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## Assessment of microsite diversity of the coastal variety of Scots pine forests: the sink and source theory applied to epigeic staphylinids (*Coleoptera*: *Staphylinidae*) at the populational and community level[1]

**Abstract:** This methodology-oriented paper proposes a number of new zooindicative indices assessing microsite diversity based on the modified Pulliam theory. The original theory has been modified so that the "source & sink" concept could be used for the purposes of zooindication. In the present paper, the following indices are tested on data regarding populations and communities of invertebrates of the coastal variety of Scots pine forest: the share of sources ($U_C$), sinks ($U_P$) and standard ($U_S$) in the area occupied by the community, an index of microsite preferences of a species ($c_s$) and an index of utilization of site heterogeneity by a given species ($C_s'$). Microsite diversity was also assessed using data regarding the coastal pine forest of Mierzeja Łebska Sand Bar.

**Key words:** zooindication, microsites, heterogeneity, communities, populations, *Staphylinidae*, *Empetro-nigri Pinetum* – coastal pine forest

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### INTRODUCTION

The site is part of the environment and it is a complex of abiotic factors. A site consists of a set of climatic and edaphic (soil-related) conditions of a given biotope. Any site may be described in terms of climatic and soil conditions in a given geographic locality. Owing to the long lasting influence of the biocoenosis, a site represents a more or less differentiated mosaic of microsites. The degree of heterogeneity within a site indirectly reflects the level of complexity and stability of the forest ecosystem, as strong site heterogeneity results in a marked complexity of the biocenosis, which in turn leads to high ecosystem stability.

Zooindication based on invertebrates and utilizing the modified source and sink theory of Pulliam is a method of assessment of microsite diversity in forest ecosystems that merits special attention. Pulliam's theory, which operates at the population level of organization, states that a well developed metapopulation source-sink network is indispensable for the durability of population-based systems (DIAS 1996; HOLT 1985; HOLT et GAINES 1992; PULLIAM 1988; PULLIAM & DANIELSON 1991). For this theory to be applicable to invertebrates, two modifications need to be introduced:

- in analyses of community structure, the source and sink theory needs to be applied at the level of communities rather than single populations;
- the indicator used for identification of communities is the richness of distinctive populations rather than the reproduction of individual populations.

Consequently, the following interpretation of the site space of populations and communities of invertebrates has been accepted in the source-sink system:

The source-sink network established for a given community should be related to the counterpart metapopulation networks of characteristic selective species. In other words, the existence of a given community depends on the maintenance of all distinctive species constituting the community.

Each community exists within a biotope in which three elements may be identified: the *sources*, the *standard* and the *sinks*.

In the context of invertebrates, the above terms may be defined as follows:

• Source for a population – the development center of populations belonging to the extended reproduction type. It is a rather diversified environment formed along a gradient of moisture, temperature or fertility, within the range of one standard deviation from the optimum value. It is the center of initiation as well as maintenance of the stability of the population. It occupies the optimal areas for the development of the population. Destruction of the centers results in decay of the population.

• Source for a community – the theoretical center of initiation and maintenance of community stability. It corresponds to the centers of the characteristic exclusive populations for the community. Once the sources have been destroyed, the community undergoes a transformation.

• Sink for a population – a marginal range of occurrence of populations characterized by the diminished reproduction type. A population can only be maintained under unfavorable environmental conditions in a sink area thanks to intensive immigration. These are the border zones of the space of occurrence of a population.

• Sink for a community – the theoretical margin of occurrence of a community, corresponding to the external or internal ecotones of an ecosystem. Assuming that a forest biocenosis is the basic unit of reference, open microsites contiguous with other ecosystems will represent another margin, apart from the external ecotones. Such sites, too small to develop their own stabile biocenoses, will function as marginal environments for that forest biocenosis.

• Standard for a community – a potential area of stable occurrence of the community that is neither its source nor sink.

Following the above assumptions, two complementary methods for zooindication of microsite differentiation in forested ecosystems have been developed based on:

- Communities (synecological zooindication);
- Populations (autoecological zooindication).

Synecological zooindication makes it possible to:

• determine the share of extreme microsites (source and sink habitats of invertebrate communities);

• determine whether a microsite is an extreme one.

Autoecological zooindication, in turn, makes it possible to:

• identify those microsites preferred by the distinctive species for the ecosystem under study;

• assess utilization of site heterogeneity by the distinctive species.

## THE COLLECTION OF FAUNISTIC MATERIAL

The results below presented are based on a sample of staphylinids collected into 200 Barber's traps installed in the coastal pine forest of the Mierzeja Łebska Sand Bar within the Słowiński National Park. The empirical data were collected over two years: from July 1996 till July 1998. The study covered a total of 40 microsites occurring in deflation depressions (*pA; pB; pD; pE*) and in one embankment dune (*pC*) (SMOLEŃSKI 2001b: 273, Fig. 2). These represent all the subassociations of the coastal pine forest type – the arid, the moderately humid and the humid one. A total of 4436 beetles belonging to 117 species of the family *Staphylinidae* were captured. A detailed methodological description may be found in an earlier paper by the present author (SMOLEŃSKI 2001b).

