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Use of symmetry theory in studying the morphogenesis of life forms: the example of the cushion plants

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It is well known that life forms reflect the impact of the environment. An interesting task in ecology is to study the connection between the morphological characteristics of life forms and physical and geographical processes, taking place in the environment. This study may profit from the application of symmetry theory which is a universal methodology in science. According to this theory both the object, that is, life form, and the environment are characterised by their own types of symmetry, which may differ from each other. If the environment acts sufficiently intensively on a plant, its form may show deformations – dissymmetry according to Curie. From the observed dissymmetry character of the vegetation it is possible to judge the symmetry of the environment, its specific impact on the vegetation, and the direction and intensity of natural matter and energy flows. All these are clearly apparent in the cushion plants growing on the abrupt slopes of south-east Altay canyons.

Keywords: Symmetry; Dissymmetry; Morphology; Life forms; Cushion plants

Introduction

Great possibilities are opened for morphological methodology in biology and ecology with the use of the theory of symmetry. The geometrical approach to studying ‘natural bodies’ (this term was given by Vladimir Vernadsky [1]) was formed in the framework of this theory, developed by crystallographers [2]. Nowadays it is widely applied to mathematics, physics, chemistry and general systems theory. There are some attempts to apply symmetry theory to biology [3–5], to soil science [6], to geography [7] and to plant and landscape ecology [8].

The theory of symmetry has a universal character and is a methodological basis of modern science. It allows the revealing of general principles and laws of morphology. Besides, it allows estimation of interactions between an object and its environment [9].

The environment is interpreted as any intervening substance such as an electromagnetic field. One can reveal the symmetry and structure of an electromagnetic field in a very simple way by spreading iron filings on the surface of a sheet of paper and applying a magnet to the underside. The symmetry of the environment displays itself as various flows: water, thermal, wind and others, which influence various natural objects.

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Figure 1. Flag-like crowns in West-Siberian northern taiga (photograph, S. Kirpotin).

According to this theory not only the object but also the environment has its own type of symmetry. Each symmetry may differ from the other, and if the environment affects the object sufficiently, then in the composition of the object the deformations appear. These deformations were called *dissymmetry* by Curie [10]. It is possible to assess the symmetry of the environment by the character of the dissymmetry, to estimate the specifics of its impact on the object, to determine the direction and even intensity of natural flows, such as water flows, wind flows, radiation flow and so on. This is what makes the method so attractive and useful for ecological prognosis.

The simplest and vivid examples of dissymmetry are flag-like wind-pruned trees (natural weathercocks) appearing under the influence of strong winds, notably along coasts, at high altitudes and in tundras (figure 1). Another expressive example is a certain character of plant overgrowing the lakes in the North. These lake plants start to overgrow from the lee-side under the influence of constantly blowing strong winds of certain direction (figure 2).

The theory of symmetry can bring the physiognomic approach of studying life forms to a higher level. Moreover, with symmetry theory, life forms of plants can be described by a universal language, understandable in any field of science. Future generations of researchers have great prospects for working in this way, because at present it is not commonly seen in use. There is a need for innovators and risk-takers!

At the same time, some general principles for the origin of forms have been discovered in the framework of this theory. For instance, the famous Russian crystallographer Ivan Shafranovskii [9] reveals that symmetry of live organisms depends on the environment. In

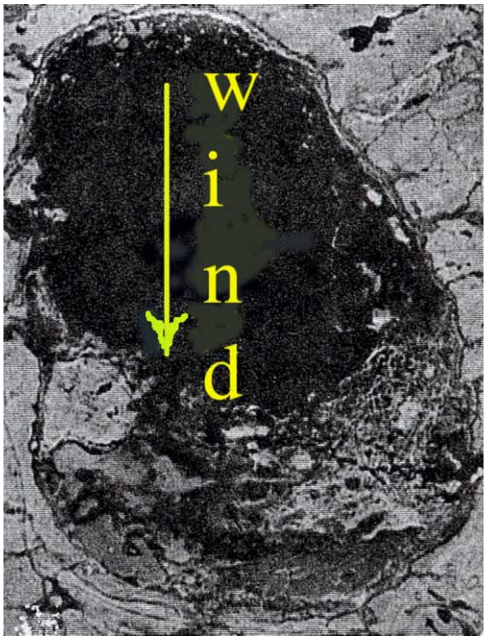

Figure 2. Overgrowing of forest-tundra lakes from the lee-side under the influence of constantly blowing strong winds, Nadym-Pur interfluve (airphoto).

