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THE ROLE OF ONTOGENETIC HERBARIUM IN STUDYING INTRAPOPULATION BIODIVERSITY

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Abstract

Studying biodiversity of plants on the population level is impossible without describing ontogenesis of species. Creatinga unique Ontogenesis herbarium at Mari State University and official registration of its collections in the International catalogue «World Herbaria» are to solve this problem. Ontogenesis herbarium is a herbarium of plants at different levels of individual development. Ontogenetic states are distinguished by using the concept of ontogenesis discrete description with regard to morphological features-markers. Plants are referred to this or that ontogenetic state on the basis of the complex of qualitative features. The most significant of them are the following: relationship with the seed, presence of embryonic, juvenile or adult structures and seed or vegetative reproduction capability of individuals, correlation of the processes of new growth and die off, individual formation degree of the life form main features.

Complete ontogenesis of perennial plants includes 12 ontogenetic states: seed, plantules, juvenile, immature, virginile (young vegetative), cryptogenerative, young (early generative), middle age (mature generative), old (later generative), subsenile, senile, dying plant. The collection of the Ontogenesis herbarium is a part of the Population-ontogenetic museum which is a scientific and educational establishment, it is presented in the form of museum exhibitions and consists of six departments: General, Theme-based, Ontogenesis first stages, Collection of fruits and seeds, Izoteka (Picture collection), Phototeka (Photo collection) and Library.

Key words: Biodiversity, Ontogenesis, Ontogenetic state, Ontogenetic herbarium, Population-ontogenetic museum.

Introduction

The end of the 20th century and the beginning of the 21st century are devoted to study of biodiversity. Nowadays, deeper knowledge on population life of plants is necessary for theoretical bases of ecological monitoring, assessment of state of renewable biological recourses. It can not be done without population-ontogenetic aspect of studying heterogeneity of populations of officinal plants different life forms. Exactly this approach has been developed in Russia since the middle of the 20th century. Founders of the original direction – population biology – Professors T.A. Rabotnov (1950a, 1950b.) and A.A. Uranov (1967, 1975) – formulated the concept of discrete description of individual development and ontogenetic heterogeneity of populations of plants. Their followers developed algorithms of distinguishing ontogenetic states of plants of different biomorths (Anon., 1976, 1985; 1988; Gatsuk *et al*., 1980; Shestakova, 1991; Zhukova, 1995; Skochilova *et al*., 2007; Skochilova, 2008; Osmanova & Kozyreva, 2011; Zakamskaya *et al*., 2013; Vedernikova & Lesnikova, 2013).

Development of population-ontogenetic approach in Moscow, Ioshkar-Ola, Novosibirsk, Voronezh, Kostroma, Lvov, Tver, Syktyvkar, Samara, Kazan etc. showed that deep study of population life of plants and the analysis of heterogeneity of their populations is not possible without detail description of full ontogenesis of individuals.

Discussion

Ontogenesis – individual development of organism. This is the most widespread biological interpretation, specified and enlarged by different authors. For modular organisms, such as plants, fungi and some animals (sponges, hydroids, corals, pearlworts) the following definition can be accepted: full ontogenesis is genetically conditioned full succession of all stages of development of one individual or a number of generations from zygote or any other diaspora till natural death at final stages as a result of senescence (Zhukova, 1995).

It coincides with the idea of a long life cycle or full development of genet (Begon *et al*., 1989). In the case of earlier death or its appearance from vegetative diaspora (ramet), ontogenesis will be incomplete.

Brief ontogenesis is ontogenesis of individual, during which omission of ontogenetic states or whole periods is possible.

The term «partial ontogenesis» is advisable to use for indication ontogenesis of different organs: shoots, partial shrub, leaf etc.

In the course of ontogenesis growth and development of organism occur, biochemical, physiological and morphological processes take place in definite succession. Ontogenetic or age changes include all aspects of development of individuals: 1) energetic and metabolic processes; 2) histogenesis and organogenesis; 3) accretion and disintegration; 4) reproduction and propagation; 5) senescence and rejuvenation.