## RESULTS

### The source and sink theory as applied to invertebrate communities

Accepting that a strong heterogeneity of an environment with its source and sink network ensures the stability of a community, we should consider the problem of working out a measurable form of assessment of the share of extreme systems, that is, the sources and the sinks of the community. What we are looking for is an answer to the question how many microsites occupied by the community is the standard, typical of the simple reproduction type, and how many of them belong to the extremes, representing either the extended or diminished type of reproduction?

There is an earlier accepted index that may serve as a formal tool capable of providing an answer (SMOLEŃSKI 2001a): the Margalef [*d*] index, supplied with additional information on the actual share of exclusive characteristic (=distinctive) species, may be a reliable measure of the occurrence of sources and sinks. This way one may obtain **the coefficient of the distinctive species' share in the community's species richness**:

$$df = \sqrt{dF_3} \quad \text{(formula 1), where:}$$

$F_3$ – Per cent share of distinctive species (SZUJECKI 1983) in the dominance structure of the community (compare SMOLEŃSKI 2001a),

$d$ – actual value of the Margalef index of species richness for the entire community:

$$d = \frac{S-1}{\log N}$$ (formula 2), where:

$S$ –number of species in the community,
$N$ – total number of individuals.

It is reasonable to assume that the standard – representing the average system – should be maintained within the standard deviation of the *df* coefficient, and that both its sources and sinks are out of its reach. The sources are associated with some overproduction, with the surplus then relocated to the area of the standard and, above all, the sinks. If this assumption is accepted, then for a system to be stable there must be more sources than sinks, to make up for the loss. The approximative relationship between the sources and sinks may be estimated under the assumption that sources have the highest values of the *df* coefficient, while sinks are characterized by the lowest values of this parameter.

If so, the site occupied by a community may be generally described as follows:

• The standard of community occurrence – the microsite of average presence of a community, within a single standard deviation from the value of the coefficient *df* of the share of distinctive species in the community's species richness;

• The source of community occurrence – the microsite with the highest share of distinctive species in the community species richness (as expressed by the coefficient *df*) , the difference being greater than one standard deviation from the *df* value;

• The sink of a community occurrence – the microsite with the lowest share of distinctive species in the community species richness, the difference being greater than one standard deviation from the *df* value.

Following the above description, three new indices are proposed:

**The share of the sources within the area occupied by the community**:

$$U_C = 100\frac{r'}{R}\,[\%]$$ (formula 3), where:

$r' = 1,...,R$, and $r'$ – number of *j*th samples (microsites) fulfilling the condition: $df_j > (df' + \sigma)$; $R$ – total number of samples,

$df_j$ – actual value of the coefficient of the share of distinctive species in the community's species richness for the *j*-th sample (cf. formula 1),

$df'$ – expected value of the coefficient of the share of distinctive species in the community's species richness (cf. formula 1) expressed as arithmetical (or weighted) average based on all samples,

$\sigma$ – standard deviation of the coefficient of the share of distinctive species in the community's species richness (*df*).

**The share of the sinks within the area occupied by the community**:

$$U_P = 100n\frac{r''}{R}\,[\%]$$ (formula 4), where:

$r'' = 1,...,R$, and $r''$ – number of *jth* samples (microsites) fulfilling the condition: $df_j < (df' - \sigma)$.

For other symbols see above.

**The share of the standard within the area occupied by the community:**

$U_S = 100 - (U_C+U_P)$ [%] (formula 5), where:

$U_C$ – the share of the sources within the area occupied by the community (formula 3),
$U_P$ – the share of the sinks within the area occupied by the community (formula 4).

Using empirical data from an earlier paper by the present author (SMOLEŃSKI 2001b), the following results are obtained for the coastal pine forest staphylinid communities occupying a total of five research plots (dune embankment *pC* and deflation basins *pA, pB, pD, pE*): given the arithmetic average $df'$=18.76 and standard deviation $\sigma$ =5.08, the expected *df* values for the epigeic staphylinid communities of the coastal pine forest are within the range 13.68÷23.84.

Thus, of the total of 40 samples, the following were outside the standard deviation:

- 8 samples above $df'+\sigma$,
- 7 samples below $df'-\sigma$.

Consequently, the respective shares of the standards, sources and sinks within the area occupied by the coastal pine forest staphylinid communities are:

$U_S = 62.5\%$, $U_C = 20.0\%$, $U_P = 17.5\%$;

The method proposed in this paper enables estimation of the actual share of extreme microsites (sources and sinks) within the area occupied by a community of invertebrates. It also makes it possible to pinpoint those samples which resemble extreme microsites by virtue of their characteristics (Table 1). The method, however, cannot establish with absolute certainty whether a given sample represents the source or the sink for the community.

