Our survey of data collected in the Chromosome Number Database for Polish angiosperms indicated that the 1,498 species with chromosome counts represent 40% of the total angiosperms (3,719) occurring in Poland, including 1,205 native species (53% of native species) and 194 anthropophytes (56% of anthropophytes). The chromosome numbers are known for all native species occurring in Poland within 298 genera and 46 families, and for all anthropophytes from 79 genera and 11 families. The remaining angiosperm groups are less explored: chromosome counts from Poland are known for 9% of cultivated species and 5% of ephemerophytes. According to generic basic chromosome numbers, 46.44% of Polish angiosperms have been classified as polyploid. By three different threshold methods, the contribution of polyploid plants to the Polish flora is 64.64%, 50.89% or 42.89%. Polyploidy is more common among indigenous than non-indigenous plants, and the ploidy distribution among plants from the Polish Tatras does not differ significantly from that observed in the rest of native Polish plants.

**Key words:** Chromosome numbers, Polish flora, polyploidy, threshold method, mountain plants.

**INTRODUCTION**

Somatic chromosome number is one of the most basic and useful pieces of information in many areas of plant research. Significant progress in our knowledge of it has greatly facilitated the resolution of issues such as the origin, relationships, relative age and peculiar distribution of plant species. Chromosomes are not just part of the plant phenotype but also the hereditary elements and units of mutation and transmission. As a remarkably dynamic feature, chromosome numbers are particularly suited for tracking plant diversification and evolution. They may be successfully used, in combination with other features (e.g., habit, nuclear DNA amount, molecular markers), to construct phylogenetic trees, particularly in taxa with extensive variation in chromosome number (Cerbah et al., 1999; Watanabe et al., 1999; Ito et al., 2000; Lysak et al., 2005; Navajas-Perez et al., 2005; Hansen et al., 2006).

Karyological studies in Poland began in the 1940s under the guidance of Professor Maria Skalińska, and in the following decades were continued by a team in the Department of Plant Cytology and Embryology of the Jagiellonian University. The results obtained by this team and other Polish researchers have been reported in many co-written and individual papers and summarized in three publications (Skalińska and Pogan, 1973; Pogan and Wcisło, 1983, 1990). A synthetic review of the karyology of Polish angiosperms was made only once, by Eugenia Pogan in 1972. At that time the Polish flora was estimated at about 2,300 species, of which only 19% had chromosome counts (438 species). Narrower karyological syntheses were made for the flora of the Tatra Mts. (110 species, Skalińska, 1963) and Polish grasses (55 species, Frey, 1973; 313 species, Mizianty, 2003).

Many new chromosome records have been published since the last publication summarizing chromosome counts of Polish angiosperms (Pogan and Wcisło, 1990). For many plants the taxonomic and/or nomenclatural treatments have changed. This stimulated work on a new summary of chromosome numbers of Polish angiosperms, published in the form of the freely available Chromosome Number Database (Góralski et al., 2009, http://www.chromosomes.binoz.uj.edu.pl). This form of publication is easily searchable and open for additions as new data are received. The survey gives the taxonomic and nomenclatural treatments
recommended in the critical checklist of vascular plants in Poland (Mirek et al., 2002) without removing the original names used by particular authors.

The breadth of research examining the karyology of Polish angiosperms has allowed us to summarize certain karyological aspects of Polish flora, to list taxa not tested so far, and to recommend the main directions of future research. We also used the collected data to estimate the share of polyploids in the Polish flora and in particular groups of species. We hope that this summary will encourage researchers to complete the data on the chromosome numbers of Polish angiosperms at a time when chromosome counting is not as popular as it once was in this country.

MATERIALS AND METHODS

Data collected in the Chromosome Number Database were used to assess the ploidy level of Polish plants, with particular emphasis on native and permanently established species. In most cases it was possible to use information on the lowest somatic chromosome numbers (LSCN) reported within genera (Appendix 1 in electronic version). The data of this subject were obtained primarily from the Index to Plant Chromosome Numbers available at http://www.tropicos.org/Project/IPCN. The LSCNs that do not match the other chromosome numbers within the genus have been omitted in the ploidy estimates, such as 2n=10 recorded in Phleum echinatum (which in all other Phleum species is x=7), or 2n=18 in Sagittaria (x=11 for all other Sagittaria specimens analyzed so far).

The data on somatic chromosome number(s) allowed us to specify basic chromosome number(s) within genera and to calculate the exact ploidy levels (2x, 3x, 4x, and so on) of the majority of analyzed species. The basic numbers were additionally consulted with syntheses (Wanscher, 1934; Darlington and Janaki Ammal, 1945; Darlington and Wylie, 1955; Raven, 1975) and taxon-specific literature. For two records the chromosome numbers could not be clearly classified as polyploid or aneuploid on a particular ploidy level (Scopolia carnolioca 2n=46, Stachys silvatica 2n=66), making it difficult to estimate ploidy precisely; these species were analyzed only by the threshold methods described below.

Chromosome number data were further used to assess ploidy level by the threshold methods developed by Grant (1963), Goldblatt (1980) and Wood et al. (2009). The threshold value was set at n=14 or more (Grant 1963) or n=11 or more (Goldblatt 1980). According to Wood et al. (2009), species with a somatic chromosome number greater than or equal to 3.5 times the lowest haploid count of the host genus should be considered polyploid. We removed taxa known to possess holocentric chromosomes (Cyperaceae, Cuscuta, Luzula) from the analysis due to extensive chromosome changes which may lead to simultaneous fusion or fragmentation of individual chromosomes or even whole chromosome sets (Kuta et al., 2004; Hipp et al., 2009). Mutations of this kind have nothing to do with true ploidy changes and make it difficult to determine the original basic chromosome number within a genus.

Differences in the proportions of diploid and polyploid plants, or the proportions of diploid, polyploid and diploid/polyploid species in the compared datasets, were cross-tabulated (2×2 and 2×3 contingency tables) and analyzed with Pearson’s chi-square test.

RESULTS AND DISCUSSION

The present Chromosome Number Database comprises 3,387 records on the chromosome numbers of 1,498 species (records relating to the 17 taxa excluded from the actualized checklist were censored). This means that we have knowledge of the chromosome numbers of about 40% of Poland’s angiosperms. This is the estimate for all 3,719 species listed by Mirek et al. (2002) from Poland, including ephemorophytes, cultivated plants, and 6 species classified "doubtful". The proportion of native and permanently established species with known chromosome numbers is higher (see below).