Shafranovskii's view, the symmetry of organisms corresponds to the Earth's gravitation, which according to P. Curie has the symmetry of a cone. Therefore many organisms, leading an attached life style, particularly plants, very often have conical or cone-like forms. The gravitational force in dense water is sufficiently equilibrated by Archimedean force, and therefore organisms, which are suspended in water like plankton, usually have a spherical form. And mobile animals have a bilateral type of symmetry.

In this paper, we take the opportunity of using the geometrical approach to study life forms on a quality level. Let us consider as an example the hemispherical form, possessed by many cushion plants in the Altai mountains, Siberia. This form is untypical for the majority of other plants.

There is a question: what are the factors which influence the production in plants of spherical forms, which are more characteristic of plankton organisms suspended in dense water?

Discussion

The expediency of similar forms from the ecological point of view is rather obvious. The sphere, as a geometrical form, has the least possible surface area with the greatest possible volume. It is advantageous for cushion plants in high mountains conditions to have just a minimal surface area for contact with an extremely adverse, severe environment (figure 3).

At the same time, the cushion plants usually grow on the substratum. They have substrates with the poorest of nutrition. Very often there is no soil at all. But the organic dust and melkozem, blown constantly by strong winds in high mountains, are accumulating inside the cushion bodies. Here, inside the dense cushion remaining from the last year's foliage, these

Figure 3. Hemispherical dense cushions of *Oxytropis tragacanthoides* (photograph, S. Kirpotin).

wind-borne debris make an additional stock of nutritious substances (figure 4). So, the cushion plant form conserves the greatest possible volume of nutritious material inside itself, with the least possible contact of its surface with an adverse environment. The hemispherical form best accomplishes this task. It maximises the advantage of the plant for living in its hostile environment.

In the opinion of A. Revushkin and I. Volkov [11] the cushion plants actively transform the external environment, and so inside the sphere of the cushion a special microclimate is formed, which is stable to the sharp daily fluctuations of temperature and humidity.

1) living part of the plant;
2) basis of the cushion, filled up by substratum;
3) roots.

But, by careful study, it has been established that the design features of cushion plants from the ecological point of view have both pluses and minuses. For example, the minimal spherical surface of a cushion intercepts an insignificant quantity of deposits, and besides that many cushion plants grow in rigid arid conditions, where deposits (as, for example, in Thuja steppe, Altai) are about 50 mm. In this case, with the absence of moisture, the plant cannot take advantage from a reserve of nutrition substances, held inside its body. The ground or back-tapered forms are much more favourable for interception of moisture. Thus, from the ecological point of view, the cushion plants have both pluses and minuses.

Apparently, a severe temperature mode, and deficiency of moisture and nutrition even with their cumulative influence, cannot explain the cushion form. Why do the cushion forms occur in such different conditions, both in cryo-arid semideserts of the Tsuja steppe and in cold humid mountains?

