Introduction

Weed control needs detailed knowledge about the biology of the target species to be efficient. In case of the invasive *Ambrosia artemisiifolia* L. several studies about its biology were performed in the 20th century in North America (Gebben 1965, Dickerson 1968, Basset and Crompton 1975). In the latest review about the biology of this species (Kazinczi et al. 2008a) some data on population biology and habitat preferences of European populations were integrated to the pool of knowledge. Since that time the number of papers about the biology of common ragweed in European populations increased seriously. In DA.4 (Deliverable: state of the art report) a short summary was given what we knew about biology and control options at the beginning of the project.

Besides the trials within this project several new studies on *A. artemisiifolia* and other comparable invasive plants were published (see the review by Smith et al. 2013). We have to expect local adaptation to the new habitat (environment, co-occurring species, predators and parasites). Therefore the analysis of the most recent biological behaviour of ragweed is essential to decide about the optimal local control measures. Scalone et al. (2013) already indicated that the European populations show specific adaptations to the northern climate by shifting the growth and flowering period towards July and June. During field work for task B (Biological fundamentals) and C (Non-chemical and integrated control strategies) we also could find some individuals within few populations in eastern Austria that started flowering in mid-June already (Karrer et al. 2011). Obviously the life cycle of common ragweed is shortened in the invasive European range.

Life cycle of *Ambrosia artemisiifolia*

Task B of the HALT-AMBROSIA-project aimed at increasing the knowledge of the biological characters of common ragweed from European populations. Like any other summer annual weed the fate of the population depends very much on the seed production in the respective year so that the future generations have a realistic chance to establish and succeed. The lifespan of a single ragweed plant (Fig. 1) begins with the barochorous release of seeds from the mother plant, followed by the phase of being part of the soil seed bank for variable times. High variation of seed morphs were found by Fumanal et al. (2007a, b) indicating pre-adaptation to be different distribution vectors. They found that the partition of light seeds is able to float on water for longer time and thus is prone to be spread easily along rivers.
Lifetime of seeds as element of the soil seed bank varies depending on the frequency of soil disturbance and dormancy. In arable fields with annual soil tillage the turnover rate of seeds is higher compared to that of abandoned fields or grassland. Consequently, the persistence of individual seeds in the soil seed bank of fields is short. In grassland, most of the seeds stay in the upper soil or on soil surface, and are integrated to the annual seed turnover, whereas the smaller partition of seeds will be integrated to deeper soil horizons by bioturbation and build the long-time persistent part of the soil seed bank.

Toole and Brown (1946) found a maximum longevity of (few) ragweed seeds by 39 years. In their experiment the storage conditions were very good, not comparable to the very stressful conditions in the upper soil and soil surface. Seeds stored at soil surface conditions turned out to lose viability within 5 years. Our studies of the soil seed bank of common ragweed along roadsides (DB.2) showed losses of 20% on average when autumn and early spring samples of the sites where compared with respect to the number of ragweed seeds in the upper soil layer (0-7 cm). Beres (2004) found that seeds exposed to field conditions (soil surface) throughout 5 years lost their viability by 100%. A screening for viability of ragweed seeds with different age stored at dry conditions and room temperature (ca. 20°C) gave comparable results (Kazinczi in DB.2). Considering the high variability in seed mass (Fumanal et al. 2007b) one could expect that smaller seeds that show higher dormancy tend to be accumulated in the lower soil, whereas heavier seeds have better chances to stay aboveground. Fenner and Thompson (2005) state that small seeds are more likely to be buried and are more dormant. It is not known if the partition of small ragweed seeds build up the more persistent seed bank whereas the seeds from upper soil/soil surface were bigger and less dormant but more successful by carrying more resources. Such was proved at least for other taxa (Zhang 1993, Imbert 1999).