As for the higher taxa, we have karyological data on 60.9% of the genera (26.7% in full and 34.2% in part) and 78% of the families (15.7% in full and 61.9% in part) (Tab. 1, Appendices 2, 3 in electronic version). There is little evidence of intraspecific karyological differentiation of Polish plants between areas of occurrence. Of the 344 taxa analyzed from the north (N) and south (S) of Poland, only two showed such variation: Cirsium arvense var. horridum (N – 2n=34,68; S – 2n=34) and Caltha f. radicans ssp. cornuta (N – 2n=32,56; S – 2n=32,48).

CHROMOSOME COUNTS OF NATIVE AND PERMANENTLY ESTABLISHED TAXA

From the standpoint of research on the structure and history of the Polish flora, the most important data concern the karyology of native species and permanently established anthropophytes (hereinafter, "anthropophytes"). This group of species determines the distinctiveness of our flora and hence deserve special attention. According to the checklist (Mirek et al., 2002), the Polish flora includes 2,256 native species and 344 anthropophytes. Chromosome counts were reported for 1,205 native species (53%) and 194
anthropophytes (56%). It can therefore be assumed that the sample size of our study provides a good taxonomic and ecological representation of these elements of the Polish flora.

The biggest challenge for the future will be to make chromosome counts of representatives of large apomictic genera. So far there has been significant progress in this respect only for *Rubus*, in which only 24% of the species (20 of 85) remain to investigate. A significant group among the 1,201 species without chromosome counts (1,051 native species and 150 anthropophytes; Appendix 4 in electronic version) are representatives of *Alchemilla* (46 species, 79%), *Hieracium* (86 species, 83%) and *Taraxacum* (259 species, 91%). Almost all of these species have been classified as native to the Polish flora.

In the most numerous and least-explored apomictic genus, *Taraxacum*, with the well defined basic chromosome number $x=8$ and dominated by triploid and tetraploid microspecies, attempts are being made to develop indirect methods of assessing ploidy level (Marciniuk et al., 2010a,b). Together with nuclear 2C DNA measurements they may provide an alternative to time-consuming chromosome counting. DNA estimations can also be helpful in determining ploidy in other agamospermous species (Trávníček et al., 2011) and in plants showing huge chromosome variation in root-tip tissues (Joachimiak et al. 2001).

It may be quite problematic to make an exhaustive examination of apomictic genera possessing many hardly recognizable microspecies. After
| Family       | NG Checklist | Genus                                                      | NG ChND | Genus                                                      |
|--------------|--------------|-----------------------------------------------------------|---------|-----------------------------------------------------------|
| Asteraceae   | 110          | Achillea Alstroemeria Anemone Asteriscus Bells Bidens Callistephus Carduus Carlina Carthamus Centaurea Chamomilla Chrysanthemum Cicerbita Chitorum Cirsiun Cnicus Coleostephanus Conyza Coreopsis Cosmos Crepis Crupina Dahlia Dendranthera Dimorphotheca Doronicum Echinacea Echinops Erichites Erigeron Eupatorium Filago Gaillardia Galinsoga Gazania Gnaophalius Guizotia Hedynopsis Helenium Helianthus Helichrysum Heliopsis Helipterum Hieracium Homogyne Hypochoeris Inula Iva Lactuca Lapsana Leonotodon Leontopodium Leucanthemum Liatris Ligularia Linosyris Matricaria Mycelis Onopordon Parthenium Petasites Picris Podospermum Prenanthes Pulicaria Pyrethrum Rhagadiolus Rudbeckia Santolina Saussurea Scotochrysos Scorzonera Senecio Serratula Silphium Solidago Sonchus Spilanthes Stokesia Tagetes Tanacetum Taraxacum Telekia Tragopogon Tussilago Verbascina Voluptaria Xanthium Xeranthemum Zinnia |
| Balsaminaceae| 1            | Impatiens                                                  | 1       | Impatiens                                                  |
| Begoniaceae  | 1            | Begonia                                                    | 0       |                                                            |
| Berberidaceae| 3            | Berberis Epimedium Mahonia                                  | 1       | Berberis                                                   |
| Betulaceae   | 2            | Alnus Betula                                               | 2       | Alnus Betula                                               |
| Bignoniaceae | 2            | Campsis Catalpa                                            | 0       |                                                            |
| Boraginaceae | 16           | Alkanna Amsinckia Anchusa Asperugo Borago Cerithome Cynoglossum Echiium Heliotropium Lappula Lithospermum Myosotis Nonea Omphalodes Pulmonaria Symphytum | 10      | Anchusa Borago Cerinthe Cynoglossum Echiium Lithospermum Myosotis Omphalodes Pulmonaria Symphytum |
| Brassicaceae | 55           | Alliaria Alyssum Arabidopsis Arabis Armoracia Aubrietia Barbarea Berterea Biscutella Brassica Bunias Cakile Camelina Capsella Cardamine Cardaminopsis Cardaria Cheiranthus Chorispora Cochlearia Coincya Conringia Coronopus Crambe Dentaria Descarudianta Diplotaxis Draba Erophila Eruca Erucastrum Erysimum Euclidiun Hesperis Hirschfeldia Hutchinsonia Iberis Isatis Kernera Lepidium Lobularia Lunaria Malcolmia Matthiola Myagrum Nasturtium Neslia Raphanus Rapistrum Rhynchosinapis Rorippa Sinapis Sisymbrium Teesdalea Thlaspi | 33      | Alliaria Alyssum Arabis Armoracia Barbarea Berteroa Biscutella Brassica Bunias Cakile Cameline Capsella Cardamine Cardaminopsis Cochlearia Dentaria Descarudiantia Diplotaxis Draba Eruca Erysimum Hesperis Hutchinsonia Kernera Lepidium Lunaria Nasturtium Raphanus Rorippa Sinapis Sisymbrium Teesdalea Thlaspi |
TABLE 1. Cont.

