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The role of rivers and streams in the migration of alien plants into the Polish Carpathians

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Abstract: The Carpathians are among the regions of Poland that are generally less susceptible to invasive alien plants. The factor limiting the spread of the species of this group is, above all, the mountain climate. Even species originating from other mountain regions, e.g. the Himalayan *Impatiens glandulifera*, have their localities only at low elevations, in the Carpathian foothills. In most cases, alien plant species migrate into the Carpathians from the lowlands. The river valleys provide the migration corridors used by alien species in the course of their progress into new territories of the upper mountain localities. The situation along some mountain rivers, where invasive alien species dominate the native vegetation, is dramatic. Their spread is facilitated not only by easy diaspore transport but also by some anthropogenic factors, such as, river engineering and the transformation of riparian habitats and progressing devastation. Currently, we can observe some invasive alien plants "*in statu nascendi*", developing a new, secondary range in the Carpathians (e.g. *Chaerophyllum aureum*) or at the foothills, along the Wisła (Vistula) and San river valleys (e.g. *Eragrostis albensis*). For some species, cities were the destination for the first stage of future migration, e.g. *Acer negundo*. In the Carpathians, where many national parks and nature reserves are located, the continuous monitoring of the spread of invasive alien plants should be one of the principal activities of botanists.

Key words: invasive alien plants, Carpathian Mts., distribution ranges, *Acer negundo, Echinocystis lobata*, *Elodea canadensis*, *Eragrostis albensis*, *Impatiens glandulifera*, *Reynoutria japonica*

1. Introduction

Invasive plants are considered to play an important part in the plant cover of Central Europe (Kornaś 1990; Jehlík 1998; Tokarska-Guzik 2005; Hulme *et al*. 2009; Pyšek *et al*. 2009). Also in the Polish part of the Carpathians and in the Carpathians foothills plant species of alien origin have acquired an increased importance in recent times (Zając M. & Zając A. 1998, 2001). In the flora of this region, 123 species of neophytes were recognised by 2001, including 42 species recognised as common neophytes, both with respect to the type of distribution, as well as, indirectly, with respect to the number of populations (Zając M. & Zając A. 2001). Recently, the number of neophytes has increased to 142 species. At the same time, the number of common neophytes has increased to 51 (original authors' data).

Numerous alien species occurring abundantly in the Polish Carpathians can be considered as invasive according to current terminology (Pyšek *et al*. 2004; Tokarska-Guzik 2005). In particular, the definition fits the majority of the common neophytes, i.e. taxa which produce reproductive offspring, often in very large numbers, at considerable distances from the parent plant, and thus have the potential to spread over a large area. Their role in the plant cover of the region is diverse. Some species occur in human-made (anthropogenic) habitats exclusively, while others also enter semi-natural and natural habitats.

The main idea behind the present study was to provide a synthesis of the knowledge accumulated to date on the role of rivers and streams in migration of alien plant species into Polish Carpathians and to investigate changes in the flora of the region. These aims have been achieved by creating an original and up-to-date catalogue of invasive alien plants occurring in the Carpathians and attempting to reconstruct periods of immigration and spread of six selected neophytes which show an affinity with river valleys.

2. Material and methods

2.1. Study area

This investigation of alien plant species focused in the area of Polish Carpathians and its foothills (Fig. 1). The Carpathians, along the national border, form a macro-region occupying an area of approximately 19.500 square km, which constitutes *ca*. 6% of the area of the whole country (Warszyńska 1995). They consist of Carpathian Foothills, Western Beskidy Mts., Eastern Beskidy Mts. (the Bieszczady Mts.), the Tatra Mts. and the Pieniny Mts. The Carpathian Foreland occupies *ca*. 10.000 square kilometres. They consist of the following mezoregions: the Carpathian Basins and the southern parts of the Southern Polish Uplands. In the study area the following altitudinal plant zones are distinguished: the sub-montane zone (which occupies the largest area), the lower montane zone, the upper montane zone, the sub-alpine Dwarf Mountain-pine zone, and the alpine meadow zone.

2.2. Sources, interpretation and synthesis of data

For the purpose of the present study, it was necessary to create an original and up-to-date catalogue of invasive alien plants occurring in the Carpathians. This was developed on the basis of previously published lists (Zając A. *et al*. 1998; Mirek *et al*. 2002; Tokarska-Guzik 2005), regional studies and personal research data.

Distribution data for the alien plant species were assembled from the database of the "Distribution Atlas of Vascular Plants in Poland" (ATPOL). In ATPOL, the basic cartogram unit is a square 10 x 10 km; these are combined in "large" 100 x 100 km squares (Zając 1978). For the purpose of the current study, each ATPOL square of 10 x 10 km was subdivided into 25 smaller squares of 2 km side, which are the basic units in the Carpathian cartograms. A detailed list of localities of individual neophytes is included in the ATPOL database. Input sources for the database include unpublished field records, published papers as well as herbarium data (the Herbarium of the Institute of Botany, Jagiellonian University – KRA, the Herbarium of the Institute of Botany, Polish Academy of Sciences – KRAM and private herbarium collections). On the basis of the data collected and using an original software package called 'The Regional Atlas of Plants' (in Polish: Regionalny Atlas Roślin – RAR), developed by Józef Gajda of the Institute of Computer Science of the Jagiellonian University, distribution maps were prepared for the neophytes occurring in the study area. For the present paper, the cartographic data collected were used to draw up an analysis of the contemporary distribution of six chosen species and of the characteristics of their local ranges in the Carpathians. The following species were selected: five species classified as transformers (Richardson *et al*. 2000): *Acer negundo, Echinocystis lobata, Elodea canadensis, Impatiens glandulifera* and *Reynoutria* (*Fallopia*) *japonica* and one considered as potentially invasive, namely *Eragrostis albensis*. For the selected group of species, which differ in origin, biology and the type of spread within Poland which they represent, the histories of their spread within the Carpathians were reconstructed and presented in cartograms drawn for consecutive time periods. Comprehensive maps illustrating the process were drawn using the options of the RAR software and in relation

