fluctuations are plus ± 67.5 degrees. The flight time of an adult insect is associated with thermal fluctuations. If the spring is warm, the weather is hot or sunny in the first ten days of June, and the sum of useful heat is 336-380°C, or the spread of flies begins on June 9-22, early release of flies starts and in the case of medium-term spreads, the spread of flies continues in the middle of June, when the sum of useful heat is 271-278 degrees Celsius, or in the cool days, the beginning of the evening spread is considered to be the end of June and the beginning of July. During the cold spring period of the year, the dispersion of flies lasts for 6 weeks for three periods with a total useful heat of 250°C and the mass dispersions last one week, and the mass dispersions begin in the first ten days of July (Shamanskaya L.D 2014).

CONCLUSIONS

- We marked the spread of Sea buckthorn fly (*Rhagoletis batava*) at 223 points in 22 soums of 6 provinces of Mongolia and described it on the distribution map.
- Due to the fact that the spread of Sea buckthorn fly covers an area with a unique and comprehensive system of mountains and gobi deserts, the amount of precipitation is uneven or not similar, and most of the territories are included in dry and cooler regions but some of them are included in wet and cold regions.
- The lifetime of Sea buckthorn flies depends on climate change and it is expected to emerge earlier and disappear late in the future, as a result, its lifetime will be increased.

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