Table 1. Natural parameters of the hypothetical sources and sinks of epigeic staphylinid (*Coleoptera*: *Staphylinidae*) communities in coastal pine forests: *pA, pB, pC, pD, pE* – research plots; 1, 2, ..., 10 – sample number, *ms* – microsite types characteristic of a given distinctive species (species characteristic of and exclusive for subassociations of the Scots pine forest): *ms* 1 – the extremely arid type, *ms* 2 – the arid type, *ms* 3 – the moderately humid type, *ms* 4 – the humid type. Data from SMOLEŃSKI 2001b.

| Sample number | Location | Subassociation of the coastal pine forest | Forest stand | Herbaceous vegetation | Microsite type |
|---|---|---|---|---|---|
| Sources of community occurrence | | | | | |
| *pA* 4 | Arid patch in central part of depression, occurrence source for: *Platydracus stercorarius* | Arid heather – heath | Fully open area | Poor shrubby | *ms 1* extremely arid |
| *pA* 5 | Arid patch in central part of depression, occurrence source for: *Othius myrmecophilus* and *Zyras laticollis* | Typical – initial stage | Pine, 40 yrs old, 4 m high, loose crown closure | Poor mossy – grassy | *ms 2* arid |
| *pA* 6 | Humid basin in central part of depression, occurrence source for: *Quedius molochinus* and *Zyras cognatus* | Humid – initial stage | Pine, 40 yrs old, 4 m high, moderate crown closure | Rich mossy – shrubby | *ms 4* humid |
| *pA* 7 | Patch in central part of depression, occurrence source for: *Lamprinodes saginatus* | Typical | Pine, 60 yrs old, 6 m high, loose crown closure | Poor mossy – shrubby | *ms 2* arid |

| | | | | | |
|---|---|---|---|---|---|
| *pD* 6 | Elevated belt in central part of depression, occurrence source for: *Stenus impressus* | Typical | Pine, 45 yrs old, 9 m high, moderate crown closure | Mossy – shrubby | *ms* 3 moderately humid |
| *pD* 7 | Humid basin in central part of depression, occurrence source for: *Boli-tobius formosus* and *Othius myrmecophilus* | Humid | Pine, 45 yrs old, 9 m high, loose crown closure | Rich mossy – shrubby | *ms* 4 humid |
| *pD* 8 | Elevated belt in southern part of depression, occurrence source for: *Mycetoporus rufescens, Oxypoda procerula, Sepedophilus marshami* and *Stenus clavicornis* | Typical | Pine, 45 yrs old, 9 m high, moderate crown closure | Mossy – shrubby | *ms* 3 moderately humid |
| *pD*10 | Humid basin at northern foothill of mild slope of grey dune at the southern edge of depression, occurrence source for: *Lathrobium brunnipes, Mycetoporus clavicornis, M. rufescens* and *Rugilus rufipes* | Humid | Pine, 45 yrs old, 9 m high, loose crown closure | Rich mossy – shrubby | *ms* 4 humid |
| Sinks of community occurrence | | | | | |
| *pB* 2 | Basin at southern foothill of white dune in northern part of depression, occurrence source for: *Proteinus brachypterus* and *Staphylinus erythropterus* | Typical | Pine, 140 yrs old, 15 m high, loose crown closure | Rich mossy – shrubby | *ms* 3 moderately humid |
| *pB* 3 | Basin at southern foothill of white dune in northern part of depression, occurrence source for: *Staphylinus erythropterus* | Typical | Pine, 80 yrs old, 10 m high, loose crown closure | Rich mossy – shrubby | *ms* 3 moderately humid |
| *pB* 9 | Basin at northern foothill of dune embankment in southern part of depression, occurrence source for: *Acidota crenata* | Typical | Pine, 80 yrs old, 10 m high, loose crown closure | Rich mossy – shrubby | *ms* 3 moderately humid |
| *pC* 4 | Southern ridge of double dune embankment, occurrence source for: *Othius punctulatus* and *Xantholinus tricolor* | Arid | Pine, 100 yrs old, 14 m high, loose crown closure | Poor mossy – grassy | *ms* 2 arid |
| *pE* 2 | Elevated belt at southern foothill of white embankment dune, in northern part of depression, occurrence source for: *Drusilla canaliculata* | Typical with elements of *Leucobryo – Pinetum* | Pine, 130 yrs old, 20 m high, loose crown closure | Rich mossy – shrubby | *ms* 3 moderately humid |
| *pE* 3 | Elevated belt in northern part of depression, occurrence source for: *Othius myrmecophilus* | Typical with elements of *Leucobryo – Pinetum* | Pine, 130 yrs old, 20 m high, loose crown closure | Rich mossy – shrubby | *ms* 3 moderately humid |
| *pE* 4 | Basin in northern part of depression, occurrence source for: *Platydracus fulvipes* | Typical with elements of *Leucobryo – Pinetum* | Pine, 130 yrs old, 20 m high, loose crown closure | Rich mossy – shrubby | *ms* 3 moderately humid |

**The source and sink theory as applied to invertebrate populations**

A comprehensive assessment of microsite differentiation based on autoecological zooindication must begin by determining the microsite preferences of the exclusive characteristic species of the ecosystem.