Like other typical summer annual weeds ragweed seeds show innate dormancy after seed set in autumn and need stratification of about 4 weeks at temperatures around 0°C (Baskin and Baskin 1998) for germination. If the conditions after stratification are not suitable for germination (darkness, drought, temperature regime at low positive values, low O₂ or high CO₂ concentration in the soil) enforced (secondary) dormancy can be initiated (Baskin and Baskin 1980). As long as the conditions
do not change seeds persist in secondary dormancy until spontaneous death (latest after 39 years after Toole and Brown 1949). Such data were published for North American populations of common ragweed. Only few data about seed biology are available from European populations (Fumanal et al. 2007a, b; Beres 2004). Adaptive evolution in the newly invaded range could have changed the preferred site conditions for the regulation of germination and growth. Therefore some experiments were started in 2012 to elucidate these important aspects of the life cycle. The burial experiment (DB.2 Germination and viability of ragweed seeds) will test the survival rates of ragweed seeds buried at upper (5-7 cm) or lower (25 cm) soil depths. Survival rates of ragweed seeds varied between 30 and 98% depending on the seed source. Before burial, seeds were collected and stored at various conditions, transported by postal services (airmail) at maybe less optimal temperatures. The older sample (3 years in age when buried) gave generally lower viability rates (30-80 %) than the younger ones (1 year old, 70-98 %).

Ragweed individuals that germinate early in the season (March to April) grow slowly at the beginning forming a rosette-like stage with 4-6 leaves. With increasing temperatures vegetative growth is enhanced during June and July by significant stem elongation and +/- branching – depending on the resource availability (Leskovšec et al. 2012 and HALT-trials C.2 in DC.5: summary report on the main findings) or population density (Patracchini et al. 2011, Simard and Benoit 2011, Karrer et al. in trial C.5 in DC.5). Consequently, the number of pollen as well as seeds produced per individual also depends largely on habitat features and population density (DC.5).

**Effects of control measures on ragweed life cycle**

If the soil seed bank of common ragweed is already established it can be reduced by crop rotation and direct control of germinated plants. On arable fields with regular ploughing a significant proportion of seeds always will be left in the soil seed bank. Switchback to summer crop cultivation will promote the ragweed population to recover from the persistent part of the soil seed bank. Only total abandonment and succession towards forests over decades might deplete the soil seed bank by death from ageing. Depletion of soil seed bank by repeated stimulation to germinate (i.e. by soil tillage every month from spring onwards) could help to control ragweed.

Seed production is positively correlated to biomass (Leskovšek et al. 2012). Cutting aboveground biomass at early stages (May or June) is +/- compensated by rapid basal regrowth from axillary buds, often supplemented by accessory buds (DC.5). Early regrowth tends to produce rather more male flowers whereas later regrowth in August or September invest more into female flowers/seeds. Regrowth from early cuts also increases the number of axillary buds positioned at lateral shoots below the cutting height. They promote ragweed to increase even the number of lateral shoots below the cutting line that bear mostly female flowers. Based on the cutting experiments in pots (Milakovic et al. 2014a) as well as in the field it can be stated that a first cut should be delayed as far as possible towards the start of female flowering. In the southern part of Central Europe (S-France, Switzerland, Austria, N-Italy, Hungary, Slovakia, Slovenia, Croatia, Serbia) such late first cut must be supplemented by at least one second cut about 3 weeks later to prohibit successful seed production from the regrowth (Karrer et al. 2011, Pixner 2012, Karrer et Pixner 2012, Milakovic et al. 2014b).

When cutting is one of the most frequent control measures against ragweed in sensitive habitats (within villages, water resource areas, nature protection areas), application of herbicides is used often as an appropriate control tool against ragweed in traditional farming. In graminoid crops ragweed can be sprayed rather effectively, but herbicides have to be applied rather sophisticated if the farmers aim at very effective regulation. Several seedling cohorts (even in maize) produce
enough seeds for future generations so that ragweed continues to be present in the soil seed bank. Maybe the crop yield is not reduced but ragweed stays in the system for long time. Furthermore, ragweed cannot be fought chemically in some minor crops (oil pumpkin, red bean, soybean, and most sunflower breeds) because of the lack of registered herbicides in some countries (Austria, Hungary, Germany, etc).

In cereal stubbles late germinating ragweed cohorts can even dominate. Simply spraying herbicides does not kill ragweed by 100% at this late developmental stage (Bohren et al. 2008b). But combined measures like mowing plus spraying the regrowth or simply ploughing can destroy ragweed most efficiently (Kazinczi et al. 2008b). Donald (2000) demonstrated that a combination of band applied herbicides in the crop rows and mowing twice between the crop rows was sufficient to control annual weeds like common ragweed without reducing the yield of the main crop in Australia.