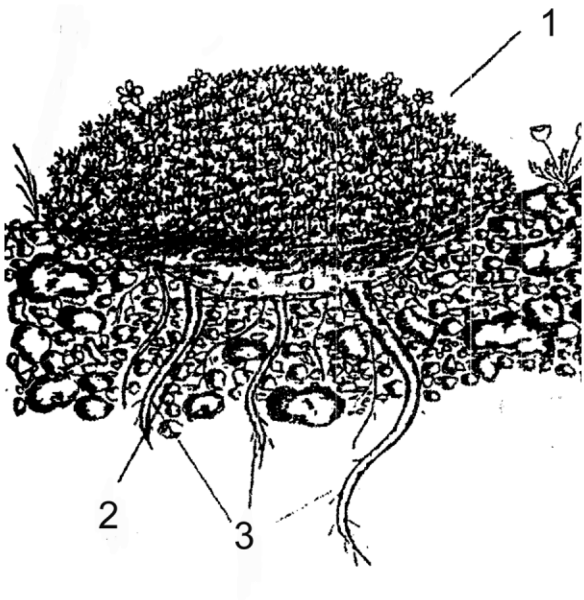

Figure 4. Hemispherical dense cushion of *Potentilla biflora* in Kuray ridge, Altai, Russia (from Volkov, 2002).

Let us consider the cushion form from the point of view of the theory of symmetry. We may be able to throw light on the conditions of its origin. Let us recollect that organisms with an attached life style correspond to the force of earthly gravitation and usually have conic or approximately conic forms. A strong disturbing factor is necessary to change, to deform, this initial form. It is clear that the dissymmetry phenomenon should be caused by the same dissymmetry reason. And wind is such a disturbing lateral factor.

Still, H. Walter [12] has observed that the cushion plants are characteristic for areas where there are habitually strong, constantly blowing winds. Really, both in deserts and tundras, in high mountains and in intermountain basins (like the Tsuja steppe) steady, strong winds are very notable. These strong winds usually carry firm particles of snow (in the Arctic) or dust and flow (in deserts) across every obstacle with a literally grinding effect, razing those obstacles to the ground, to one common level. This phenomenon has received the name ‘corrasion’.

The hemispherical form of cushion plants has large advantages just from the aerodynamic point of view. A wind and the particles, drawn by it, pass in relation to a hemisphere, pressed to the ground, always on a tangent, being reflected from its surface and not causing particular damage to the plant (figure 5).

But, to form the hemispherical shapes of the cushion plant, winds, even strong winds, must not have one steady direction only. Under the influence of such winds only the flag-like or dune-like shapes may be formed, but not the hemispherical one. So, winds must have different unsteady directions. These very conditions are observed in high mountains and intermountain basins like the Tsuja steppe.

It is very interesting to note that dwellings of nomadic people in the steppes both of the Russian Altai and Mongolia have a hemispherical form, the same as cushion plants. The reasons for this form of dwelling are the same too: i) to keep maximal useful internal volume with minimal contact with a severe environment; ii) to resist strong winds, which are usual in steppe conditions.