In the 20th century in our (Poshkurlat, 1941) and foreign literature (Harper, 1977) there were numerous attempts to differentiate ontogenesis. In 1950 T.A. Rabotnov proposed a more detail periodization of plant ontogenesis. Further studies in this directions (Uranov, 1967, 1975; Shestakova, 1991; Zhukova, 1995; Nukhimovsky, 1997; Zhivotovsky, 2001) worked out in detail and supplemented ontogenesis periodization: age

disparity of individuals in populations of plants of different biomorphs was well-grounded, generative period were subdivided into cryptogenerative, young, middle age and old generative states were made, and in post generative period i.e. dying off plants was singled out.

In 1975. Uranov developed the theory of the age structure of plants population, suggested indexes of age (ontogenetic) states identified by the first letters of their Latin names. Using his own approach to measuring biological time. Uranov (1975) calculated conventional «price» (mi) of each ontogenetic state as a relative share of the absorbed energy to the given stage of ontogenesis and suggested age ratio (Δ). Based on this theory. Zhivotovsky (2001) introduced the concept of plants energy efficiency (ei) in the given ontogenetic state and average population efficiency (ω), developed a new classification of age structure types called «delta-omega» which is based on the correlation of age ratio andaverage population efficiency. Ontogenetic states and their features are given in Table 1.

Table 1. Complete ontogenesis periodization of plants.

Periods and stages	Ontogenetic state	Indices	Age, m_i	Efficiency, e_i
1. Embryonic				
a) Actually-embryonic (prenatal)	Forming seed and embryo located on the maternal plant	–	–	–
b) Latent	Seed or indehiscent monospermous fruits	se	0.0025	0.0099
2. Pre-generative (virginal)	Plantules	p	0.0067	0.0266
	Juvenile	j	0.0180	0.0707
	Immature	im	0.0474	0.1807
	Virginile (young vegetative)	v	0.1192	0.4200
3. Generative	Cryptogenerative	g_o	–	–
	Young (early generative)	g_1	0.2689	0.7864
	Middle age (mature generative)	g_2	0.5	1
	Old (later generative)	g_3	0.7311	0.7864
4. Post- generative (senile)	Subsenile	ss	0.8808	0.4200
	Senile	s	0.9526	0.1807
	Dying plant	sc	0.9820	0.0707

In the monograph «Cenopopulations of plants» (1976) ontogenetic state of individual is considered as a definite stage of ontogenesis of plant, distinguishing by specific physiological-biochemical state, presence of a number of indicated morphological and biological features, certain position of individual in space and particular relation to the environment. Each stage of ontogenesis characterizes biological age of individual.

Plants are referred to this or that ontogenetic state on the basis of the complex of qualitative features (Uranov, 1975). The most important of them are the following: way of nutrition, presence of embryonic, juvenile or adult structures and ability of individuals, to seed and vegetative reproduction, correlation of processes of newgrowth and die off, degree of formation of main features of living form (biomorph). In this case, after Serebryakov (1964), Serebryakova (1972) and other folloowere, biomorh is defined by adult individuals, which is formed in different states: from v to g_2 (rare g_3). Below are the most common qualitative features of ontogenetic states for plants of different biomorths:

1. Seeds (se) or indehiscent monospermous fruits (achene, galls etc.): are in state of primary rest, morphological characteristics are species-specific;
2. Plantules (p) – mixed nutrition (due to substances of seed and assimilation of first leaves); presence of embryonic structures: seed-lobes, embryo root and shoot; preservation of connection with seed;
3. Juvenile plants (j) – simplicity of organization, preservation of some embryonic structures (root, shoot); loss of connection with seed; as a rule absence of seed-lobes; non-formation of features and properties peculiar to adult plants. Presence of leaves of another form and position, another type of overgrowth and ramification of shoots and roots, than of adult individuals;
4. Immature plants (im) – presence of features and properties, transitional from juvenile plants to adult: development of leaves and root system of transitional type, appearance of single adult features in the structure of shoots, beginning of ramification, isochronic retaining of some elements of embryo shoots;
5. Virginal plants (v) – appearance of main features, typical for this living forms. Plants have adult leaves, shoots and root system characteristic for species. Generative organs are not yet formed, processes of die-off are not expressed, excluding seasonal changing of mono-dicyclic shoots and deaf of a small number of roots (sometimes main, more often - additional or branch);
6. Cryptogenerative plants (g_0) – similar to virginal plants, but in their buds generative organs (flowers or inflorescence) are embedded; in some cases specific, macromorphological features of state are revealed; degree of partition of leaf, leaf edge etc. (Shestakova, 1991). If they are absent or it is not possible to check the presence of generative buds, then cryptogenerative state is not singled out, though in fact it is always present, at least for a short period of time;
7. Young generative plants (g_1) – appearance of first generative organs. In some cases final formation of adult structures: larger shoots, leaves and biomorphs in the whole. Predominance of processes of newgrowth over die-off;

8. Middle age plants (g_2) – balancing of processes of newgrowth and die-off. Maximum expressed for concrete ecological conditions indices of biomass, seed productivity, morphological parameters, presence of died offshoots, leaves, roots etc;
9. Old generative plants (g_3) – predominance of processes of die-off over newgrowth, sharp decrease of generative function, weakening of processes of root and shoot-formation. In some cases – simplification of living form, expressed in weakening or loss of ability to form new shoots, increase of the number of died offshoots, roots and other organs;
   Quite often in plant populations interruptions in flowering are registered, and then temporarily (this year) among generative plants there are non-blooming young, middle age and old generative individuals, for which it is advisable to introduce indices g_1v, g_2v and g_3v. These groups are clearly distinguished by traces of last year's generative shoots, by scars from them at absence of generative shoots in the current year;
10. Subsenile plants (ss) – sharp predominance of processes of die-off over newgrowth, absence of generative shoots, possible simplification of living form, expressing in changing of type of overgrowth (or in loss of ability of ramification), second appearance of leaves of transitional (immature or juvenile) type; accumulation of died off parts of plants;
11. Senile plants (s) – predominance of died-off parts and parts stopped growing. Maximum simplification of living form, second appearance of some juvenile features of organization (leaf forms, shoots etc.). In some cases – complete absence of regeneration buds and other new growths;
12. Dying plants (sc) – final stage of full ontogenesis of plants, absence of living aboveground plants, preservation of resting buds, few living roots and underground shoots.
    Thus, full ontogenesis of perennial plants includes 12 ontogenetic stages, to which 3 groups of temporary non-flowering elements can be added. An example of ontogeny is presented in figure 1.

For monocarps, including annual plants, full ontogenesis ends in generative period, post-generative period is absent, as shown in Fig. 2. That's why the number of ontogenetic states for annuals and biennials is 6 (9). In this case generative period is divided only into g_0 and g states, further generative plants have phenophases. For some species of plants at slow development of individuals in pre- generative period, it is advisable to subdivide ontogenesis periodization and single out 2-3 subgroups within the limits of some ontogenetic states distinguishing by clear morphological markers.