To achieve this, the extreme microsites for particular species have to be identified using the following three characteristics (SMOLEŃSKI 2001a):

- species abundance (number of individuals);
- share of the species in the community's dominance structure;
- the maximum share of the species in the dominance structure of the community.

Analyses of microsite preferences are feasible only for species occurring frequently and with considerable constancy at their site. When the sample consists of individuals captured into Barber's pitfall traps, analyses may only concern epigeic species, due to their high trapability.

By combining these three characteristics (abundance, maximum dominance and actual dominance of a species), it is possible to quantify data on a species' preferences with regard to microsites, using **the index of a species' microsite preferences**:

$$c_s = \frac{I_{fd}}{I_{fd}(\max)} \quad \text{(formula 6), where:}$$

$I_{fd} = \sqrt{\frac{n_j^2}{N_j}}$ – the coefficient of dominance of a species in *j*-th sample (microsite),

$I_{fd}(max)$ – the highest recorded value of the coefficient of dominance of the species in all samples (*R*),

$n_j$ – number of individuals of the species in the *j*-th sample,

$N_j$ – total number of individuals in the *j*-th sample.

Values of the index $c_s$ of species microsite preferences may range from 0 to 1. Application of the standard normal distribution yields the following conclusions:

- when $c_s > 0.85$, the population occupies the source region;
- when $0.85 \geq c_s \geq 0.15$ the population occupies the standard region;
- when $c_s < 0.15$ the population occupies the sink area of its range.

The zooindication procedure presented above may be illustrated using empirical data collected earlier by the author (SMOLEŃSKI 2001b) and concerned with epigeic staphylinid communities of the coastal pine forest. When data from the five experimental plots (the dune embankment *pC* and deflation basins *pA, pB, pD, pE*) are used in formula 6, the following results are obtained:

It was possible to determine the preferred microsites of 36 abundant species of epigeic staphylinids (Table 2). 72.5% of their site range belongs to the sources.

15 species were classified as characteristic of the coniferous forest with well-defined microsite preferences (Table 2). 37.5% of their site space was identified as sources.

Table 2. Occurrence sources for 36 most frequently occurring species; microsite types: *ms* 1 – the extremely arid type, *ms 2* – the arid type, *ms 3* – the moderately humid type, *ms 4* – the humid type. The data were drawn from an earlier paper by the present author (SMOLEŃSKI 2001b)

| No. | Species | Research plots | | | | |
|---|---|---|---|---|---|---|
| | | *pA* | *pB* | *pC* | *pD* | *pE* |
| | | Sample number / Microsite type | | | | |
| 1 | *Acidota crenata* | | 9 / *ms* 3 | | | |
| 2 | *Anthobium athrocephalum* | 1 / *ms* 3 | | 3 / *ms* 3 | | |
| 3 | *Bolitobius formosus* | | | | 1 / *ms* 2<br>7 / *ms* 4<br>9 / *ms* 4 | |
| 4 | *Drusilla canaliculata* | | | | | 2 / *ms* 3 |
| 5 | *Evanystes circellaris* | | | 5 / *ms* 1 | | |
| 6 | *Gabrius pennatus* | 3 / *ms* 4 | | | | |
| 7 | *Lamprinodes saginatus* | 7 / *ms* 2 | | | | |
| 8 | *Lathrobium brunnipes* | | | | 9 / *ms* 4<br>10 / *ms* 4 | |
| 9 | *Mycetoporus baudueri* | 9 / *ms* 2 | | | | |
| 10 | *M. brunneus* | 2 / *ms* 3<br>9 / *ms* 2 | | | | |
| 11 | *M. clavicornis* | | | | 10 / *ms* 4 | |
| 12 | *M. rufescens* | | | | 8 / *ms* 3<br>10 / *ms* 4 | |
| 13 | *M. splendidus* | 2 / *ms* 3 | | | | |
| 14 | *Ocypus copressus* | | | 2 / *ms* 2 | | |
| 15 | *Olophrum piceum* | | | | 2 / *ms* 4 | |
| 16 | *Othius myrmecophilus* | 5 / *ms* 2 | 8 / *ms* 4 | | 7 / *ms* 4 | 3 / *ms* 3 |
| 17 | *O. punctulatus* | | | 4 / *ms* 2 | | |
| 18 | *Oxypoda procerula* | | | | 8 / *ms* 3 | |
| 19 | *Platydracus fulvipes* | | | | | 4 / *ms* 3 |
| 20 | *P. stercorarius* | 4 / *ms* 1 | | | | |
| 21 | *Proteinus brachypterus* | | 2 / *ms* 3 | | | |
| 22 | *Quedius molochinus* | 6 / *ms* 4 | | | | |
| 23 | *Rugilus rufipes* | | | | 10 / *ms* 4 | |
| 24 | *Sepedophilus immaculatus* | | 8 / *ms* 4 | | | |
| 25 | *S. marshami* | | | | 8 / *ms* 3 | |
| 26 | *Staphylinus erythropterus* | 2 / *ms* 3 | 2 / *ms* 3<br>3 / *ms* 3<br>4 / *ms* 3 | | | 5 / *ms* 4 |
| 27 | *Stenus clavicornis* | | | | 8 / *ms* 3 | |
| 28 | *S. impressus* | | | | 6 / *ms* 3 | |
| 29 | *Tachyporus corpulentus* | | | | 5 / *ms* 2 | |
| 30 | *T. transversalis* | 3 / *ms* 4 | | | | |
| 31 | *Xantholinus linearis* | | | | 5 / *ms* 2 | |
| 32 | *X. longiventris* | | | 5 / *ms* 1 | | |
| 33 | *X. tricolor* | | | 4 / *ms* 2 | | |
| 34 | *Zoosetha procidua* | | | 5 / *ms* 1 | | |
| 35 | *Zyras cognatus* | 6 / *ms* 4 | | | | |
| 36 | *Z. laticollis* | 5 / *ms* 2 | | | | |

