ANOMALIES IN THE STRUCTURE OF *SPERGULARIA MARINA* (L.) GRISEB.
(= *S. SALINA* J. ET C. PRESL) SEEDS IN THE AREA AFFECTED
BY SODA INDUSTRY IN KUJAWY (CENTRAL POLAND)

MIROSLAWA CEYNOWA-GIELDON

Institute of Biology, Nicholas Copernicus University,
Gagarina 9, 87-100 Torun, Poland

(Received: July 12, 1994. Accepted: October 6, 1994)

ABSTRACT

In some populations of *Spergularia marina* round soda industry waste-dumps in Kujawy more than 90% seeds have been found to be anomalous, incapable of germination. The outline of the seeds is apparently normal, but inside they contain empty cavities. In many of them sharp, irregular outgrowths or bluntly ended structures with a chimney-like aperture pierce the seed coat from inside. With increasing distance from the sources of contamination of the environment the number of anomalies in question was observed to diminish until they disappeared altogether. However, in wet periods there were nearly 50% fewer anomalous seeds in the same stands than in dry and warm years.

KEY WORDS: *Spergularia marina*, halophytes, seeds, anomaly, flora, contamination.

INTRODUCTION

Spergularia marina is generally an annual herb, seldom biennial or perennial. It grows in coastal and inland salt areas. According to Wendelberg's ecological classification, this species has been referred to obligatory halophytes, occurring solely on saline soils and requiring the presence of salt in soil for optimum development (Wilkoń-Michalska 1963). Its phytocenoses, generally referred to *Puccinellio-Spergularietum saline* Feekes 1936, develop as pioneer communities on saline roadsides, round canals and salt springs as well as on sodden, saline meadows. In natural and seminatural salt areas they usually contain a fairly large number of other halophilous species. On strongly contaminated soils round soda works, however, *S. marina* often forms nearly conspecific aggregations. This is evidence of the taxon's high capability of rapid spreading and its exceptional, compared with other species, tolerance to soil contamination caused by soda industry. However, the developmental potential of that species is also limited.

The seeds showing anomalies, presented in the present work, need special anatomical and physiological studies. For the ecologist, however, the mere fact of their occurrence is important, since it reflects the plants' condition and the potential of their population to adapt to adverse developmental conditions. So far, some information has been acquired about the demography of *S. marina* and the dynamics of that species' population in the meadows of the Baltic coast (Torstensson 1987a, b). Attention has been focused on the effect of external factors promoting or inhibiting germination of *S. marina* seeds (Ungar 1982, 1984), but no mention has been made of the existence of anomalous seeds of that species, unable to germinate due to anomalies in their structure.

MATERIAL AND METHODS

A survey was made of the fruits and seeds of *Spergularia marina* from TRN herbarium and from special population samples – 30 specimens each – taken randomly in various vegetation periods, from various stands in the main sites of the species' occurrence in Kujawy.

The material for study contains samples from old, probably relict, meadow stands as well as those taken from recently formed synanthropic stands. In some stands, mainly synanthropic ones, situated round soda works, sampling was repeated in several seasons. The seeds were viewed in a CARL ZEISS – Jena stereomicroscope. The percentages of normal and anomalous seeds were roughly estimated. The observed anomalies have been presented in figures, which were made under a BIOLAR microscope using a drawing apparatus. The photographs were taken using a DOCUVAL microscope.

RESULTS

Structure of normal seeds and fruits of Spergularia marina in industrial areas of Kujawy

Spergularia marina adaptation to rapid spreading over new habitats is linked with the polymorphism of its seeds. The main types of seeds, and consequently the types of plants, of Polish populations of *S. marina* have been presented in a separate paper (Ceynowa-Gieldon 1993). Out of four types of *S. marina* plants differing in seeds composition of the capsules presented in that paper only one has been found in the industrial areas of Kujawy. This is the most commonly found in Poland type of *S. marina* plants characterized by having cap-

sules in which all the seeds are smooth (at most only slightly rugose, without tubercles), unwinged, or smooth unwinged seeds with one or several winged seeds placed at the bottom of the capsule.