The most sensitive phases of ragweed's life cycle for appropriate application of the commonly used control measures are illustrated in Fig. 2. When optimizing the available tools with respect to timing and sequence, the effort for control can be kept low. Which kind of measure to apply, depends primarily on the habitat type infected and on the season.

Most important for hindering the invasion to not yet infected sites/countries is prevention of seed dispersal by human vectors. I.e., commodities (seed material, soil, relevant for trading and construction areas) should be kept clean as well as vehicles that move from infected to uninfected areas (most relevant in agricultural landscapes).

Once ragweed seeds arrive on or in the soil the seed bank can be managed by depletion or long-time full abandonment. Stimulating seeds to germinate and subsequent kill is a way to decrease the presence of weeds aboveground as well as belowground (Swanton et al. 2000, Murphy et al. 2006). Pre-emergence herbicides would not help so much if subsequent soil disturbance provides new seeds from deeper soil horizon. Even better would be to provoke ragweed to germinate and to kill afterwards by ploughing. During and short time after germination (seedling and juveniles up to the 4 leaf stage) is the best time for herbicide application in habitats where they are registered. Sophisticated mechanical weeding could also have high efficacy at this early stage of ragweed development as the ragweed seedlings and juveniles are prone to being killed by drought because of the lack of a well-developed tape root at that time of the year. The older ragweed gets the less effective are mechanical treatments and herbicide application (Bohren et al. 2008a, b; task C trials in this project).

Young adults are the best stage for hand-pulling: easy to detect and to identify, mechanically firm enough to be hold tight but the roots still not too deep. Therefore, pulling is generally the most effective control measure against ragweed (Bohren et al. 2008c) at least for small to medium sized populations (1-1000 individuals). Pulling before flowering is fine also for getting rid of the plant by use in simple humus composters. Pulling late in the year will produce individuals with ripened seeds that have to undergo a serious destruction of organic material by burning or fermentation.

Fostering competition by other plants (crops, intercrops, lawn species, tall grasses and herbs) is an admitted control option. Competition by shading green leaves or by litter can hamper already germination what can be documented easily on fallow land (Karrer et al. 2011). Competition can enforce germinated ragweed to develop quickly in height and therefore bearing only few buds for regrowth below cutting height (Milakovic et al. 2014b). If germinated without competition in early spring ragweed tends to grow only slowly in height forming almost a rosette of 4 to 6 leaves near to the ground. Consequently, such plants have very high regrowth potential from lower axillary buds.
after being cut. The number of available meristems for regrowth below the cutting height is also increased by the torsion of the main root and the shoot base in older ragweed plants. This causes the indirect lowering of the shoot base with its regrowth meristems (Vitalos, unpubl.). Outcompeting regrowing lateral shoots of mown ragweed by even faster regrowing competitors can help to keep the number of ragweed flowers or seeds at low levels (Milakovic and Karrer 2011). Fostering of competing vegetation after every mowing event is only possible on nutrient rich sites. Unfortunately, the substrate used to cover road shoulders since about 10 years is very unfavourable for any plant to grow. As a typical (CS)R-strategist (CSR theory: Competitors, Stress tolerators and Ruderals) ragweed is able to establish even at such unfavourable site conditions (gravel as substrate) and it will take many years to establish a competitive vegetation cover (DC.5).

Fig. 2: Life cycle of common ragweed and the optimized timing for appropriate application of control measures.

**Consequences and conclusions**

The HALT-trials gave improved insight to the biology of seeds and seed production in European populations of common ragweed at different habitat types. But we have to face new problems when ragweed succeeds to adapt to lower temperatures for growth, to higher temperatures for stratification and to earlier initiation of flowering and seed set. Future research has to be on the qui vive when adaptive processes in ragweed evolution call for continuous adaptation of control measures.


**References**


Milakovic, I., Fiedler, K. & Karrer, G. 2014a Fine tuning of mowing regime, a method for the management of the invasive Ambrosia artemisiifolia L. at different population densities. (in revision)