| Families           | NG Checklist | Genus            | NG ChND | Genus            |
|--------------------|--------------|------------------|---------|------------------|
| Buddlejaceae       | 1            | Buddleia         | 0       |                  |
| Butomaceae         | 1            | Butomus          | 1       | Butomus          |
| Buxaceae           | 2            | Buxus Pachysandra| 0       |                  |
| Caesalpinaceae     | 1            | Gleditsia        | 1       | Gleditsia        |
| Callitricaceae     | 1            | Callitriche      | 1       | Callitriche      |
| Calycanthaceae     | 1            | Calycanthus      | 0       |                  |
| Campanulaceae      | 6            | Adenophora Campanula Jasion Legousia Phyteuma Platycedon | 4 | Adenophora Campanula Jasion Phyteuma |
| Cannabaceae        | 2            | Cannabis Humulus | 2       | Cannabis Humulus |
| Cannaceae          | 1            | Canna            | 0       |                  |
| Capparaceae        | 1            | Cleome           | 0       |                  |
| Caprifoliaceae     | 7            | Kolkwitzia Linnea Lonicera Sambucus Symphoricarpus Viburnum Weigela | 5 | Linnea Lonicera Sambucus Symphoricarpus Viburnum |
| Caryophyllaceae    | 30           | Agrostemma Arenaria Celosia Cerasium Corrigiola Cucubalus Dianthus Gypsophila Heliosperma Herniaria Holosteuem Honckenya Illecebrum Lychnis Melandrium Miruaaria Moehringia Moenchia Myosoton Petrhoragia Polycarpon Sagina Saponaria Scleranthus Silene Spergula Spergularia Stellaria Vaccaria Viscaria | 21 | Agrostemma Arenaria Cerastium Cucubalus Dianthus Gypsophila Heliosperma Herniaria Honckenya Illecebrum Lychnis Melandrium Miruaaria Moehringia Moenchia Myosoton Petrhoragia Polycarpon Sagina Saponaria Scleranthus Silene Spergula Spergularia Stellaria Vaccaria Viscaria |
| Celastraceae       | 2            | Celastrus Euonymus | 1       | Euonymus         |
| Ceratophyllaceae   | 1            | Ceratophyllum     | 1       | Ceratophyllum    |
| Cercidiphyllaceae  | 1            | Cercidiphyllum   | 0       |                  |
| Chenopodiaceae     | 13           | Atriplex Axyris Bassia Beta Chenopodium Corispermum Halimione Kochia Polycenenum Salicornia Salsola Spinacia Suada | 5 | Atriplex Chenopodium Corispermum Kochia Salicornia |
| Cistaceae          | 1            | Helianthemum     | 1       | Helianthemum     |
| Commelinaceae      | 2            | Commelina Trasdecantia | 0 |                  |
| Convolulaceae      | 4            | Calystegia Convolulus Ipomoea Merremia | 2 | Calystegia Convolulus |
| Cornaceae          | 1            | Cornus           | 1       | Cornus           |
| Corylaceae         | 2            | Carpinus Corylus | 2       | Carpinus Corylus |
| Crassulaceae       | 5            | Crassula Jovibara Rhodiola Sedum Semprevium | 1 | Sedum |
| Cucurbitaceae      | 6            | Bryonia Cucumis Cucurbita Echinocystis Sicyos Thalianta | 4 | Bryonia Echinocystis Sicyos Thalianta |
| Cuscutaceae        | 1            | Cuscuta          | 1       | Cuscuta          |
| Cyperaceae         | 16           | Baeothryon Blysmus Bulboschoenus Carex Cladium Cyperus Dichostylis Eleocharis Eleogiton Eriophorum Isolepis Rhynchospora Schoenoplectus Schoenus Scirpoides Scirpus | 9 | Blysmus Bulboschoenus Carex Eleocharis Eriophorum Isolepis Rhynchospora Schoenoplectus Scirpus |
| Dipsacaceae        | 7            | Cephalaria Dipsacus Knautia Scabiosa Succisa Succisella Virga | 4 | Dipsacus Knautia Scabiosa Succisa |
| Family               | NG Checklist | Genus                  | NG ChND | Genus                  |
|----------------------|--------------|------------------------|---------|------------------------|
| Droscurcaceae        | 2            | Aldrovanda Drosera      | 2       | Aldrovanda Drosera      |
| Elaeagnaceae         | 2            | Elaeagnus Hippophae    | 2       | Elaeagnus Hippophae    |
| Elatinaceae          | 1            | Elatine                | 1       | Elatine                |
| Empertraccae         | 1            | Empetrum               | 0       |                        |
| Ericaceae            | 10           | Andromeda Arctostaphylos Caltuna | 3       | Caltuna Oxyccoccus Rhododendron |
|                      |              | Chamaedaphne Erica Kalmia Ledum |          |                        |
|                      |              | Oxycoccus Rhododendron Vaccinium |          |                        |
| Euphorbiaceae        | 2            | Euphorbia Mercurialis  | 2       | Euphorbia Mercurialis  |
| Fabaceae             | 40           | Amorpha Anthyllis Arachis Astragalus | 24      | Anthyllis Astragalus Caragana |
|                      |              | Caragana Ceratonia Chamaeysirus |          | Caragana Ceratonia Chamaeysirus |
|                      |              | Cicer Colutea Coronilla Dorycnium |          | Cicer Colutea Coronilla Dorycnium |
|                      |              | Galega Genista Genistella Glycine |          | Galega Genista Genistella Glycine |
|                      |              | Gymnociadus Hedysarum Hippocris |          | Gymnociadus Hedysarum Hippocris |
|                      |              | Laburnum Lathyrsus Lembotopsis Lens |          | Laburnum Lathyrsus Lembotopsis Lens |
|                      |              | Lotus Lupinus Medicago Melilotus |          | Lotus Lupinus Medicago Melilotus |
|                      |              | Onobrychis Ononis Ornithopus |          | Onobrychis Ononis Ornithopus |
|                      |              | Oxytropis Phaseolus Pisum Robinia |          | Oxytropis Phaseolus Pisum Robinia |
|                      |              | Sarothamnus Tetragonolobus Trifolium |          | Sarothamnus Tetragonolobus Trifolium |
|                      |              | Trigonella Ulex Vicia Wisteria |          | Trigonella Ulex Vicia Wisteria |
| Fagaceae             | 3            | Castanea Fagus Quercus  | 2       | Fagus Quercus          |
| Fumariaceae          | 3            | Corydalis Dicentra Fumaria | 1       | Corydalis              |
| Gentianaceae         | 4            | Centaurium Gentiana Gentianella Swertia | 4       | Centaurium Gentiana Gentianella Swertia |
| Geraniaceae          | 3            | Erodium Geranium Pelargonium | 2       | Erodium Geranium       |
| Grossulariaceae      | 1            | Ribes                  | 1       | Ribes                  |
| Haloragaceae         | 1            | Myriophyllum           | 1       | Myriophyllum           |
| Hamamelidaceae       | 1            | Hamamelis              | 0       |                        |
| Hippocastanaceae     | 1            | Aesculus               | 1       | Aesculus               |
| Hippuridaceae        | 1            | Hippuris               | 1       | Hippuris               |
| Hydrangeaceae        | 1            | Hydrangea              | 0       |                        |
| Hydrocharitaceae     | 4            | Elodea Hydilla Hydrocharis Stratiotes | 3       | Elodea Hydilla Hydrocharis |
| Hydrocotylaceae      | 3            | Hydrocotyle Hydrophyllum Nemphila | 1       | Hydrocotyle            |
| Hydrophylaceae       | 1            | Phacelia               | 0       |                        |
| Hypericaceae         | 1            | Hypericum              | 1       | Hypericum              |
| Iridaceae            | 6            | Crocosmia Crocus Gladiolus Iris Narcissus Sisyrinchum | 3       | Crocus Gladiolus Iris |
| Juglandaceae         | 3            | Carya Juglans Pierocarya | 1       | Juglans                |
| Juncaceae            | 2            | Juncus Luzula          | 2       | Juncus Luzula          |
| Juncagnaceae         | 1            | Triglochin             | 1       | Triglochin             |
| Lamiaceae            | 34           | Acinos Ajuga Amethystea Ballota | 22      | Acinos Ajuga Ballota Betonica |
|                      |              | Betonica Calamintha Chaithurus |          | Betonica Calamintha Chaithurus |
|                      |              | Clinopodium Dracocephalum Elsholtzia |          | Clinopodium Dracocephalum Elsholtzia |
|                      |              | Galeobdolon Galeopsis Glechoma |          | Galeobdolon Galeopsis Glechoma |
|                      |              | Hyssopus Lamium Lavandula Leonurus Lycopus |          | Hyssopus Lamium Lavandula Leonurus Lycopus |
|                      |              | Marrubium Melissa Melittis Mentha Monarda Nepeta Oeicum |          | Marrubium Melissa Melittis Mentha Monarda Nepeta Oeicum |
|                      |              | Orgianum Physostegia Prunella Salvia Scutellaria Sideritis Stachys Teurcum Thymus |          | Orgianum Physostegia Prunella Salvia Scutellaria Sideritis Stachys Teurcum Thymus |
| Family            | NG Checklist | Genus                          | NG ChND | Genus                          |
|-------------------|--------------|--------------------------------|---------|--------------------------------|
| Lemnaceae         | 3            | Lemna Spirodela Wolffia         | 3       | Lemna Spirodela Wolffia         |
| Lentibulariaceae  | 2            | Pinguicula Utricularia         | 2       | Pinguicula Utricularia         |
| Liliaceae         | 26           | Allium Anthericum Asparagulus  | 15      | Allium Anthericum Asparagulus  |
|                   |              | Colchicum Convallaria Eremurus |         | Colchicum Convallaria Eremurus|
|                   |              | Erythronium Fritillaria Gagea  |         | Erythronium Fritillaria Gagea  |
|                   |              | Hemerocallis Hosta Hyacinthoides|         | Hemerocallis Hosta Hyacinthoides|