Normal seeds of *S. marina* from anthropogenic habitats in Kujawy do not differ from the description of seeds of that species from many other areas (Kowal 1966, Sterk 1969). They are either inverse – egg – or triangular – kidney – shaped. Their length, borders not included, ranges from 0.6 to 0.9 mm, their width is 0.4–0.8 mm, their thickness 0.2–0.4 mm. One of the lateral sides of the seed is flat or slightly convex, the other is flat or slightly concave, their edge is rounded. In the centre there is a vitreous perisperm encompassed by a horseshoe – or crescent-shaped embryo with clearly marked cotyledons and a slightly convex radicle. The surface of the seed is glossy and the colour from light to dark brown. Under the microscope there are visible heavily indented epidermal cells of the testa.

From the edges of the lateral sides of some, generally averaging larger, *S. marina* seeds project membranous borders, which usually surround nearly the entire circumference except the seed hilum. The widest borders, called wings, are easily visible. Alongside with unwinged and winged seeds there

sometimes occur intermediate seeds with a narrow, often scarcely visible border; the narrower borders are smooth, while the wider ones are often jagged or dentate at the edges.

S. marina fruits mature gradually inside biparous cymes, from early summer till late autumn. Those are capsules, 3–6 mm in length, opening by three wide valves. The number of seeds in the capsules varies widely depending on the habitat and condition of the plants. The average is 50–60 seeds per capsule. Part of the ovules do not develop, or form quickly drying up, wrinkled forms, which never achieve the size of a seed.

The largest numbers of dried up, immature seeds are found in the upper part of the capsules. It is there that are generally located the smallest seeds, whereas the largest ones (often with borders) are found at the capsules' bottoms. Plants bearing capsules with a pronounced preponderance of unwinged seeds only rarely produce also capsules containing only or nearly only winged seeds. In the latter the total number of seeds is comparatively small, which indicates that the development of the larger, in this case winged, seeds proceeded at the cost of a reduction in the number of the smaller, unwinged ones. Except in areas strongly affected by soda industry in Kujawy and elsewhere in Poland, small populations of

Fig. 1. Unwinged *Spergularia marina* (L.) Griseb seeds from Kujawy.
a – normal seed

Fig. 2. Winged *Spergularia marina* (L.) Griseb. seeds from Kujawy.
a – normal seeds
b – anomalous seeds

S. marina have been found, with all capsules containing mainly winged seeds, but unlike those mentioned above, the total number of seeds in the capsules in those populations does not noticeably diverge from the mean total number of seeds in the capsules of the species *S. marina*.

Structure of anomalous seeds, incapable of germination

The anomalies described below have been found in all types of *Spergularia marina* seeds occurring in the industrial areas of Kujawy, both unwinged and winged as well as in forms with narrower borders.

The seeds which I call anomalous are in general light brown, similar in size to normal ones (Figs 1, 2). They are also similar in shape to normal seeds, but their surface, unlike in normal seeds, is mat and often uneven. In the most transformed seeds there are irregular outgrowths on their surface, which pierce the seed coats from inside. Some of the outgrowths are sharp, others are blunt, terminated with a characteristic chimney-like aperture (Figs 3, 4). Due to the presence of those outgrowths, the anomalous seeds in the capsules often stick together.

The main characteristic differing the seeds in question from normal seeds is their lack of a well – developed embryo. Under the seed coats there are empty cavities instead of embryonic cotyledons. When lighted under the microscope, the central part of the normal seed is transparent, while the peripheral part occupied by the cotyledons and the radicle is darkened (Fig. 5a). Anomalous seeds, on the other hand, lighted from below present a converse image: their peripheral parts are transparent and their central parts are dim (Figs. 5b, 6). There occur also quite a number of intermediate forms, in which the seed disk, at least in some places, is vitreous like in normal seeds.