The sources of the species may be described using the zooindication method (Table 3):

- *Evanystes circellaris, Lamprinodes saginatus, Tachyporus corpulentus* and *Zoosetha procidua* prefer arid or extremely arid microsites (sample 7 in deflation basin *pA*, sample 5 in the dune embankment *pC* and sample 5 in the basin *pD*);

- *Mycetoporus baudueri* and *Platydracus stercorarius* prefer arid type sites (samples 4 and 9 in deflation basin *pA*);

- *Bolitobius formosus, Lathrobium brunnipes, Mycetoporus clavicornis, Mycetoporus rufescens, Othius myrmecophilus, Sepedophilus immaculatus* and *Sepedophilus marshami* prefer moderately humid microsites (sample 5 in basin *pA*, sample 8 in basin *pB*, and samples 1, 7, 8, 9 and 10 in basin pD, as well as sample 3 in basin *pE*);

- *Quedius molochinus* and *Tachyporus transversalis* prefer humid microsites (samples 3 and 6 in the basin *pA*).

Table 3. Valuation of coastal pine forest microsites as sources for epigeic staphylinids (*Coleoptera: Staphylinidae*) using the zooindication method. Data from an earlier paper by the present author (SMOLEŃSKI 2001b)

| No. of sample | Location | Subassociation of the coastal pine forest | Forest stand | Herbaceous vegetation | Microsite type |
|---|---|---|---|---|---|
| Extremely arid microsites – sources for epigeic staphylinids | | | | | |
| *pA* 7 | Patch in central part of depression, | Typical | Pine, 60 yrs old, 6 m high, loose crown closure | Poor mossy – shrubby | *ms* 2 arid |
| *pC* 5 | Southern slope of double embankment dune | Gray dune | Open area partly shadowed from the south | Poor Psammophilous vegetation | *ms* 2 extremely arid |
| *pD* 5 | Elevated belt in central part of depression | Typical | Pine, 80 yrs old, 12 m high, loose crown closure | Poor mossy– shrubby | *ms* 2 arid |
| Arid microsites – sources for epigeic staphylinids | | | | | |
| *pA* 4 | Arid patch in central part of depression | Arid heather – heath | Fully open area | Poor shrubby | *ms* 1 extremely arid |
| *pA* 9 | Foothill of northern slope of embankment dune at the southern edge of depression | Arid | Pine, 60 yrs old, 6 m high, moderate crown closure | Poor mossy– shrubby | *ms* 2 arid |
| Moderately humid microsites – sources for epigeic staphylinids | | | | | |
| *pA* 5 | Arid patch in central part of depression | Typical – initial stage | Pine, 40 yrs old, 4 m high, loose crown closure | Poor mossy – grassy | *ms* 2 arid |
| *pB* 8 | Humid basin in southern part of depression | Humid | Pine, 80 yrs old, 10 m high, loose crown closure | Rich mossy– shrubby | *ms* 4 humid |
| *pD* 1 | Foothill of southern slope of double embankment dune, edge of coastal pine forest at northern edge of depression | Arid | Pine, 40 yrs old, 8 m high, moderate crown closure | Poor grassy– shrubby | *ms* 2 arid |
| *pD* 7 | Humid basin in central part of depression | Humid | Pine, 45 yrs old, 9 m high, loose crown closure | Rich mossy – shrubby | *ms* 4 humid |
| *pD* 8 | Elevated belt in southern part of depression | Typical | Pine, 45 yrs old, 9 m high, moderate crown closure | Mossy – shrubby | *ms* 3 modeately humid |

| | | | | | |
|---|---|---|---|---|---|
| *pD* 9 | Humid basin at northern foothill of gray dune, southern part of depression | Humid | Pine, 45 yrs old, 9 m high, moderate crown closure | Rich mossy–shrubby | *ms* 4 humid |
| *pD*10 | Humid basin at northern foothill of mild slope of grey dune at the southern edge of depression | Humid | Pine, 45 yrs old, 9 m high, loose crown closure | Rich mossy – shrubby | *ms* 4 humid |
| *pE* 3 | Elevated belt in northern part of depression | Typical with elements of *Leucobryo – Pinetum* | Pine, 130 yrs old, 20 m high, loose crown closure | Rich mossy – shrubby | *ms* 3 moder-ate–ly humid |
| Humid microsites – sources for epigeic staphylinids | | | | | |
| *pA* 3 | Humid basin in northern part of depression | Humid heather–heath | Fully open area | Rich mossy | *ms* 4 humid |
| *pA* 6 | Humid basin in central part of depression | Humid – initial stage | Pine, 40 yrs old, 4 m high, moderate crown closure | Rich mossy – shrubby | *ms* 4 humid |