|                   |              | Hyacinthus Kniphofia Lilium    |         | Hyacinthus Kniphofia Lilium    |
|                   |              | Lloidia Maianthemum Muscari    |         | Lloidia Maianthemum Muscari    |
|                   |              | Ornithogalum Polygonatum Scilla|         | Ornithogalum Polygonatum Scilla|
|                   |              | Tulipa Streptopus Tofieldia    |         | Tulipa Streptopus Tofieldia    |
|                   |              | Tulipa Veratrum                |         | Tulipa Veratrum                |
| Linaceae          | 2            | Linum Radiola                  | 1       | Linum                          |
| Lobeliaceae       | 1            | Lobelia                        | 1       | Lobelia                        |
| Lorantheae        | 1            | Viscum                         | 1       | Viscum                         |
| Lythraceae        | 2            | Lythrum Peplis                 | 2       | Lythrum Peplis                 |
| Magnoliaceae      | 2            | Liriodendron Magnolia          | 0       |                                |
| Malvaceae         | 9            | Abutilon Alcea Althaea Anoda  | 4       | Althaea Lavatera Malope Malva  |
|                   |              | Hibiscus Lavatera Malope Malva |         | Malva                          |
| Martyniaceae      | 1            | Martynia                       | 0       |                                |
| Menyanthaceae     | 2            | Menyanthes Nymphoides          | 2       | Menyanthes Nymphoides          |
| Monotropaceae     | 1            | Monotropa                      | 0       |                                |
| Moraceae          | 2            | Ficus Morus                    | 1       | Morus                          |
| Myricaceae        | 1            | Myrica                         | 0       |                                |
| Najadaceae        | 1            | Najas                          | 1       | Najas                          |
| Nyctaginaceae     | 2            | Mirabilis Oxybaphus            | 0       |                                |
| Nymphaeaceae      | 2            | Nuphar Nymphaea                | 2       | Nuphar Nymphaea                |
| Oleaceae          | 4            | Forsythia Fraxinus Ligustrum   | 3       | Fraxinus Ligustrum Syringa     |
|                   |              | Syringa                        |         |                                |
| Onagraceae        | 6            | Chamaenerion Circeae Epilobium | 4       | Chamaenerion Circeae Epilobium |
|                   |              | Godetia Luduvigia Oenothera    |         | Godetia Luduvigia Oenothera    |
| Orchidaceae       | 24           | Anacamptis Cephalanthera       | 14      | Cephalanthera Coeloglossum     |
|                   |              | Chamorhics Coeloglossum        |         | Cephalanthera Coeloglossum     |
|                   |              | Corallorhiza Cyripedium       |         | Corallorhiza Cyripedium       |
|                   |              | Dactylorhiza Epipactis Epipogium|         | Dactylorhiza Epipactis Epipogium|
|                   |              | Goodyera Gymnadenia Hammarbya  |         | Goodyera Gymnadenia Hammarbya  |
|                   |              | Herminium Leuconorhis Liparis Liparis |         | Herminium Leuconorhis Liparis Liparis |
|                   |              | Listera Neottia Ophrys Orchis |         | Listera Neottia Ophrys Orchis |
|                   |              | Orchis Platanthera Spirantes  |         | Orchis Platanthera Spirantes  |
|                   |              | Platanthera Traunsteinera      |         | Platanthera Traunsteinera      |
| Orobanchaceae     | 1            | Orobanche                      | 1       | Orobanche                      |
| Oxalidaceae       | 1            | Oxalis                         | 1       | Oxalis                         |
| Paeoniaceae       | 1            | Paeonia                        | 0       |                                |
| Papaveraceae      | 5            | Argemone Cheilodium Eschscholtzia| 3       | Cheilodium Glaucum Papaver    |
|                   |              | Glaucum Papaver                |         |                                |
| Parnassiacae      | 1            | Parnassia                      | 1       | Parnassia                      |
| Philadelphaceae   | 2            | Deutzia Philadelphus           | 0       |                                |
| Plantaginaceae    | 2            | Littorella Plantago            | 2       | Littorella Plantago            |
| Platanaceae       | 1            | Platanus                       | 0       |                                |
| Plumbaginaceae    | 2            | Armeria Limonium               | 1       | Armeria Limonium               |
| Family       | NG Checklist | Genus                                                                 |
|--------------|--------------|----------------------------------------------------------------------|
| Poaceae      | 86           | Aegilops Agropyron Agrostis Aira                                      |
|              |              | Alopecurus Ammophila Anthoxanthum                                     |
|              |              | Apera Arrhenatherum Avena Avenula                                     |
|              |              | Beckmannia Bellardiocha Bothriochloa                                  |
|              |              | Brachypodium Briza Bromus                                             |
|              |              | Calamagrois Catabrosa Chloria Coix                                    |
|              |              | Cortaderia Corynephorus Corynoda                                      |
|              |              | Cynosurus Daetlylis Daetlyloctenium                                    |
|              |              | Danthonia Dasyaerum Deschampsina                                      |
|              |              | Desmazeria Digitaria Dinebra Echinocloa                               |
|              |              | Eleusine Elymus Eltygriga Erargostis                                  |
|              |              | Eriochloa Festuca Gastridium Gaudinia                                 |
|              |              | Glycera Hapnardea Heliotrichon                                        |
|              |              | Hierochloë Holecus Hordelymus Hordeum                                |
|              |              | Koeleria Lagurus Leersia Lollum                                       |
|              |              | Lophiocha Melica Millet Miseanths                                     |
|              |              | Molinia Nardus Oreochoa Panicum                                       |
|              |              | Paraphilus Paspalum Pennisetum Phalaris                               |
|              |              | Phleum Phlilus Phragmites Poa                                        |
|              |              | Polypocon Pucinellia Schismus Sceloclooa                              |
|              |              | Sclerochoa Selce Sesleria Setaria Sorghum                             |
|              |              | Stipa Trisetum Triticum Ventenata Vulpia                              |
|              |              | xCalamomphila xFestubolium Zea                                        |
| Polemoniaceae | 5            | Cobaea Callomia Gilia Phlox Polemonium                                |
| Polygalaceae | 1            | Polygala                                                               |
| Polygonaceae | 7            | Fagopyrum Fallopia Oxyria Polygonum                                   |
|              |              | Reynoutria Rheum Rumex                                                |
| Portulaceae  | 3            | Calandrinia Montia Portulaca                                          |
| Potamogetonaceae | 2   | Groenlandia Potamogoton                                               |
| Primulaceae  | 13           | Anagallis Androsace Centunculus                                        |
|              |              | Cortusa Glauca Hotonia Lysimachia Primula Samolus Soldanella          |
| Proteaceae   | 1            | Simia                                                                  |
| Pyrolaceae   | 4            | Chimpisia Moneses Orthilia Pyrola                                      |
| Ranunculaceae| 24           | Aconitum Actaea Adonis Anemone                                        |
|              |              | Aquilegia Batrachium Callianthemen                                    |
|              |              | Caltha Ceratophyllum Cimicifuga                                       |
|              |              | Clematis Convolvulus Delphinium Eranthis                              |
|              |              | Ficaria Helleborus Hepatica Isopyrum                                  |
|              |              | Mjosurus Nigella Palsatilla Ranunculus Thalictrum Trollius            |
| Resedaceae   | 1            | Reseda                                                                 |
| Rhamnaceae   | 3            | Ceanothus Frangula Rhamnus                                            |
| Rosaceae     | 39           | Acaena Agrimonia Alchemilla                                           |
|              |              | Armeniaca Aruncus Cerasus                                             |
|              |              | Chamaemes Comarum Cotoneaster                                         |
|              |              | Crataegeus Cydonia Dryas Eocochorda                                   |
|              |              | Filipendula Fragaria Geum Holodiscus                                  |