The percentage of anomalous seeds in the studied population samples

The percentage of anomalous seeds in the samples of *Spergularia marina* used for study ranges from 0 to 99% (Table 1). Complete absence of anomalous seeds was found in relict sites and in peat meadows less affected by human activity, while the largest number of anomalous seeds was noted in samples from synanthropic habitats situated close to pipelines and waste-heaps of soda industry (Fig. 7).

Fig. 3. Anomalous *Spergularia marina* (L.) Griseb. seeds from Mątwy near Inowrocław
a, c – anomalous seeds with narrow border
d, g, f – anomalous seeds without border (g – viewed from above, f – viewed from side)
b, e, h – fragments of seed coat pierced by irregular outgrowths
b – outgrowths with chimney-like aperture

TABLE 1. Percentage of anomalous seeds in 19 representative population samples of *Spergularia marina* (L.) Griseb.

No.	Locality of population	Anomalous seeds [%]
1	Janikowo, near a waste-heap belonging to soda works, among <i>Salicornia patula</i> , July 20, 1983	90-99
2	Janikowo, near the previous stand, among <i>Phragmites australis</i> , July 20, 1983	20-50
3	Janikowo, next to previous stand, on peat soil with dense sodding, September 5, 1988	sporadically
4	Janikowo, on a meadow in previous stand, October 12, 1991	0
5	Mątwy, near a waste sewer from factory, at the base of a limestone heap, July 14, 1989	90-99
6	Mątwy, on a roadside along waste-heaps of soda works, July 14, 1989	80-90
7	Mątwy, on cinder, near the previous stand, October 8, 1991	20-30
8	Mątwy, in dry place near a pipeline along waste-heaps of soda works, July 30, 1992	80-90
9	Mątwy, in wet place near a leak from pipeline, next to previous stand, July 30, 1992	0
10	Mątwy, on a meadow near waste-heaps of soda works, July 16, 1993	sporadically
11	Sikorowo, near pipeline, in a field, July 7, 1992	20-40
12	Inowrocław, near salt-works, October, 1992	5-10
13	Jacewo, near a dried up pond, August 13, 1992	0
14	Ciechocinek, along the evaporation towers, sprayed by saline water, July 26, 1989	sporadically
15	Ciechocinek, next to previous stand, July 26, 1989	0
16	Zgłowiączka, on a meadow, July 8, 1992	sporadically
17	Kłodawa, in a roadside ditch, near salt mine, July 3, 1992	sporadically
18	Wapno, in a hollow near former salt mine, July 20, 1993	0
19	Słonawy near Szubin, on a meadow, June 28, 1994	0

sample = seeds from 30 plants

With growing distance from the waste-heaps and progressing into meadow habitats, the number of anomalous seeds decreases gradually down to zero. The ratio of anomalous to normal seeds in the same stand sometimes varies depending on weather conditions. It is highest in dry and warm years, and in wet periods it is sometimes reduced by nearly one half.

In samples with more than 90% anomalous seeds the ratio of anomalous to normal seeds is generally much the same in the capsules of all individuals of the same population. However, where the total number of anomalous seeds in the samples is lower, these proportions in the capsules of individual plants of the population are different. Part of the plants in those populations produce only fruits with all seeds normal, while in the remaining plants the fruits differ widely with respect to the number of normal and anomalous seeds. On one plant can be found capsules with all seeds normal side by side with capsules containing only anomalous seeds and those with different proportions of normal and anomalous seeds.

DISCUSSION

Seeds of *Spergularia marina* with underdeveloped embryo remind to a certain extent of situations observed in interspecies hybrids with a disturbed development cycle. However, the morphological structure of the unit in question does not provide sufficient ground to refer it to that category of plants. It is in line with the description of the species *S. marina*, and the species most closely related to it, *S. media* (L.) C. Presl, which does not occur in Poland (Piotrowska 1993). According to Sterk and Dijkhuizen (1972), *S. marina* is autogamous but outbreeding may occur.