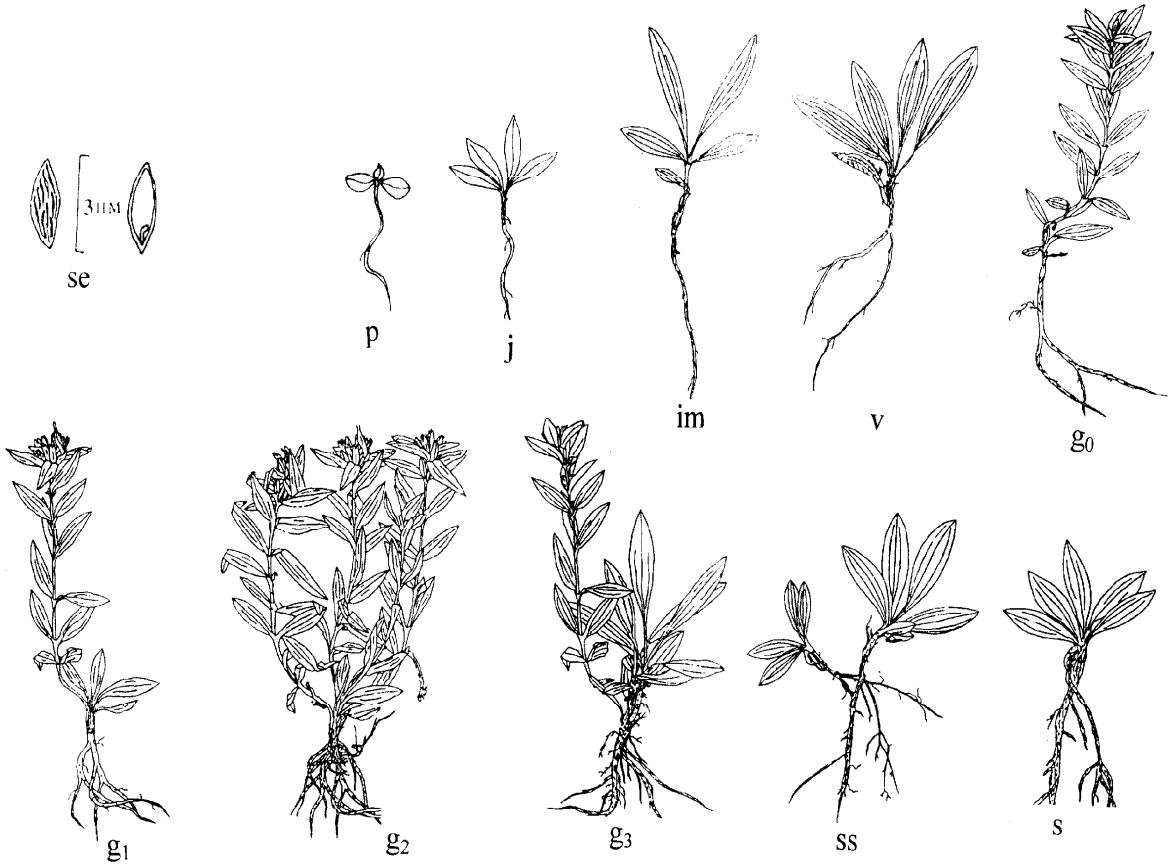

Fig. 1. Ontogenesis *Gentiana cruciata* L. (Ontogenetic atlas …, 2002, p. 129).

Fig. 2. Ontogenesis *Crepis tectorum* L. (Ontogenetic atlas …, 2013, p. 139).

Nowadays, in all countries there are large collections of systematic herbarium including millions of herbarium leaves, which are basis for studying floristic biodiversity. The largest and oldest herbaria are herbaria in British Museum, Paris, Geneva, in the USA (National Herbarium and in New-York botanical garden), in Russia – Herbarium of Komarov's Botanical Garden with more than 5 mil., specimens of plants, Moscow State University named after M.V. Lomonosov, Moscow Teacher Training University, Tver University, Tomsk University and some others. At the same time intraspecies biodiversity is rather poorly studied and it is not represented in these herbaria. The formation of Ontogenesis herbarium and official registration of its collection in the International catalogue «World Herbaria» of New York botanical garden are to solve this problem. This herbarium has an international index – MARI (site http://sweetgum.nybg.org/ih/herbarium.php?irn=176924). The credit is greatly due to Honoured Scientist, Dr of Biology, Prof. L.A. Zhukova.