The next step in the autecological zooindication procedure assessing microsite differentiation is:

Estimation of the degree of utilization of the system of actual site differentiation by individual species, using **the index of site heterogeneity utilization by a species**:

$$C_s' = \frac{2\sum_{j=1}^{R} c_{sj}}{R} \qquad \text{(formula 7), where:}$$

$c_{sj}$ – index of a species' microsite preferences in the *j*-th sample (microsite) (formula 6),
*R* – number of samples (microsites).

This index provides a quantitative measure of the degree of saturation of the site with the population of a given species (SMOLEŃSKI 2001a). If the range of a stable population extends over a mosaic of microsites, the microsites valuated as sinks by a given species must at least be offset by those valuated as sources. Given the above assumption, the model stable population is characterized by a normal distribution curve of microsite preferences over the whole of its coenosis, so that the value of the $C_s'$ index is 1.

When $C_s'>1$, the microsite mosaic is more-than-average favourable for the population. The sources of the population prevail within the site.

If $1\geq C_s'\geq 0.3$ the degree of preference of the population towards the microsite mosaic should be regarded as more or less average. The sources are balanced by the sinks.

When $C_s'<0.3$, the population obviously does not prefer the site mosaic available. The sinks of the population prevail within the site.

Using data regarding the epigeic staphylinid communities of the coastal pine forest, the following results (Table 4) were obtained after the empirical data were applied to formula 7; the data originally came from five research plots: a dune embankment *pC* and four deflation basins *pA, pB, pD, pE,* (SMOLEŃSKI 2001b):

1. Out of a total of 117 species caught into Barber's traps, only 20 species reached the average value range of the index of site heterogeneity utilization ($0.3 \leq C_s' \leq 1$); none of them reached the above-average level ($C_s' > 1$) – see also last column of Table 4.

2. 7 species, belonged to the group of distinctive (=exclusive characteristic) species, 9 belonged to the group of preferencial characteristic species and only 4 were classified as eurytopic species (according the fidelity class of species given by SZUJECKI 1983). These date suggest a rather high degree of uniqueness of the coastal pine forest.

3. The highest index values were recorded for three euzoophagous species: *Othius myrmecophilus, Bolitobius formosus* (distinctive species) and *Staphylinus erythropterus,* and one parazoophagous species *Acidota crenata* (preferencial characteristic species).

4. The index of site heterogeneity utilization was higher than 1 in the deflation basin *pD* for *Othius myrmecophilus* and *Xantholinus linearis* and in the deflation basin *pE* for *Drusilla canaliculata, Othius myrmecophilus* and *Platydracus fulvipes*. These results suggest that the sites mentioned above favour the listed species.

5. The largest number of species with at least average values of the $C_s'$ index occurred in *pA* basin (19 species), the number being smallest in *pE* (10 species).

6. Only *Acidota crenata* reached at least average values of the index of site heterogeneity utilization in all research plots.

7. *Anthobium atrocephalum, Bolitobius formosus, Othius myrmecophilus, Staphylinus erythropterus* and *Xantholinus longiventris* unfavourably valuated only one plot each.

8. *Drusilla canaliculata, Lamprinodes saginatus, Mycetoporus rufescens, Mycetoporus splendidus, Olophrum piceum, Sepedophilus marshami, Xantholinus linearis* and *Xantholinus tricolor* – these species unfavourably valuated two plots each.

9. *Mycetoporus brunneus, Mycetoporus clavicornis, Oxypoda procerula, Stenus clavicornis, Stenus impressus, Tachyporus corpulentus* unfavourably valuated three plots each.

10. The microsite which was unfavourably valuated most frequently was deflation basin *p,* which had a transitory character of the basin, situated between *Empetro nigri-Pinetum, Leucobryo-Pinetum* and *Betuletum pubescentis*. The deflation basin *pD* was unfavourably valuated the least frequently. The above results may be interpreted as revealing the least favourable and the most favourable sites for the populations of coniferous characteristic species, respectively.

The method also enables assessment and identification of the plot which was most efficiently utilized by particular populations. As an example (Table 4):

- For *Tachyporus transversalis,* an exclusive characteristic species (hemizoophage, preferring microsites of the humid type) the most advantageous conditions were found in the deflation basin *pA*.
- For *Zoosetha procidua,* an exclusive characteristic species (hemizoophage, preferring microsites of the arid type) the most advantageous conditions were found in the southern slopes of the dune embankment *pC*.
- For *Tachyporus corpulentus,* an exclusive characteristic species (hemizoophage, preferring microsites of the arid type) the most advantageous conditions were found in the deflation basin *pD,* and then in the *pA* basin.