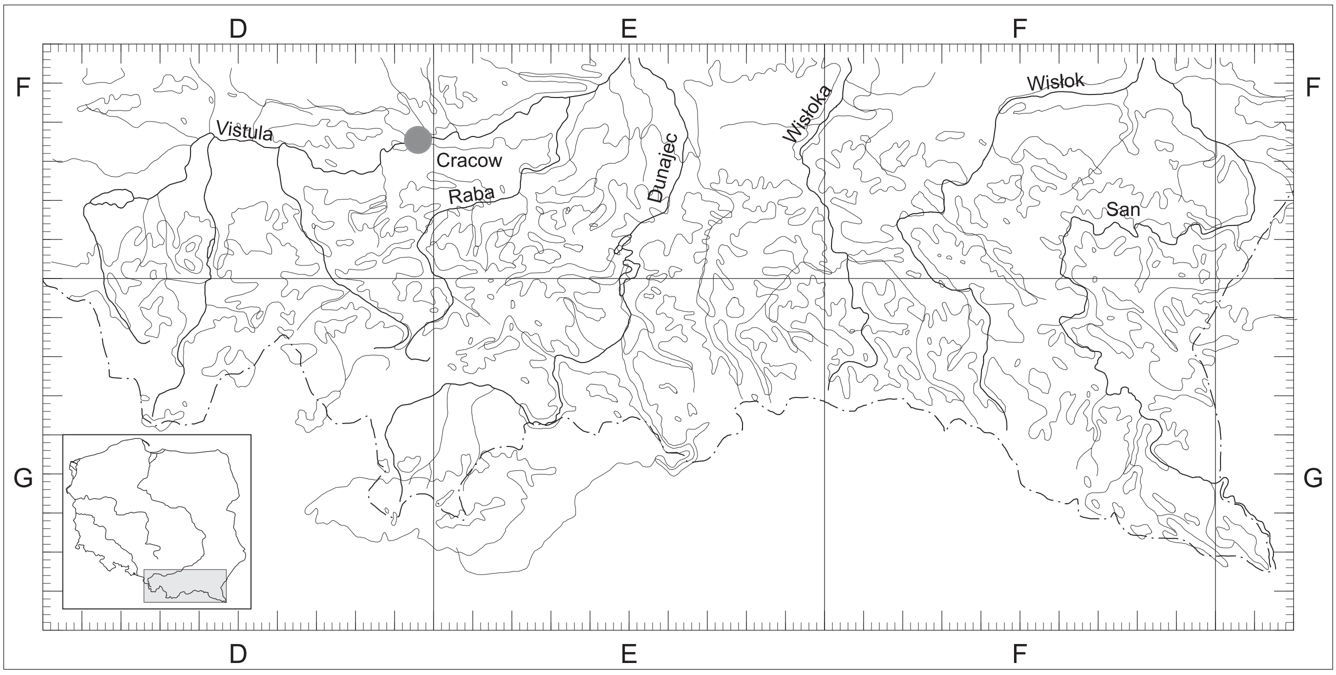

Fig. 1. Location of the Polish Carpathians and its foothills

to the data sets in the database as they increase over time. The number of basic units occupied by a particular species in the consecutive time periods was assessed by a special RAR subprogram. The actual area of the Carpathians was distinguished on the maps by an emboldened line. The names of species were adopted from 'Flowering Plants and Pteridophytes of Poland, a checklist' (Mirek *et al.* 2002).

3. Results

The first, tentative list of 54 invasive alien plant species (kenophytes = neophytes) for Poland was proposed by Tokarska-Guzik (2005). In the Polish Carpathians, 44 alien plant species have been identified on the basis of the criteria of IAS (Invasive Alien Species) (Pyšek *et al.* 2004) (Table 1). Among the species listed, nine species have not been included before as 'invasive'. The explanation for this could be the different invasion rate of particular species under the local or regional conditions. Also, four of the species added currently have the status of 'potentially invasive' (*Chaerophyllum aureum, Eragrostis albensis, Erechtites hieracifolia, Telekia speciosa*). They have started to spread in some regions of Poland, but because of their high rate of expansion, it could be expected that during the next twenty years they will become successful invaders, occupying significant areas in the Polish Carpathians. The status of one of them, namely *Telekia speciosa*, is uncertain. Some botanists used to consider the species as native in the Eastern Carpathians (Zemanek & Winnicki 1999). However, its current spread over long distances and numerous localities in ruderal habitats within its eastern distribution range suggest that it is not native in Poland.

Among the alien plant species considered as invasive in the area of the Polish Carpathians, 11 species are classified as 'weeds', another 29, (excluding the species identified as 'potentially invasive') which are penetrating into natural habitats, are classified as 'transformers'. Eight species from the latter group show an affinity with river valleys. For the present account, six species have been selected to illustrate the current distribution and the probable course of expansion within the territory of the Carpathians together with the stages of their expansion documented by means of maps.

Table 1. Invasive vascular plant species in the Polish Carpathians

Name of species	1	2
Acer negundo	•	T
Acorus calamus		T
Amaranthus retroflexus		W
Aster novi-belgii		T
Bidens frondosa	•	T
Bunias orientalis		W
Cardaria draba		W
Chaerophyllum aureum	*	P
Chamomilla suaveolens		W
Conyza candensis		W
Digitalis purpurea		T
Diplotaxis muralis	*	W
Echinocystis lobata	•	T
Elodea canadensis	•	T
Epilobium ciliatum		T
Eragrostis albensis	*, •	P
Erechites hieracifolia	*	P
Erigeron annus	•	T
Fraxinus pennsylvanica		T
Galinsoga ciliata		W
Galinsoga parviflora		W
Helianthus tuberosus		T
Heracleum mantegazzianum s. l.	•	T
Hesperis matronalis subsp. *matronalis*	*	T
Impatiens glandulifera	•	T
Impatiens parviflora		T
Juncus tenuis		T
Lolium multiflorum	*	T
Lupinus polyphyllus		T
Medicago sativa	*	W
Mimulus guttatus		P
Oxalis fontana		W
Padus serotina		P
Parthenocisus inserta	•	T
Quercus rubra		T
Reynoutria ×bohemica	•	T
Reynoutria japonica	•	T
Reynoutria sachalinensis	•	T
Robinia pseudacacia		T
Rosa rugosa	*	T
Rudbeckia laciniata	•	T
Rumex confertus		T
Solidago graminifolia		P
Solidago canadensis		T
Solidago gigantea	•	T
Telekia speciosa	*	P
Trifolium patens		T
Veronica filiformis		T
Veronica persica		W
Vicia dasycarpa		W
Vicia grandiflora		T

Explanations. Column 1: * – species not given in the list of invasive vascular plant species in Poland (Tokarska-Guzik 2005); • – species, which the important routes of spreading are rivers and streams in the Carpathian Mts.; Column 2: T – transformer, W – weed, P – potentially invasive

Acer negundo L. [syn.: *Negundo aceroides* Moench, *N. fraxinifolia* Nutt., *N. negundo* Karst.] – Box-elder; Ashleaf Maple, Aceraceae

A north American species, planted in Poland in ornamental parks and gardens, probably as early as in the beginning of the 19th century. It has undergone an evident expansion only within the last 50-60 years (Adamowski *et al.* 2002; Tokarska-Guzik 2005). It is especially abundant along the tributaries of big rivers in Poland (Tokarska-Guzik 2005; Zając A. & Zając M. 2001). The earliest occurrences of this species in the Polish Carpathians and the Carpathian foothills were recorded in the mid-fifties. Its subsequent spread is illustrated on maps from the time series: 1975, 1990 and 2009 (Fig. 2). Before 1975, it had few localities in