Ontogenetic herbarium is herbarium of plants of different stages of individual development. Ontogenetic states were revealed with the use of the concept of discrete description of ontogenesis taking into account morphological features-markers (Rabotnov, 1950a and b; Uranov, 1975; Shestakova, 1991). All species in the Ontogenesis herbarium are represented by samples in different ontogenesis states from sprouts to senile plants (complete ontogenesis), but sometimes the ontogenesis is incomplete as it's rather difficult to collect complete ontogenesis, that is why samples are constantly added to this herbarium.

It includes mainly plants of flora of Mari El Republic, less plants, brought by L.A. Zhukova from reserves Kandalashski, Karadagski, «Kivach», floodplain meadows of the Oka and Northern Dvina rivers, Solovetskie islands and mountain meadows of the Carpathians; by L.B. Zaugolnova, A.M. Bylova, L.M. Shafranova from Naurzum reserve; I.M. Ermakova from Kaluga district; O.P. Vedernikova, G.I. Arnautova, N.V. Ivshin, S.S. Lisitsin, A.A. Pchelintsev, O.E. Maksimenko from Georgia, Krasnodar district and Dagestan; O.P Vedernikova and S.V. Kozyreva from the Republics of Gorny Altai and Tatarstan, Krasnodar Region; E.V. Akshentsev from Chelyabinsk and Orenburg regions; T.M. Bychenko from Irkutsk region; V.A. Cheremushkina, G.R. Nozirova, E.A. Basargina, V.N. Godin from Novosibirsk region, N.A. Polyanskaya from Arkhangelsk, Murmansk and Nizhniy Novgorod regions; G.O. Osmanova from the Republic of Azerbaijan.

Plants of different living forms (trees, shrubs, subshrubs, dwarf shrubs, dwarf subshrubs, annuals and perennial herbaceous plants) are presented there.

G.O. Osmanova, O.P. Vedernikova, S.Y. Faizullina, E.V. Shestakova, N.P. Grosheva, S.V. Balakhonov, S.V. Kozyreva, E.A. Alyabysheva, E.S. Zakamskaya, E.A. Skochilova, I.A. Bogolubova, N.V. Ivshin, Y.G. Suetina, N.V. Ilyushechkina, I.V. Knyazeva, T.A. Polyanskaya, L.V. Prokopyeva, T.V. Ivanova, I.V. Shivstova, L.I. Terentyeva have taken an active part in collecting and making the Ontogenesis herbarium.

The collection of the Ontogenesis herbarium is a part of the Population-ontogenetic museum which has worked at the Department of Ecology of Mari State University for about 25 years and is a member of Eurasia association of university museums (Smurov *et al*., 2012; Vedernikova *et al*., 2013; Vedernikova & Kozyreva, 2014, Kozyreva *et al*., 2015). The museum is a scientific and educational establishment, it is presented with exhibits in six departments: General, Theme-based, Ontogenesis first stages, Collection of fruits and seeds, Izoteka (Picture collection), Phototeka (Photo collection) and Library. The museum includes 22 exhibition stands with herbarium samples and photos of ontogenetic states of plants of different life forms, herbarium material on different types of ontogenesis polyvariety:

1. *General department,* or Ontogenesis herbarium, consists of scientific and educational parts.

Scientific herbarium includes plants of various biomorphs, belonging to 87 families, 376 genera, 620 species of angiosperm plants, and 2 species of gymnospermous, higher cryptogams plants and lichens. Training herbarium also includes plants of various biomorphs, belonging to 60 families, 198 genera, 286 species. The exhibits in the herbarium are represented in the alphabetic order of the Latin names of families and species in these families. The catalogue is constantly renovated; it has the information about the ontogenetic states of species, their amount, the places of collecting and the main collectors.

Training herbarium is actively used at the lessons of «Population ecology and botany», «Ecological morphology», as well as in field work. The work with this herbarium allows students to acquire skills of determination ortogenetic states of different biomorphs and use them of studying intrapopulaion biodiversity.