In my opinion, the presence of anomalous seeds in the *S. marina* populations under study is due to a change in the plants' metabolism caused by life in extreme environmental conditions developed under the impact of soda industry. Evidence of this is both the character of the anomalies and their occurrence close to the sources of contamination. The most notable are the irregular outgrowths which pierce the coats of the most transformed seeds, since some of them have chimney-like apertures, which most probably are associated with change in the plant's metabolism.

The intensity of the impact of contamination of the environment often varies depending on weather conditions; that is why it is not surprising that the fruits set successively from early spring till late autumn on the same plant often vary considerably with respect to the proportion of normal and anomalous seeds. This phenomenon is associated with the fact that the seeds of the species under study show a wide range of variation in the length of time of their dormancy (Unger 1984), as well as with the polymorphism of the seeds, even inside one capsule. A particularly noteworthy phenomenon observed in the capsules of *S. marina* is the inhibition of development and falling off of some seeds, usually the upper and at the same time the smallest ones. That creates better conditions for further development of the remaining seeds. The seeds termed here anomalous are different from the underdeveloped ones which fall off before the fruit matures. Sometimes in one capsule there are both those kinds of seeds, and both unable to germinate. In populations containing anomalous seeds the total number of fully grown seeds (including the anomalous ones) is sometimes larger than the number of the remaining ones, which points to a lower reduc-

Fig. 4. Anomalous *Spergularia marina* (L.) Griseb. seed from Kujawy.

a, b – unwinged seed

c, d – outgrowth with chimney-like aperture

tion and therefore inferior conditions for development of seeds in the capsules of those populations.

The production of anomalous seeds has already been reflected to a certain extent in the structure of *S. marina* popu-

lations in the industrial habitats of Kujawy; they are not so variable as those in many meadow stands. Unlike the meadow populations, they form communities of low or medium density, consisting of medium ramified plants. The dependence of

Fig. 5. *Spergularia marina* (L.) Griseb. seeds from Kujawy.

a – normal, unwinged seed

b – anomalous, unwinged seed.

Fig. 6. Anomalous, winged *Spergularia marina* (L.) Griseb. seed from Kujawy.

the populations on the production of seeds capable and incapable of germination is suggested indirectly by the results of studies on the dynamics of the *S. marina* populations in the meadows of the Baltic coast (Terstensson 1987b).

The main source of contamination affecting *S. marina* plants in Kujawy is the waste stored in vast overground basins called "white seas" (Wilkoń-Michalska, Sokół 1969). They contain among others the following compounds: NaCl,

Fig. 7. Distribution of *Spergularia marina* (L.) Griseb. stands in Kujawy (Approximate percentage of anomalous seeds has been represented by shading the circle).

CaCl_2 , CaCO_3 , NaOH , Na_2CO_3 , BaSO_4 , CaO and small amounts of $\text{Ca}(\text{OH})_2$ and CaSO_4 . Particularly harmful for plants are the strongly dissociated compounds CaCl_2 and NaCl , which permeate with water from the waste basing into the soil of the adjoining areas and cause great changes there. One of the effects of those changes is the appearance in the soil of the CO_3^{--} ion, which is even more toxic to plants than Cl^- , and excess of SO_4^{--} ion (Czerwiński, Pracz 1986). The present studies do not provide sufficient ground to formulate allegations concerning the direct cause of the anomalies under study. It is suggested that this is a coincidence of a number of chemical and physical factors.