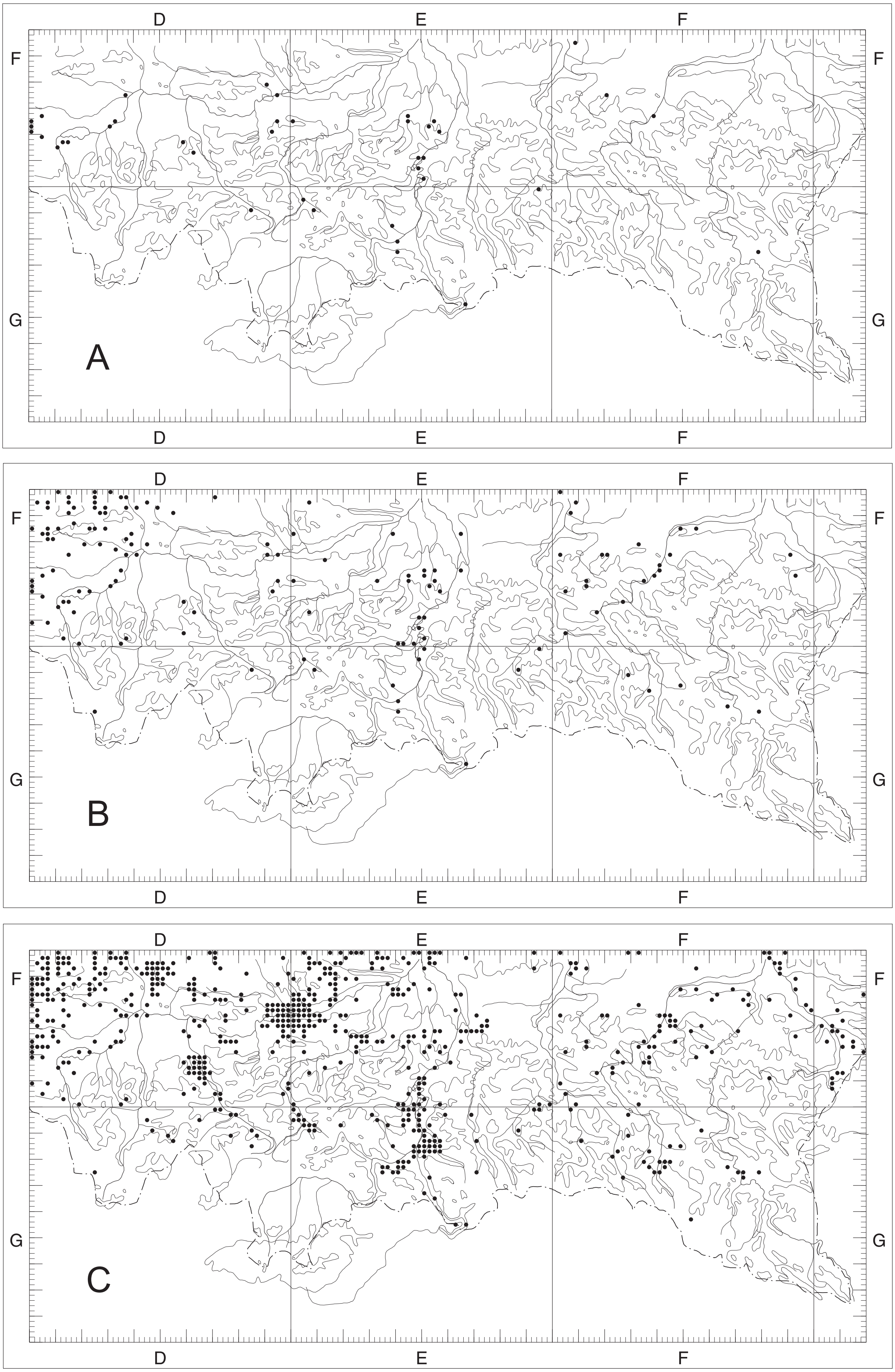

Fig. 2. Recorded history of the spread of *Acer negundo* in the Polish Carpathians and its foothills: A – number of localities up to 1975, B – up to 1990, C – up to 2009 respectively