2. *Thematic* (*by polyvariant*) *herbarium* includes materials on polyvariant of individual development of plants (Zhukova, 1995; Zhukova & Osmanova, 1999; Osmanova, 2007, 2008). The following types of polyvariant are represented rather full: morphological polyvariant of vegetative and generative organs (*Betula pendula* Roth., *Fragaria vesca* L., *Plantago lanceolata* L.), extreme display of morphological polyvariant was the change of living form; polyvariant of types of reproduction, for example in unstable habitats *P. lanceolata* has additional type of reproduction – vegetative, with the main type – seed reproduction. Figure 3 shows polycentric system of rootshoots *P. lanceolata*.

Fig. 3. Polycentric system of rootshoots *P. lanceolata*:

1 – maternal rosette-like sprout; 2 – rhizome; 3 – adventitious root; 4 – daughter rosette-like sprout (Osmanova, 2007)

3. The *initial stages of ontogenesis* present albums with the herbarium of the 228 plant species of different life forms from 57 families.

4. *Collection of fruits and seeds* includes seeds and fruits of 352 plant species from 91 families.

5. *Izoteka* consists of 331 pictures of individuals of plants of different life forms from 65 families and also pictures of individuals of 2 ferns and one lichen.

6. The *photo collection* of Ontogenetic herbarium gives you the opportunity to look through ontogenetic series in electronic form.

Working with Ontogenetic samples of herbarium allows you to get the skills to identify ontogenetic States of plants of different biomorph and apply them to the study of intraspecific biodiversity. The knowledge of the peculiarities of life of individuals and populations is necessary in the development of practical recommendations for assessing the status of populations of different species of plants, identifying the resources of the studied plants and their sustainable use, and development of guidelines for the preservation and introduction of securities, including rare and medicinal plants.

Conclusion

The results of the study of the ontogenesis of plants compiled in seven volumes of the periodical the «Ontogenetic atlas ...», which described the individuals 278 plant species from 67 families, the authors of which was 231 researcher working in population-ontogenetic trend in Russia and the near abroad (Ontogenetic Atlas of medicinal plants, 1997, 2000, 2002, 2004; Ontogenetic Atlas of plants, 2007, 2011, 2013). The fifth volume of Ontogenetic Atlas of plants at the all-Russian competition of the people's friendship University (Moscow) received the Diploma of III degree – for the best book of 2010 in the field of ecology. Now any Botanical collections are needed because of the store and they represent samples is the primary sources of information about plants. Since our Ontogenetic herbarium has no analogies in the world, its scientific, applied and educational value is high, which promotes the development of population-ontogenetic trends and population of botany and ecology in General.

Work with the samples of the Ontogenesis herbarium gives an opportunity to gain skills in distinguishing ontogenetic states pf plants of different bio forms and to use them in studying interpopulation biodiversity. It is necessary to know the peculiarities of the life of species and population to work out practical recommendations for assessing the state of populations of different kinds of plants, evaluating the resources of the plants studied and their reasonable usage. This knowledge is also important for working out instructions for preservation and introduction of valuable plants including rare and medical herbs.

The results of the work on plant ontogenesis studying are summarized in seven volumes of the periodical «Ontogenetic atlas…» which includes the description of the ontogenesis of 278 plant species of 67 families. The authors were 231 scientists working in the population-ontogenesis field in Russia and Russia's neighboring states (Ontogenetic atlas of medical herbs, 1997, 2000, 2002, 2004; Ontogenetic atlas of plants, 2007, 2011, 2013). In 2010 Volume 5 of Ontogenetic atlas was awarded the third prize as the best book of the year in the field of ecology at all-Russian contest (Russian University of Peoples Friendship, Moscow).

At present any botanic collections are of great demand as the samples kept in them are the first sources of information about plants. As our Ontogenesis herbarium is unique in the world, its scientific, practical and educational significance is great, it contributes to intensive development of population-ontogenetic direction and population botany and environmental science on the whole.

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