ACKNOWLEDGEMENT

Work supported by grant KBN nr 604049101

LITERATURE CITED

- CEYNOWA-GIEŁDON M., 1993. The variability of seeds in *Spergularia marina* (L.) Griseb. (= *S. salina* J. et C. Presl) growing on seacoast and inland saline soils in Poland. Acta Soc. Bot. Pol. 62, 3-4: 185-191.
- CZERWIŃSKI Z., PRACZ J., 1986. Wpływ stawów odpadowych na tereny rolnicze w rejonie Janikowskich Zakładów Sodowych – maszynopis. Katedra Gleboznawstwa SGGW-AR. Warszawa.
- KOWAL T., 1966. Studia systematyczne nad nasionami rodzaju *Delia* Dum., *Spergula* L. i *Spergularia* Presl. Monogr. Bot. 21: 245-270.
- PIOTROWSKA H., 1993. *Ex Spergularia media* (L.) C. Presl [*S. marginata* (DC.) Kittel] muchotrzew trwały. In: Polish Plant Red Data Book. W. Szafer Institute of Botany Polish Academy of Sciences. Kraków pp. 55-56.
- STERK A.A., 1969. Biosystematic studies of *Spergularia media* and *S. marina* in the Netherlands II. The morphological variation on *S. marina*. Acta Bot. Neerl. 18: 467-476.
- STERK A.A., DIJKHUIZEN L., 1972. The relation between the genetic determination and the ecological significance of the seed wing in *Spergularia media* and *S. marina*. Acta Bot. Neerl. 21 (5): 481-490.
- TORSTENSSON P., 1987a. The demography of the annual halophyte *Spergularia marina* on a Baltic seashore meadow. Vegetatio. 68: 157-168.
- TORSTENSSON P., 1987b. Population dynamics of the annual halophyte *Spergularia marina* on a Baltic seashore meadow. Vegetatio. 68: 169-172.
- UNGAR I.A., 1984. Alleviation of seed dormancy in *Spergularia marina*. Bot. Gaz. 145(1): 33-36.
- UNGAR I.A., 1982. Germination ecology of halophytes. In: D. N. Sen and K. S. Rajpurohit [eds.], Tasks for vegetation science. Dr. W. Junk Publishers, The Hague. Vol. 2. pp. 143-154.
- WILKOŃ-MICHALSKA J., 1963. Halofity Kujaw (The halophytes from Kujawy). Studia Soc. Torunensis. Sec. D. 7.1: 1-222.
- WILKOŃ-MICHALSKA J., SOKÓŁ M., 1968. Flora zwałów wapiennych Inowrocławskich i Janikowskich Zakładów Sodowych. Zesz. Nauk. UMK w Toruniu. Biologia 11: 173-208.

ANOMALIE W BUDOWIE NASION *SPERGULARIA MARINA* (L.) GRISEB. (= *S. SALINA* J. ET C. PRESL) NA OBSZARZE ODDZIAŁYWANIA PRZEMYSŁU SODOWEGO NA KUJAWACH (POLSKA ŚRODKOWA)

STRESZCZENIE

W pracy przedstawiono nienormalne nasiona *Spergularia marina* z siedlisk silnie skażonych przez przemysł sodowy w Janikowie i Mątwach koło Inowrocławia. Nasiona te są w zarysie pozornie normalne, lecz wewnątrz ich brak dobrze wykształconego zarodka. Na miejscu liścieni znajdują się puste komory a na powierzchni łupiny nasiennej wielu z nich widoczne są małe, nieregularne wyrostki, przebijające łupinę od wewnątrz. Niektóre z wyrostków są rurkowate, zaopatrzone w kominowate otwory, które wiążą się najprawdopodobniej ze zmianą metabolizmu roślin pod wpływem rozwoju w warunkach silnego skażenia środowiska. Najwięcej, bo około 99% nasion nienormalnych, niezdolnych do kiełkowania, stwierdzono w próbach *S. marina* ze stanowisk położonych najbliżej hałd odpadów. Dalej, w miarę oddalania się od źródeł skażenia obserwowano na ogół stopniowe zmniejszanie się omawianych anomalii aż do ich całkowitego zaniku. W okresach wilgotnych na tych samych stanowiskach było jednak niemal o połowę nasion nienormalnych mniej niż w latach suchych i ciepłych.

SŁOWA KLUCZOWE: *Spergularia marina*, halofity, nasiona, anomalie, flora, skażenie.