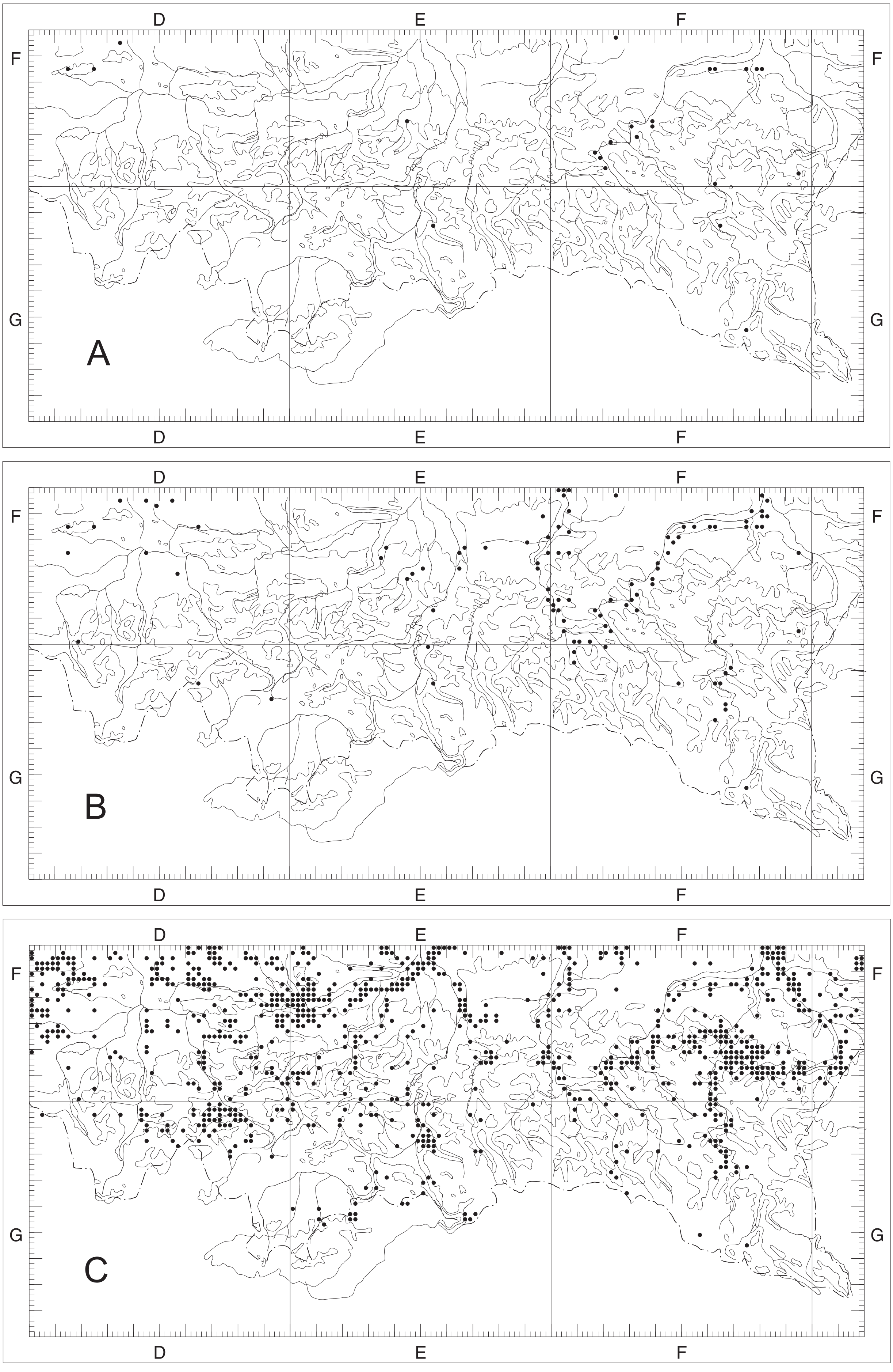

Fig. 4. Recorded history of the spread of *Echinocystis lobata* in the Polish Carpathians and its foothills: A – number of stations up to 1975, B – up to 1990, C – up to 2009, respectively

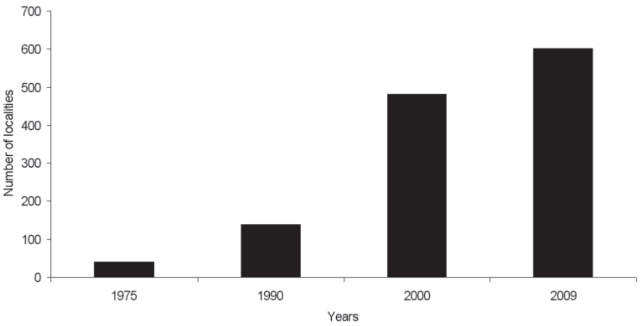

Fig. 3. Number of localities of *Acer negundo* in the Polish Carpathians and its foothills for consecutive time periods

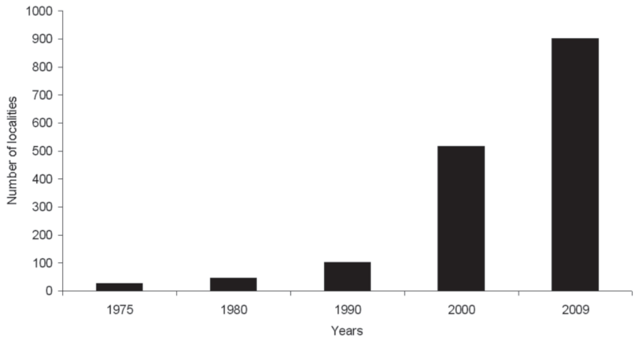

Fig. 5. Number of localities of *Echinocystis lobata* in the Polish Carpathians and its foothills for consecutive time periods

the study area. Of particular interest are localities on the outskirts of the Carpathians in the Upper Vistula valley and in the Dunajec valley. During next fifteen years, the number of localities increased slowly. Not before 2009, new concentrations of localities were clearly seen along the Skawa river near Wadowice and in the middle part of the Dunajec river valley. New localities were recorded along other Carpathian rivers, e.g. the Raba river (its upper part in the Carpathian foothills and lower elevations of the Beskidy Mts.). Presumably, the species is stabilizing its range in the area of the Polish Carpathians (Fig. 3).

Echinocystis lobata (F. Michx.) Torr. & A. Gray – Wild Cucumber, Cucurbitaceae

A species of North American origin, introduced into Europe at the end of 19th and the beginning of the 20th century as an ornamental plant. Almost at once, it started to spread spontaneously (Heine & Tschopp 1953; Jehlík 1998; Prischter 1958). The first data from "the wild" for Poland date back to the beginning of the 20th century. According to Tokarska-Guzik (2005), it was probably brought into Poland from two directions: from the west (Germany) and from the east (the Ukraine). Figure 4 illustrates periods of its spread in the Carpathians and in its foothills in 1975, 1990 and 2009, respectively. The first spontaneous localities in the Polish Carpathians were recorded in the mid-sixties of the last century. Already the first map (1975) confirms the above-mentioned hypothesis about two migration routes for Wild Cucumber into Poland, which are clearly seen in the Carpathians. Its affinity with river valleys is also obvious. By 1990, the number of its localities began to increase, while the distribution disjunction in the central part of the Carpathians was still visible. After 2009, the directions of its spread have been no longer clearly visible, and the species became widespread in the entire area. It was still colonising new sites, particularly in riparian habitats. The number of its localities increased slowly up to 1990, whilst in recent times (1990-2009) the increase was significant (Fig. 5).

Elodea canadensis Michx. [syn.: *E. canadensis* Rich.] – Canadian Waterweed, Hydrocharitaceae

A species of North American origin. In Europe its spread started in the first half and in Poland in the beginning of the second half of the 19th century (Tokarska-Guzik 2005). Its expansion in the Carpathians did not start before the mid-fifties of the 20th century. By 1955, it occurred only in the Carpathian Basins (Fig. 6). During the following 35 years, it occupied a majority of big Carpathian rivers, old river beds, ditches and fish ponds. Its expansion into the study area shows an easterly direction. The dynamics of the increase in the number of localities showed a significant increase in the most recent period of time 1990-2009 (Fig. 7).