Table 4. The index C' of site heterogeneity utilization for 36 most frequent staphylinid species (*Coleoptera: Staphylinidae*); *pA, pB, pC, pD, pE* –research plots, *ms* – microsite types characteristic of a given distinctive species of the Scots pine forest type: *ms* 1 – the extremely arid type, *ms* 2 – the arid type, *ms* 3 – the moderately humid type, *ms* 4 – the humid type. The data were drawn from SMOLEŃSKI (2001b.)

| No. | Species | *ms* | *pA* | *pB* | *pC* | *pD* | *pE* | Total |
|---|---|---|---|---|---|---|---|---|
| 1 | *Acidota crenata* | – | 0.58 | 0.76 | 0.44 | 0.70 | 0.50 | 0.62 |
| 2 | *Anthobium athrocephalum* | – | 0.46 | 0.40 | 0.34 | 0.50 | 0 | 0.38 |
| 3 | *Bolitobius formosus* | *ms* 3 | 0.86 | 0.48 | 0.94 | 0.96 | 0.28 | 0.72 |
| 4 | *Drusilla canaliculata* | – | 0.12 | 0.32 | 0.13 | 0.36 | 1.04 | 0.34 |
| 5 | *Evanystes circellaris* | *ms* 2 | 0.24 | 0.20 | 0.86 | 0.20 | 0.12 | 0.28 |
| 6 | *Gabrius pennatus* | – | 0.24 | 0 | 0 | 0 | 0 | 0.06 |
| 7 | *Lamprinodes saginatus* | *ms* 1 | 0.32 | 0.16 | 0.14 | 0.44 | 0.30 | 0.30 |
| 8 | *Lathrobium brunnipes* | *ms* 3 | 0.34 | 0.06 | 0 | 0.70 | 0 | 0.28 |
| 9 | *Mycetoporus baudueri* | *ms* 3 | 0.42 | 0.04 | 0.56 | 0.10 | 0 | 0.20 |
| 10 | *M. brunneus* | *ms* 3 | 0.86 | 0.14 | 0.54 | 0.22 | 0.08 | 0.38 |
| 11 | *M. clavicornis* | *ms* 3 | 0.68 | 0.14 | 0.10 | 0.70 | 0.14 | 0.40 |
| 12 | *M. rufescens* | – | 0.28 | 0.34 | 0.22 | 0.92 | 0.36 | 0.46 |
| 13 | *M. splendidus* | – | 0.72 | 0.34 | 0.38 | 0.12 | 0.06 | 0.34 |
| 14 | *Ocypus copressus* | – | 0.08 | 0.08 | 0.76 | 0 | 0 | 0.14 |
| 15 | *Olophrum piceum* | – | 0.26 | 0.36 | 0 | 0.48 | 0.60 | 0.34 |
| 16 | *Othius myrmecophilus* | *ms* 3 | 0.66 | 0.76 | 0.18 | 1.08 | 1.44 | 0.82 |
| 17 | *O. punctulatus* | – | 0.04 | 0.02 | 0.68 | 0.06 | 0.20 | 0.14 |
| 18 | *Oxypoda procerula* | – | 0.40 | 0.04 | 0 | 0.78 | 0 | 0.30 |
| 19 | *Platydracus fulvipes* | – | 0 | 0 | 0.24 | 0 | 1.06 | 0.16 |
| 20 | *P. stercorarius* | *ms* 3 | 0.26 | 0.02 | 0.02 | 0.12 | 0 | 0.10 |
| 21 | *Proteinus brachypterus* | – | 0.18 | 0.54 | 0.18 | 0 | 0 | 0.20 |
| 22 | *Quedius molochinus* | *ms* 3 | 0.54 | 0.28 | 0.04 | 0.18 | 0 | 0.26 |
| 23 | Rugilus rufipes | – | 0.08 | 0.04 | 0.08 | 0.38 | 0 | 0.14 |
| 24 | *Sepedophilus immaculatus* | *ms* 3 | 0.10 | 0.68 | 0.18 | 0.02 | 0.44 | 0.28 |
| 25 | *S. marshami* | *ms* 3 | 0.28 | 0.22 | 0.32 | 0.76 | 0.38 | 0.40 |
| 26 | *Staphylinus erythropterus* | – | 0.72 | 1.00 | 0.52 | 0.06 | 0.94 | 0.62 |
| 27 | *Stenus clavicornis* | – | 0.16 | 0.30 | 0.10 | 0.64 | 0.04 | 0.30 |
| 28 | *S. impressus* | – | 0.42 | 0.12 | 0.10 | 0.56 | 0.12 | 0.30 |
| 29 | *Tachyporus corpulentus* | *ms* 1 | 0.44 | 0.22 | 0 | 0.56 | 0.26 | 0.34 |
| 30 | *T. transversalis* | *ms* 4 | 0.38 | 0 | 0 | 0.06 | 0 | 0.10 |
| 31 | *Xantholinus linearis* | – | 0.34 | 0.18 | 0.40 | 1.10 | 0.02 | 0.48 |
| 32 | *X. longiventris* | – | 0.32 | 0.40 | 0.52 | 0.56 | 0.16 | 0.40 |
| 33 | *X. tricolor* | – | 0.36 | 0.72 | 0.60 | 0 | 0 | 0.34 |
| 34 | *Zoosetha procidua* | *ms* 2 | 0.10 | 0.04 | 0.40 | 0.02 | 0 | 0.10 |
| 35 | *Zyras cognatus* | – | 0.24 | 0.06 | 0 | 0.14 | 0 | 0.10 |
| 36 | *Z. laticollis* | – | 0.22 | 0.06 | 0 | 0.24 | 0 | 0.14 |