|              |              | Kerria Laurocerasus Malus Mesophilus                                  |
|              |              | Padus Persica Physocarpus Potentilla                                  |
|              |              | Prunus Pyracantha Pyrus Rosa Rubus                                    |
|              |              | Sanguisorba Silbaldia Sorbaria Sorbus                                 |
|              |              | Spiraea Waldsteinia                                                  |
|              |              | Aegilops Agrostis Aira Alopecurus                                      |
|              |              | Ammophila Anthoxanthum Apera                                          |
|              |              | Arrhenatherum Avena Avenula                                            |
|              |              | Bellardiocha Bothriochloa                                             |
|              |              | Brachypodium Briza Bromus                                             |
|              |              | Calamagrois Catabrosa                                                 |
|              |              | Corynephorus Cynosurus Daetlylis                                       |
|              |              | Danthonia Deschampsia Digitaria                                        |
|              |              | Echinocha Elymus Festuca Glycera                                       |
|              |              | Hierochloë Holecus Hordelymus Hordeum                                 |
|              |              | Koeleria Lagurus Leersia Lollum                                        |
|              |              | Lophiocha Melica Millet Miseanths                                     |
|              |              | Molinia Nardus Oreochoa Panicum                                       |
|              |              | Panicum Phalaris Phleum Phragmites                                   |
|              |              | Poa Pucinellia Sclerochoa Sesleria                                    |
|              |              | Setaria Stipa Trisetum Vulpia                                          |
|              |              | xCalamomphila xFestubolium Zea                                        |
|              |              | Anagallis Androsace Centunculus                                        |
|              |              | Cortusa Glauca Hotonia Lysimachia Primula Samolus Soldanella          |
|              |              | Aconitum Actaea Adonis Anemone                                        |
|              |              | Aquilegia Batrachium Callianthemen                                    |
|              |              | Caltha Clematis Consolida                                            |
|              |              | Delphinium Ficaria Helleborus                                         |
|              |              | Hepatica Isopyrum Nigella                                             |
|              |              | Ranunculus Thalictrum Trollius                                        |
|              |              | Chimpisia Moneses Orthilia Pyrola                                      |
|              |              | Aconitum Actaea Adonis Anemone                                        |
|              |              | Aquilegia Batrachium Callianthemen                                    |
|              |              | Caltha Clematis Consolida                                            |
|              |              | Delphinium Ficaria Helleborus                                         |
|              |              | Hepatica Isopyrum Nigella                                             |
|              |              | Ranunculus Thalictrum Trollius                                        |
|              |              | Aconitum Actaea Adonis Anemone                                        |
|              |              | Aquilegia Batrachium Callianthemen                                    |
|              |              | Caltha Clematis Consolida                                            |
|              |              | Delphinium Ficaria Helleborus                                         |
|              |              | Hepatica Isopyrum Nigella                                             |
|              |              | Ranunculus Thalictrum Trollius                                        |
|              |              | Chimpisia Moneses Orthilia Pyrola                                      |
|              |              | Aconitum Actaea Adonis Anemone                                        |
|              |              | Aquilegia Batrachium Callianthemen                                    |
|              |              | Caltha Clematis Consolida                                            |
|              |              | Delphinium Ficaria Helleborus                                         |
|              |              | Hepatica Isopyrum Nigella                                             |
|              |              | Ranunculus Thalictrum Trollius                                        |
|              |              | Aconitum Actaea Adonis Anemone                                        |
|              |              | Aquilegia Batrachium Callianthemen                                    |
|              |              | Caltha Clematis Consolida                                            |
|              |              | Delphinium Ficaria Helleborus                                         |
|              |              | Hepatica Isopyrum Nigella                                             |
|              |              | Ranunculus Thalictrum Trollius                                        |
|              |              | Chimpisia Moneses Orthilia Pyrola                                      |
|              |              | Aconitum Actaea Adonis Anemone                                        |
|              |              | Aquilegia Batrachium Callianthemen                                    |
|              |              | Caltha Clematis Consolida                                            |
|              |              | Delphinium Ficaria Helleborus                                         |
|              |              | Hepatica Isopyrum Nigella                                             |
|              |              | Ranunculus Thalictrum Trollius                                        |
|              |              | Chimpisia Moneses Orthilia Pyrola                                      |
|              |              | Aconitum Actaea Adonis Anemone                                        |
|              |              | Aquilegia Batrachium Callianthemen                                    |
|              |              | Caltha Clematis Consolida                                            |
|              |              | Delphinium Ficaria Helleborus                                         |
|              |              | Hepatica Isopyrum Nigella                                             |
|              |              | Ranunculus Thalictrum Trollius                                        |
|              |              | Chimpisia Moneses Orthilia Pyrola                                      |
|              |              | Aconitum Actaea Adonis Anemone                                        |
|              |              | Aquilegia Batrachium Callianthemen                                    |
|              |              | Caltha Clematis Consolida                                            |
|              |              | Delphinium Ficaria Helleborus                                         |
|              |              | Hepatica Isopyrum Nigella                                             |
|              |              | Ranunculus Thalictrum Trollius                                        |
|              |              | Chimpisia Moneses Orthilia Pyrola                                      |
|              |              | Aconitum Actaea Adonis Anemone                                        |
|              |              | Aquilegia Batrachium Callianthemen                                    |
|              |              | Caltha Clematis Consolida                                            |
|              |              | Delphinium Ficaria Helleborus                                         |
|              |              | Hepatica Isopyrum Nigella                                             |
|              |              | Ranunculus Thalictrum Trollius                                        |
|              |              | Chimpisia Moneses Orthilia Pyrola                                      |
|              |              | Aconitum Actaea Adonis Anemone                                        |
|              |              | Aquilegia Batrachium Callianthemen                                    |
|              |              | Caltha Clematis Consolida                                            |
|              |              | Delphinium Ficaria Helleborus                                         |
|              |              | Hepatica Isopyrum Nigella                                             |
|              |              | Ranunculus Thalictrum Trollius                                        |
excluding these genera (Alchemilla, Hieracium, Taraxacum), 1,812 native species remain, of which 1,150 (63%) have established chromosome numbers. Among the large non-apomictic genera poorly researched so far, Carex, with 76 species lacking chromosome counts, deserves special attention.