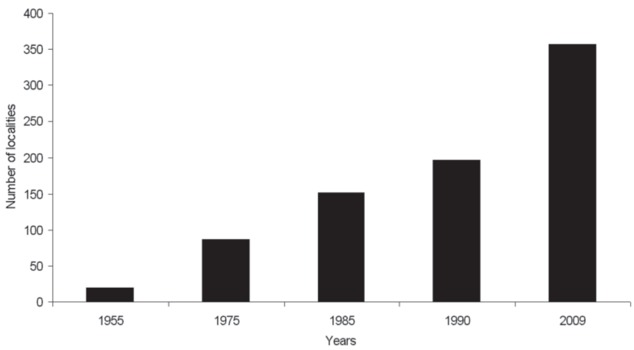

Fig. 7. Number of localities of *Elodea canadensis* in the Polish Carpathians and its foothills for consecutive time periods

Eragrostis albensis H. Scholz , Poaceae

The species originates most probably from south-western Asia (Michalewska & Nobis 2005) and is considered as potentially invasive. In Poland, it is widespread along the Vistula river valley (Sudnik-Wójcikowska & Guzik 1996 – under the name *E. pilosa* (L.) P. Beauv.; Guzik & Sudnik-Wójcikowska 2005) and along Odra valley (Kącki & Szczęśniak 2009). It recently entered the Carpathian foothills from the east along the San river valley (Fig. 8). Contemporarily, it is spreading significantly in the Sandomierz Basin (Michalewska & Nobis

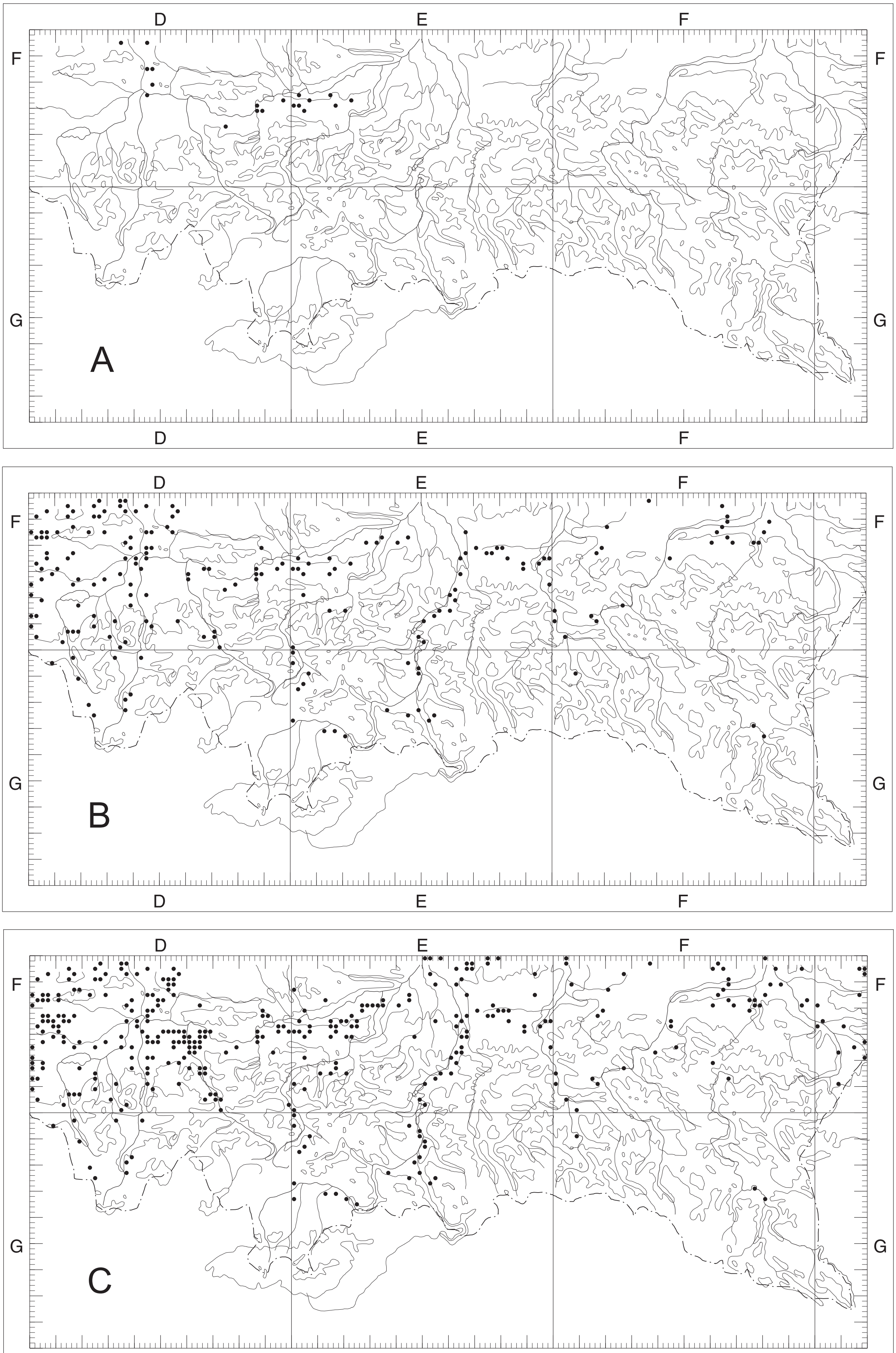

Fig. 6. Recorded history of the spread of *Elodea canadensis* in the Polish Carpathians and its foothills: A – number of stations up to 1955, B – up to 1990, C – up to 2009, respectively

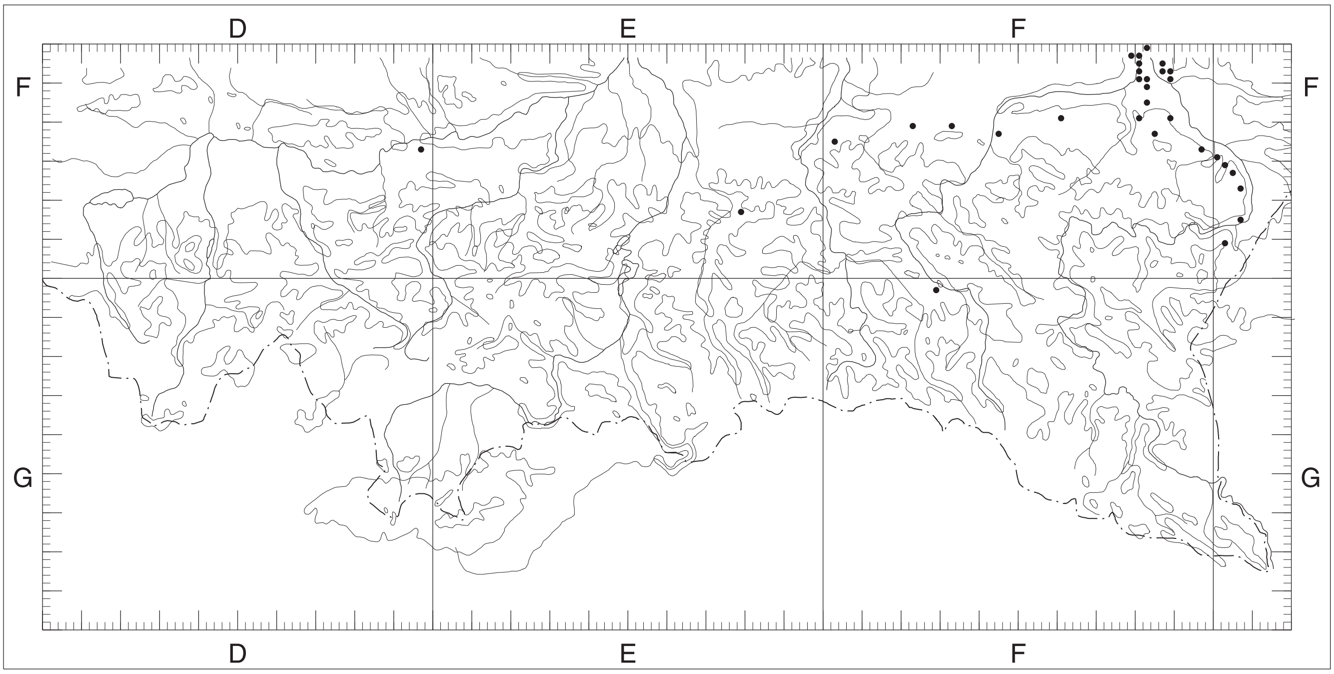

Fig. 8. Recorded history of the spread of *Eragrostis albensis* in the Polish Carpathians and its foothills