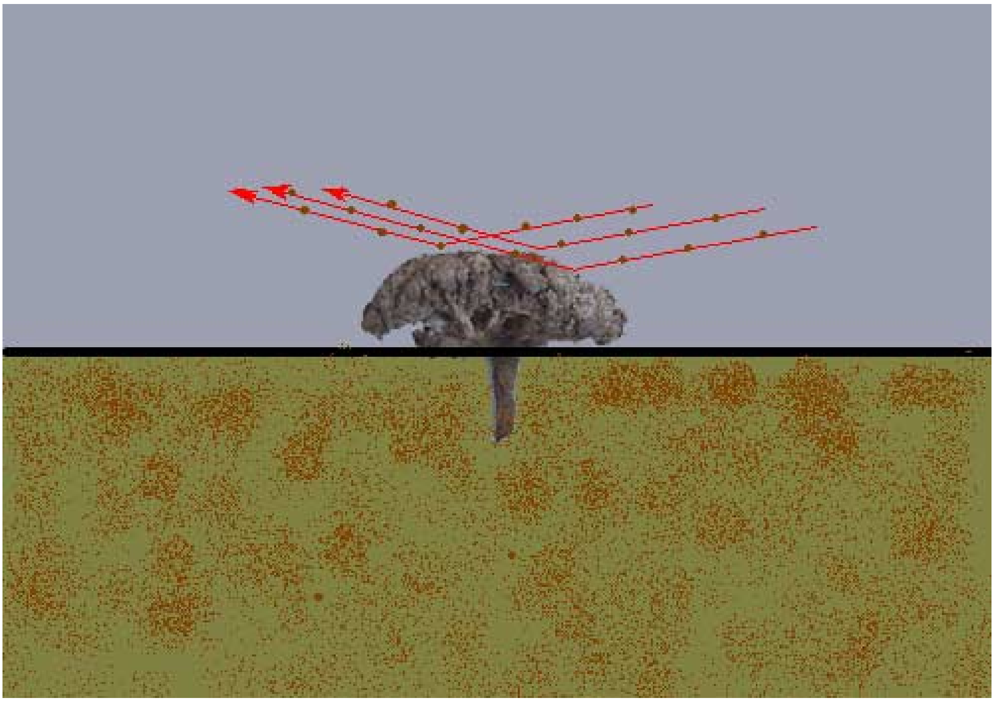

Figure 5. The influence on cushion plant by wind.

Another common feature for cushion plants is their growing on the crushed-stone slopes. In such conditions the gravel constantly dislocates down under the influence of gravitation. More often it slowly slips down, but sometimes it crumbles.

It is possible to consider the process of gravel dislocation as another lateral flow, relative to cushion plants. The streamlined hemispherical form of cushion resists this flow well. But even this form, perfect from the aerodynamic point of view, may in certain conditions be deformed. Such conditions are created on abrupt, almost sheer slopes. The upper part of the cushion begins to die off under the influence of constantly crumbling gravel and the characteristic dissymmetric cutting shape of the cushion appears.

Even at the first inspection of cushion plants in 1994 we have put forward the assumption, that if we can collect and process statistical material about the steepness of slopes and degrees of deformation of cushions, growing on them, it will be possible then to estimate the steepness of slopes only by the degree of the cushions' dissymmetry. Such opportunity appeared in 2004. Morphological measurements of cushion plants were carried out on six test sites on abrupt rock-slides in the Chagan-Uzun canyon. *Oxytropis tragacanthoides* was chosen as the modelling object for measurements. The following measurements were made on the test sites:

- the steepness of the slopes;
- the linear sizes of the cushion and hollows diameters a) perpendicular to the slope orientation (D lateral) and b) parallel to the slope orientation (D radial) (figure 8).

Table 1 contain the statistical results of measurements showing that dissymmetry of the cushions strongly correlates with the steepness of slopes, being a reliable indicator of it.

Figure 6. Hemispherical dwelling ‘yurta’ (yurt) of nomadic people in Tsuja intermountain steppe, Altai (photograph, A. Ebel).

Conclusions

1. The theory of symmetry has a universal character and could be used to explain the origin of a form in different fields of science, including plant ecology.
2. The universal terminology, using the framework of this theory, can describe morphogenesis of life forms of plants with language understandable in any field of science.
3. The level of dissymmetry allows estimation of environment-object interactions, determining direction and even intensity of different environmental flows.
4. From the standpoint of the theory of symmetry the cushion forms of plants appear to be the best way to resist the constantly blowing strong winds and ground landslides in severe high mountain conditions.

Table 1. Statistical results of measurements

No. test sites	Steepness of slopes (degrees)	Dlat/Drad of cushions (mean value)	Dlat/Drad of hollows (mean value)
3	28	1.36	1.6
1	29	1.36	1.63
4	30	1.5	1.7
5	33	1.5	1.74
6	35	1.54	1.8