Poland’s native flora is represented by 533 genera and 111 families; anthropophytes are listed among 176 genera and 46 families. The karyological data include chromosome numbers of native species from 448 genera and 104 families, and anthropophytes from 117 genera and 34 families.

| Family            | NG Checklist | Genus                          | NG ChND | Genus                           |
|-------------------|--------------|--------------------------------|---------|---------------------------------|
| Rubiaceae         | 5            | Asperula Cruciat a Galium Rubia Sherardia | 4       | Asperula Crucia t a Galium Sherardia |
| Ruppiaceae        | 1            | Ruppi a                        | 0       | Ruppi a                        |
| Rutaceae          | 5            | Citrus Dicta mum Phellodendron Ptelea Ruta | 1       | Ruta                           |
| Salicaceae        | 2            | Populus Salix                  | 2       | Populus Salix                  |
| Santalaceae       | 1            | Thesium                       | 1       | Thesium                       |
| Saururaceae       | 1            | Houttuynia                    | 0       | Houttuynia                    |
| Saxifragaceae     | 5            | Astilbe Bergenia Chrysosplenium Heuchera Saxifraga | 2       | Chrysosplenium Saxifraga  |
| Scheuchzeriaceae  | 1            | Scheuchzeria                   | 0       | Scheuchzeria                   |
| Scrophulariaceae  | 25           | Antirrhinum Bartsia Chaenorhinum Cymbalaria Digitalis Limosella Linaria Lindernia Melampyrum Mimus Misopates Odontites Orhantha Pedicularis Penstemon Rhinanthus Scrophularia Tozzia Verbascum Veronica | 17      | Bartsia Chaenorhinum Cymbalaria Digitalis Limosella Linaria Lindernia Melampyrum Mimus Misopates Odontites Orhantha Pedicularis Penstemon Rhinanthus Scrophularia Tozzia Verbascum Veronica |
| Simaroubaceae     | 1            | Alant hus                     | 0       | Alant hus                     |
| Solanaceae        | 12           | Atropa Capsicum Datura Hyoscyamus Lycium Lycopersicon Nicandra Nicotiana Physalis Salpiglossis Scopolia Solanum | 6       | Datura Hyoscyamus Lycium Physalis Scopolia Solanum |
| Sparganiaceae     | 1            | Sparganium                    | 1       | Sparganium                    |
| Staphyleace       | 1            | Staphylea                     | 1       | Staphylea                     |
| Tamaricaceae      | 1            | Myricaria                     | 1       | Myricaria                     |
| Thymelaceae       | 2            | Daphne Thymelaea              | 1       | Daphne Thymelaea              |
| Tiliaceae         | 1            | Tilia                         | 1       | Tilia                         |
| Trapaceae         | 1            | Trapa                         | 1       | Trapa                         |
| Trilliaceae       | 1            | Paris                         | 1       | Paris                         |
| Tropaeolaceae     | 1            | Tropaeolum                    | 0       | Tropaeolum                    |
| Typhaceae         | 1            | Typha                         | 1       | Typha                         |
| Ulmaceae          | 1            | Ulmus                         | 1       | Ulmus                         |
| Urticaceae        | 2            | Parietaria Urtica             | 2       | Parietaria Urtica             |
| Valerianaceae     | 2            | Valeriana Valerianella        | 1       | Valeriana Valerianella        |
| Verbenaceae       | 1            | Verbena                       | 1       | Verbena                       |
| Violaeeae         | 1            | Viola                         | 1       | Viola                         |
| Vitaceae          | 2            | Parthenocissus Vitis          | 2       | Parthenocissus Vitis          |
| Zannichelliaceae  | 1            | Zannichellia                  | 1       | Zannichellia                  |
| Zosteraceae       | 1            | Zosteria                      | 1       | Zosteria                      |
| Zygodophyllaceae  | 2            | Tribulus Zygodophyllum       | 0       | Tribulus Zygodophyllum       |
Chromosome numbers are known for all native species listed in 298 genera and 46 families, and all anthropophytes from 79 genera and 11 families. We have no information on the chromosome numbers of any of the native species in 85 genera and 7 families, nor for the anthropophytes listed in 59 genera and 12 families. Most of the genera not examined on this respect contain 1–2(3) species, with the exception of *Euphrasia* (11 native species), *Pulsatilla* (6 native species), *Minuartia* (5 native species), *Sagina* (5 native species) and *Vaccinium* (4 native species). The same applies to unexplored families, with the exception of *Fumariaceae* (4 anthropophytes). Although plants belonging to karyologically unexplored genera/families in Poland represent a small share (9%) of native and permanently established anthropophyte species, they form a significant share (17%) of the plants without established chromosome numbers.