2005). The species occurs not only in river valleys, from which it started its spread, but also in human-made habitats, which seems to confirm the likelihood of its future, rapid, invasive spread.

Impatiens glandulifera Royle [syn.: *Impatiens roylei* Walp.] – Indian Balsam, Balsaminaceae

The species originates from the Himalayas and eastern India where it grows in humid riparian forest at higher altitudes (Tokarska-Guzik 2005). In Europe, it has been cultivated as a decorative and medicinal plant since the first half of the 19th century. As a synanthropic plant, it started to spread at the end of the mid-19th century (Beerling & Perrins 1993; Drescher & Prots 2003; Lhotská & Kopecký 1966; Pyšek & Prach 1995). In Poland, it colonized riparian habitats in particular, and was the object of previous studies (e.g. Dajdok *et al.* 1998, 2003; Dajdok & Kącki 2003; Kucharczyk 2001, 2003; Kucharczyk & Krawczyk 2004). The earliest records from the Polish Carpathians date back to the mid-sixties of the last century. On a map showing its distribution by 1970, there are only a few localities (Fig. 9). Twenty years later (1990), it was recorded quite frequently, in particular, in river valleys (particularly mountain and foothill rivers), but it did not yet show any particular type of range. By 2009, the situation was completely different. In some regions, like the Dynowskie Foothills or the Biała and Soła river valleys (in the western part of the Carpathians), it was abundant and formed continuous, local ranges. The dynamics of its number of localities was unexpected here. In the period of years 1990-2009, the number of localities increased almost eight times (Fig. 10). Observations made recently suggest that it has not yet reached its maximal distribution range and it is expected to spread up into the lower mountain elevations.

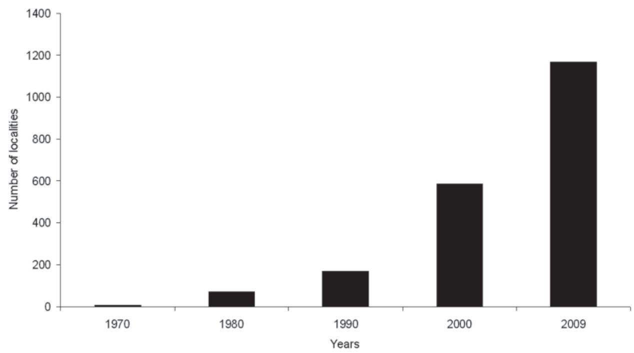

Fig. 10. Number of localities of *Impatiens glandulifera* in the Polish Carpathians and its foothills for consecutive time periods

Reynoutria japonica Houtt. [syn.: *Fallopia japonica* (Houtt.) Ronse Decraense; *Polygonum cuspidatum* Siebold & Zucc.] – Japanese Knotweed, Polygonaceae

The species originates from Eastern Asia (Tokarska-Guzik 2005). It was introduced in Europe in the first half of the 19th century as an ornamental plant. It was extending its secondary, European range since the second half of the 19th century (e.g. Beerling *et al.* 1995; Child & Wade 1999). In Poland, according to the recorded history of its spread, it was spreading since the end of the same century (Tokarska-Guzik 2005), while in the Polish Carpathians, since the mid-20th. Previously, in 1930s, it was a successful species on the