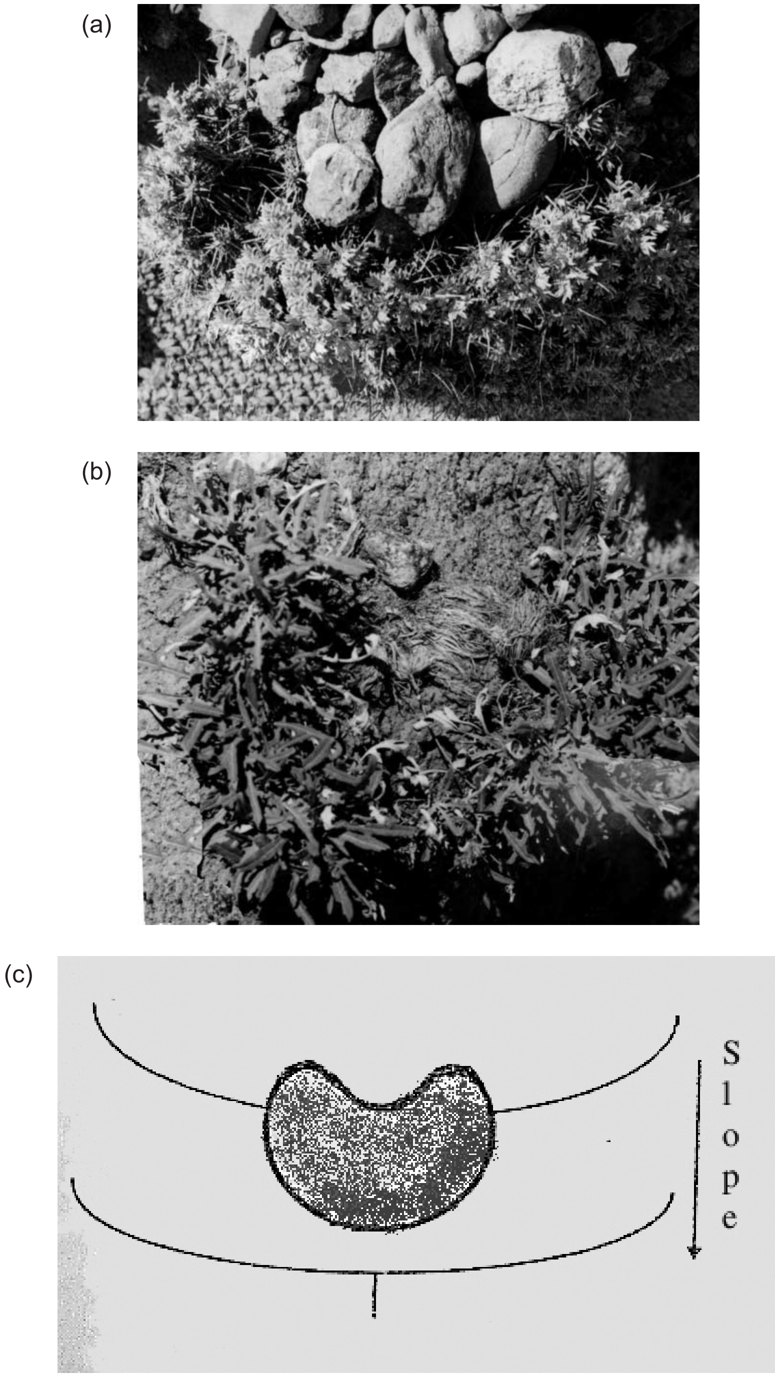

Figure 7. The ‘kidney shape’ dissymmetry forms of cushions on abrupt gravel slopes (photograph, S. Kirpotin): (a) – *Oxytropis tragacanthoides;* (b) – *Saussurea pricei;* (c) – generalised scheme.

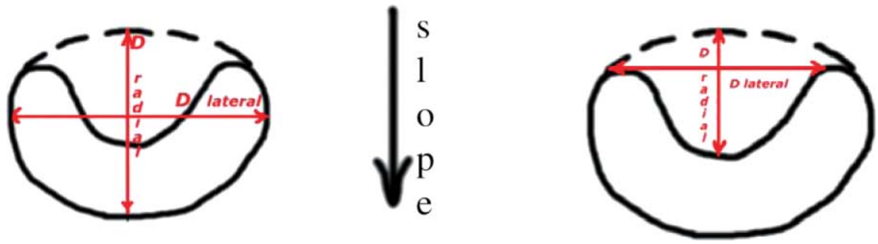

Figure 8. Measurements of cushions.

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