The data on chromosome numbers of native and permanently established taxa should be supplemented by direct chromosome counting in the Polish plants not studied so far. Only then will they be fully reliable and of use for summarizing the karyology and distinctiveness of the Polish flora. When possible, the data on taxa already in the Chromosome Number Database should be broadened to include plants collected from different localities in Poland. Currently the data on plants from the south (1,337 species) far outweigh the data from other areas (Fig. 1). This can be only partially explained by the higher species richness of southern Poland.

**OTHER TAXA**

The remaining angiosperms recorded from Poland are classified as cultivated species (534; "frequently cultivated and having the potential to establish permanently in the wild"), ephemerophytes (511), and extinct or probably extinct (40) (Mirek et al., 2002). The status of 33 species in Polish flora remains to be clarified, and 6 previously reported species are doubtful.

Almost all of those groups are insufficiently researched in Poland. Of the taxa with recognized statuses, the Chromosome Number Database contains only 9% (45) of the cultivated plants, 5% (25) of the ephemerophytes, and 8% (3) of the extinct or probably extinct species. Besides those, chromosome numbers are known for 64% (21) of the species with uncertain status. Among the doubtful species, only *Arum maculatum* has a record in the database.

Much remains to be done in terms of direct examination of Polish plants, but reliable data on the two largest poorly investigated groups of species (cultivated species and ephemerophytes) may be obtained from existing databases and the scientific literature. These species come from different, often remote areas, and presumably their chromosome numbers are unaffected by the fact of their presence in Poland. The data obtained indirectly will be a valuable supplement to the Chromosome Number Database. For chromosome counting, attention should focus on cultivated plants and ephemerophytes with completely unknown chromosome numbers and species showing diverse chromosome numbers, to determine which cytotype(s) occur in Poland. The species of interest are listed in Appendix 5 (in electronic version).

**FREQUENCY OF POLYPLOID PLANTS**

Polyploidy is the most common karyotype variation and a key factor in the formation of new vascular plant species (Stebbins, 1950, 1971; Levin, 2002). Polyploidization probably was also critical to the
The evolution of bryophytes (Przywara and Kuta, 1995; Kuta and Przywara, 1997). Despite the fundamental role of polyploidy in plant diversification, the frequency of polyploid speciation in angiosperms is still a debated issue (Otto and Whitton, 2000; Wood et al., 2009; Mayrose et al., 2011).