## GENERAL CONCLUSIONS

1. A comprehensive assessment of site heterogeneity is possible in both synecological and autecological zooindication, thanks to the application of the modified Pulliam theory of source and sink.
2. The method of synecological zooindication proposed in this paper allows for determination of microsite differentiation of forest ecosystems through:

A. Determination of shares of extreme microsites, the sources and sinks of invertebrate communities;
B. Identification of sources and sinks among specific sets of microsites,
C. Description of their natural parameters.

3. The proposed method of autoecological zooindication determines microsite differentiation of forest ecosystems through:
   A. Identification of population sources for particular species;
   B. Description of their natural parameters;
   C. Assessment of the degree of utilization of site heterogeneity by particular species.
4. The results of synecological zooindication:
   A. The ecosystems of the coastal pine forest dsecribed in this paper are:
      - Considerably differentiated in terms of microsite make-up, as indicated by a nearly 40% share of extreme sites;
      - Stable, as indicated by a prevalence of sources.
   B. The spatial pattern and natural parameters of the microsites identified as potential sources supply a model for bio-intervention in degraded coniferous ecosystems.
5. The results of autoecological zooindication:
   A. The ecosystems of the coastal pine forest studied in this paper are characterised by a high degree of uniqueness.
   B. The spatial pattern and natural parameters of the microsites identified as sources of coniferous characteristic species supplement the model used in bio-intervention efforts in degraded coniferous ecosystems.
   C. The determination of species fidelity in the coastal pine forest is useful for assessing their zooindication value.
   D. The identification of sites favoring the characteristic coniferous species to a greater-than-average degree is useful in the planning of forms of protection of particular sites of the coniferous ecosystem.
   E. The results of valuation based on the phytoindication method (the last column of Table 3) are only partially consistent with those obtained via zooindication assessment. This proves that the two techniques: phytoindication and zooindication, are complementary and in order to fully valuate natural habitats both need to be applied jointly.

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STRESZCZENIE

[Tytuł: Ocena zróżnicowania mikrosiedliskowego nadmorskich borów bażynowych: zastosowanie teorii źródło-ujście na poziomie populacji i zgrupowania epigeicznych kusakowatych (*Coleoptera, Staphylinidae*)]

Praca stanowi oryginalną propozycję metodyczną oceny zróżnicowania mikrosiedliskowego ekosystemów leśnych w oparciu o zmodyfikowaną teorię Pulliama. Propozycja ta oparta jest na nowych wskaźnikach zooindykacyjnych, tj.:

- udział źródeł ($U_C$), ujść ($U_P$) i tła ($U_S$) na obszarze występowania zgrupowania,
- wskaźnik preferencji mikrosiedliskowych gatunku $c_s$,
- wskaźnik wykorzystania przez gatunek heterogenności siedliska $C_s'$.

Metoda waloryzacyjna wykorzystuje zgrupowania i populacje bezkręgowców, operując zooindykacją synekologiczną i autoekologiczną jednocześnie.

Metoda zooindykacji synekologicznej określa zróżnicowanie mikrosiedliskowe ekosystemów leśnych poprzez:

- zaliczenie konkretnych mikrosiedlisk do ekstremalnych,
- ustalenie udziałów mikrosiedlisk ekstremalnych (źródeł i ujść),
- opisanie ich parametrów przyrodniczych.

Natomiast metoda zooindykacji autoekologicznej określa zróżnicowanie mikrosiedliskowe ekosystemów leśnych, poprzez:

- ustalenie źródeł występowania poszczególnych gatunków,
- opisanie ich parametrów przyrodniczych,
- ocenę wykorzystania heterogenności siedliska przez poszczególne gatunki.

Obie, komplementarne metody zooindykacyjne opisują układ przestrzenny i parametry przyrodnicze mikrosiedlisk, hipotetycznych źródeł, stanowiących w inżynierii ekologicznej wzorzec dla postępowania biomanipulacyjnego w zdegradowanych ekosystemach borowych. Obie metody zostały przetestowana na epigeicznych zgrupowaniach kusakowatych nadmorskich borów bażynowych Mierzei Łebskiej. Wykazano, że badane ekosystemy borowe: są silnie zróżnicowane mikrosiedliskowo (z blisko 40% udziałem mikrosiedlisk ekstremalnych, tj. źródeł i ujść), są stabilne (z przewagą udziału źródeł nad ujściami), a także posiadają wysoką swoistość.