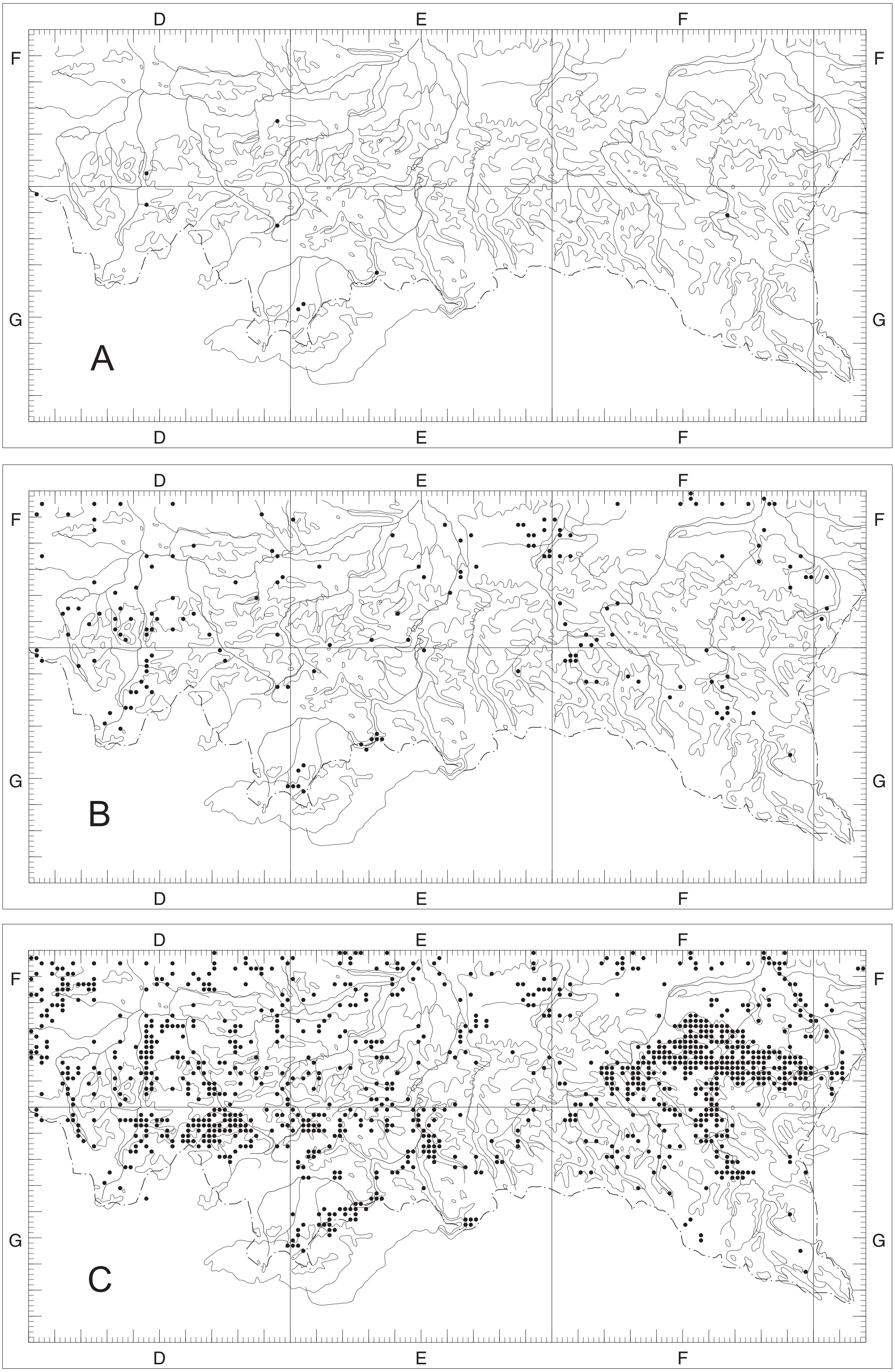

Fig. 9. Recorded history of the spread of *Impatiens glandulifera* in the Polish Carpathians and its foothills: A – number of stations up to 1970, B – up to 1990, C – up to 2009, respectively

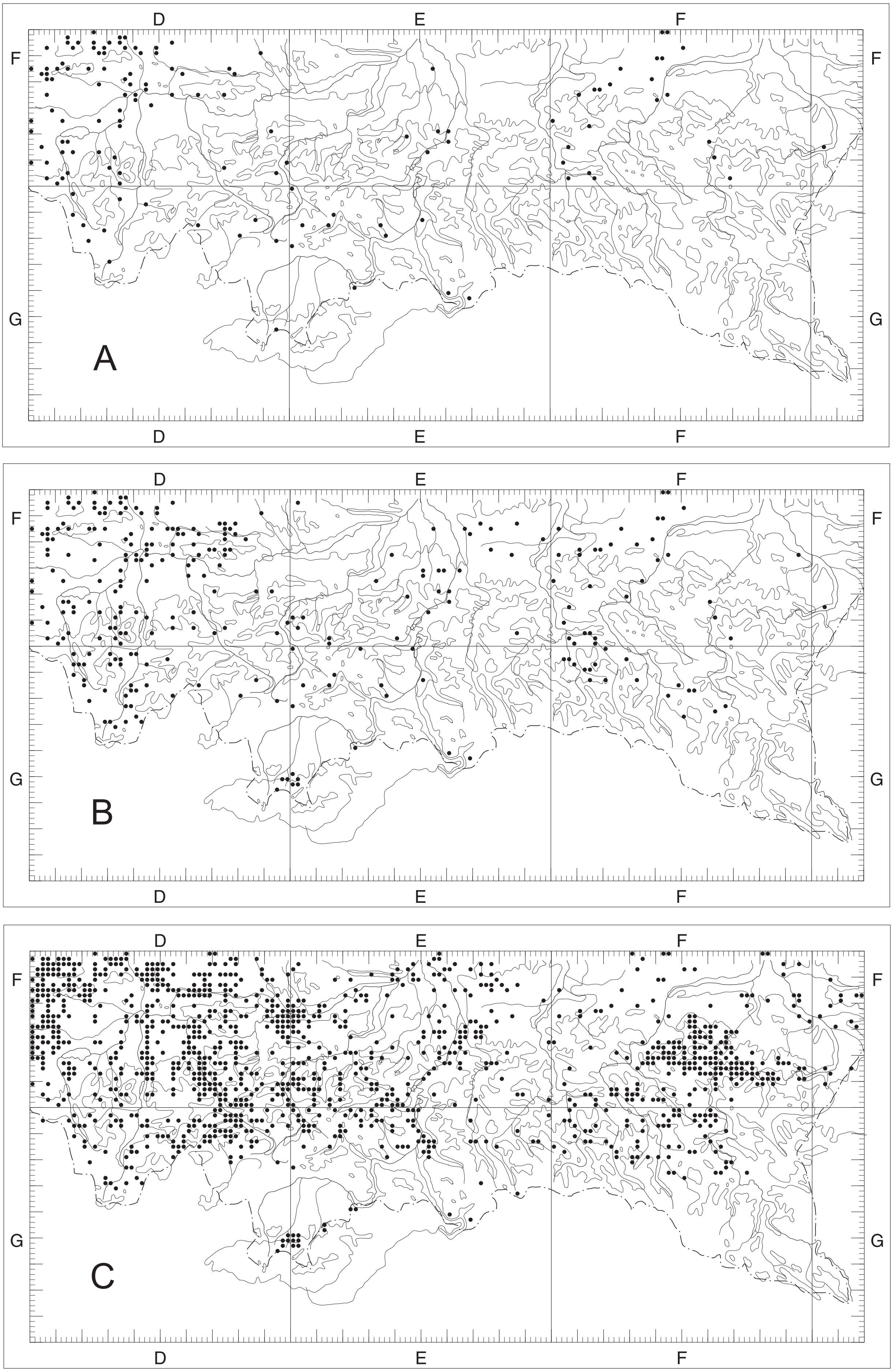

Fig. 11. Recorded history of the spread of *Reynoutria japonica* in the Polish Carpathians and its foothills: A – number of stations up to 1980, B – up to 1990, C – up to 2009, respectively

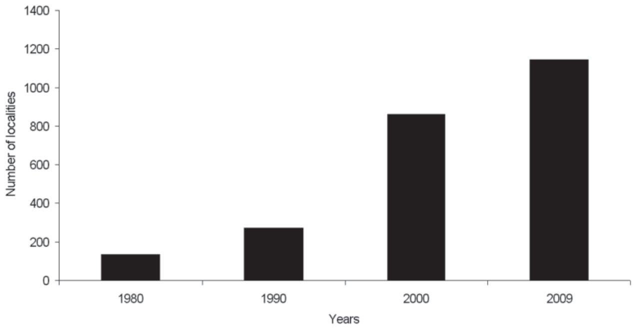

Fig. 12. Number of localities of *Reynoutria japonica* in the Polish Carpathians and its foothills for consecutive time periods

northern edge of the Carpathian hinterland. Its spread into the Carpathians was not rapid at the very beginning. In 1980, it was recorded in a few localities in river valleys (Fig. 11). Ten years later, its spread was visible in the western part of the study area. By 2009, it became fairly widespread over the whole territory, and was rarer only in the central part of the lower altitudes. It still continues to colonize new sites, on a massive scale in many parts of the region (Fig. 12).