Polyploidy commonly is inferred when somatic chromosome numbers among related species follow a polyploid series (Stebbins, 1950), but this approach is questionable in the case of ancient polyploids (Otto and Whitton, 2000). For this reason, various indirect methods have been proposed, largely based on analysis of haploid chromosome numbers (Grant, 1963; Stebbins, 1971; Goldblatt, 1980; Masterson, 1994), guard cell size (Masterson, 1994) or molecular traces of ancient genome duplication (Lysak et al., 2005; Cui et al., 2006). Depending on the estimation method, the inferred proportion of polyploid taxa among angiosperms ranges from 30% to 80% (Bennett, 2004). A recent in-depth phylogenetic analysis indicates that almost all angiosperms underwent at least one polyploidization event in their evolutionary history (Soltis et al., 2009).

When polyploidy was calculated according to generic basic chromosome numbers, 46.44% of Polish angiosperm species with chromosome counts were inferred to be polyploid (possessing three or more basic chromosome sets). The rest of the plants showed diploid (49.45%) or diploid/polyploid chromosome numbers (4.11%). The difference in the shares of diploids and polyploids between native plants and anthropophytes is highly significant ($\chi^2=22.16$, $P<0.0001$, $N=1302$). On the other hand, anthropophytes do not differ in this respect from the rest of the non-indigenous Polish plants with established chromosome numbers ($\chi^2=0.03$, $P>0.8$, $N=288$). The differences do not change after diploid/polyploid species are included in the diploids or polyploids (data not shown).

The relatively high frequency of polyploid species presumably is a specific feature of Poland's indigenous flora. The frequencies obtained by the three threshold methods for native plants (67.58%, 53.46%, 47.22%) and anthropophytes (48.45%, 37.63% and 25.77%) confirmed the substantial difference between them. The higher share of polyploids in native plants may be related to the Quaternary history of Polish flora. The majority of them were recruited from nearby regions after the last deglaciation, whereas the anthropophytes arrived relatively recently. Arguing that polyploids were more successful than diploids in colonizing deglaciated areas, Brochman et al. (2004) demonstrated that in arctic plants the frequency of diploids is much higher among taxa restricted to the Atlantic (glaciated) than to the Beringian (non-glaciated) region.

Some authors have suggested that polyploids are better adapted for harsher environmental conditions than diploids are (Flovik, 1940; Brochmann et al., 2004; Nie et al., 2005, and references therein). Skalińska (1963), however, reported a relatively low proportion of polyploids (43.6%) in the Polish Tatras, based on chromosome counts of 110 taxa. Our estimates using the basic numbers for 228 species from that area showed 115 (50.44%) diploid, 107 (46.93%) polyploid and 6 (2.63%) diploid/polyploid species. A comparison with the rest of the native Polish plants with chromosome counts (417, 473 and 49 species, respectively) showed a nonsignificant difference between the Tatras and the rest of Poland ($\chi^2=4.51$, $P>0.1$, $N=1167$). This counterintuitive outcome is in accord with results Hadac (1989) gave for plants from two mountain valleys in the Slovak Tatras (51% and 53% diploids). Hadac suggested that high mountains could provide a favorable habitat for native diploids because "... high mountain plants could well survive [glaciation] in the mountain com-

### TABLE 2. Ploidy distribution among Polish native species and anthropophytes (%)

|                  | Diploids (2x) | Lower polyplids (3x, 4x) | Higher polyplids (5x-22x) | Diploid/polyploid | Mixed polyplids* |
|------------------|---------------|--------------------------|---------------------------|-------------------|------------------|
| Native species (N=1167) | 45.59         | 29.21                    | 15.89                     | 4.71              | 4.60             |
| Anthropophytes (N=194)   | 64.95         | 21.56                    | 10.26                     | 2.13              | 1.10             |

* – lower and higher polyplids (e.g. 4× and 6×)
plex or in the adjacent tundra, and come back without losing contact with their original home. So the natural selection of less adapted forms was very slight and even diploids with a relatively narrow scale of adaptation could survive."

A study of the alpine flora of the Hengduan Mts. (Nie et al., 2005) based on 522 taxa belonging to 152 genera and 44 families showed a great prevalence of diploid taxa (78%). Moreover, the endemic species from this area (considered one of the world’s richest centers of endemism) were characterized by the lowest known share of polyploids (only 16%). In this context it is interesting to examine the frequency of polyploids among the endemic plants inhabiting Tatra Mts.

The Tatras are the northernmost center of endemism in Europe; there are 34 endemic and subendemic species (ESS) occurring in the Polish Tatras (Piękoś-Mirkowa et al., 1996). All of them except Melampyrum herbichii have chromosome records in Polish and/or Slovak chromosome number databases (http://www.binoz.uj.edu.pl;8080/ chromosomes/, Marhold et al., 2007 and http://www.chromosomes.sav.sk/). According to basic chromosome number, 11 of them are diploid, 21 polyploid, and 1 diploid/polyploid. Thus, in contrast to all Tatra plants, the share of polyploids within this group (63.64%) is extremely high. This value also differs radically from that observed in all arctic plants analyzed by Nie et al. (2005) for endemic species of the Hengduan Mts. On the other hand, the ploidy distribution (diploid – polyploid – diploid/polyploid) in ESS from the Polish Tatras does not differ significantly from that observed in all arctic plants analyzed by Brochman et al. (2004) ($\chi^2=2.78$, P>0.2, N=1752). In terms of the 5 zonal groups distinguished by Brochman and coworkers, ESS from the Tatra Mts. showed the greatest similarity to group 4, representing mainly arctic taxa with infrequent occurrence in boreal and/or temperate alpine areas ($\chi^2=0.56$, P>0.7, N=177). The difference in the proportion of polyploids between ESS (63.64%) and the rest of the plants from the Tatra Mts. (44.62%) probably is not conditioned environmentally. The lack of a direct link between polyploidy and habitat has been stressed by a number of authors (e.g., Ehrendorfer, 1980; Nie et al., 2005; Brochman et al. 2004).

This statistical survey showed a significant difference in the proportion of polyploids between indigenous and non-indigenous plants and between ESS and the rest of the plants inhabiting the Tatra Mts. Further studies on chromosome numbers and polyploidy in the different taxonomic, geographical and ecological elements of the Polish flora should yield more comprehensive data on the extent of karyological diversification among Polish angiosperms – and its possible causes.

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