4. Discussion

Selected species represent different types of dissemination. *Acer negundo* is an anemochorous species (winged fruits dispersed by wind, seeds germinate easily) but may also spread by suckers. *Impatiens glandulifera* disperses its diaspores in two ways: by autochory and by allochory through wind, animals and water. In the case of balsams, autochory is implemented through the process called ballochory, where a ballistic mechanism causes the throwing out (hurling) of diaspores following the abrupt release of a tension in the fruit, triggering movements of the pericarp walls (Podbielkowski 1995). *Echinocystis lobata* dispersal involves seeds and fruits. *Reynoutria japonica* spreads mainly through vegetative processes but the role of generative (sexual) reproduction is increasing, in particular, in mixed stands (co-occurrences of two parental species and their hybrid) along rivers and streams (Tokarska-Guzik *et al.* 2007). *Elodea canadensis* spreads only through vegetative processes owing to the fact that only female individuals were introduced into Europe. The fragments of shoots are transported by water, birds and humans (Tokarska-Guzik 2005). In all cases, in the spread of this group of species, anthropochory is also of importance, reflecting the role of humans in their migrations over long distances.

What is the role of habitats along streams and rivers in the Polish Carpathians? Such habitats enable neophytes to establish a new population without greater competition from native species. Riparian habitats provide suitable conditions for colonization by alien plant species. Particularly large rivers, still only slightly disturbed by humans, with the dynamic and diverse natural process present in their environment, support plant migration (Planty-Tabacchi *et al.* 1996; Faliński 2000; Burkart 2001; Tokarska-Guzik 2005; Dajdok & Tokarska-Guzik 2009). According to Richardson *et al.* (2007 and literature cited therein), 'river ecosystems are highly prone to invasion by alien plants, largely because of their dynamic hydrology and because rivers act as conduits for efficient dispersal propagules'. Recent studies confirm how water-mediated dispersal rather than the more expected wind-mediated dispersal can affect the establishment of some invasive plants (e.g. *Ailanthus altissima*) in riparian corridors by changing the germination rate and velocity and by providing the option of a new pathway of vegetative propagation (Kowarik & Säumel 2008). Additionally, some anthropogenic factors (river engineering in some stretches, location of settlements and towns in river valleys, transport routes crossing rivers, etc.) facilitate the migration of plant species both along and across river valleys. These conditions are used by alien species which implement the subsequent phases of their invasion along the river valley (penetrating into a new territory through the corridor created by the river) (Faliński 2000; Tokarska-Guzik 2005; Śliwiński 2008).

For some alien plants, the so-called river-related migration is not clearly seen because they are already widespread in the whole mountain region. Also one should not overlook the role of human settlements and, particularly, bigger towns and cities located upon rivers. The urban areas are in many cases a 'foothold, which enables the species to expand further into adjacent areas' using rivers as migration routes (Burkart 2001; Dajdok & Tokarska-Guzik 2009).

From such newly occupied habitats many, species are able to colonize semi- and natural vegetation type, such as rush communities or riparian forests (Pyšek 1994; Tokarska-Guzik 2005; Tokarska-Guzik *et al.* 2006; Uzięblo 2008). The latter, in the Carpathians, are significantly transformed by humans, which further facilitates colonization. Therefore, the characteristics of streams and rivers means that they are highly appropriate migration corridors enabling species to migrate into the Carpathians.

Let us address the question of how deeply an alien plant species can migrate into the mountain system of the Carpathians. In general it can be stated that the main area of penetration by newcomers is the Carpathian foothills. These are localities at the altitude from 300 up to 550 m a.s.l. Here the valleys of streams and rivers are wide enough, not bordered by steep slopes, and are characterized by diverse plant communities. Among the species described in the present paper, two, namely *Acer* *negundo* and *Elodea canadensis*, occur mainly in this part of region. The latter species has even penetrated much more deeply into the Beskidy Mts., along the Dunajec river, rarely having its localities at lower altitudes. Three other species penetrate into habitats located in higher elevations. They tend to concentrate in the lower mountain sites (up to the lower montane zone). Attempting to locate the studied species in order of increasing altitude, one can assess that *Echinocystis lobata* can reach only the lower localities, and that *Impatiens glandulifera* can reach the highest elevations attained by neophytes. It should be expected that this species reaches its ecological optimum in mountain areas, but nevertheless its upper limit is reached at *ca*. 1000 m a.s.l.

Data gathering for the Czech Republic reveal that alien species gradually penetrated into higher altitudes (Pyšek *et al*. 2011 and literature cited therein). According to the above-mentioned authors, their spread to higher altitudes became increasingly easier over the last two centuries and was connected with increasing disturbance, increased propagule pressure as well as with climate change.

All the species studied (excluded *Eragrostis albensis* and *Elodea canadensis*) were cultivated before spreading spontaneously. Usually, they were introduced from their native range in numerous diaspores or plants, which influenced their genetic diversity and future success. In comparison with other alien species, where populations appeared from one incidental introduction of a low number of (or sometimes even one) diaspores, reaching an ecological success was much easier. An analysis of invasive neophytes provided by Tokarska-Guzik (2005) confirmed such a hypothesis. The majority of transformers were plant species introduced deliberately by humans.

The preparation of regional atlases which illustrate the distribution of individual vascular plant species, in different time periods, makes it possible to trace the spread and retreat of species on local scale (e.g. Chmiel 1993; Zając M. & Zając A. 1998; Faliński *et al*. 2000; Kucharczyk 2001; Urbisz 2001) and at the national scale (Zając A. & Zając M. 2001).

The maps included in this paper illustrate two more rules: firstly, that colonising success is reached by alien newcomers in river valleys with the locations of human settlements offering additional diaspore sources and secondly, that maintaining the more natural plant cover is the best option from the nature conservation point of view in preventing the spread of alien species (e.g. in an extensive Beskid Niski Mts., where alien plant species still constitute the minority of the entire, regional flora). This needs to be borne in mind, especially, because the strong negative effect on species diversity of invaded communities in river valleys was confirmed in case of some alien plants, namely *Heracleum mantegazzianum* (Pyšek & Pyšek 1995; Müllerová *et al*. 2005), *Impatiens glandulifera* (Hulme & Bremner 2005, whilst opposite results were reported by Hejda & Pyšek 2006) and taxa of the *Reynoutria* genus (Bímová *et al*. 2004; Tokarska-Guzik *et al*. 2006; Gerber *et al*. 2007; Koszela & Tokarska-Guzik 2008).

The analysis also shows that detailed and comprehensive collections of floristic data are of considerable practical importance. They provide the scientific background for the planning of nature protection-related activities on regional scale.

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