Acta Zool. Fennica 196:206–211 ISBN 951-9481-41-9 ISSN 0001-7299
Helsinki 28 February 1995

XI International Colloquium on Soil Zoology, Jyväskylä, Finland, 10–14 August, 1992

Modern ecology methods and means allowing broadcasting and application of the rôles of soil fauna knowledge

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As soil zoologists, necessarily narrow minded by our specialization, we must contribute to a global (generalized) assessment of human actions on ecosystems. Our contribution must be opened to everybody for any kind of evaluation. In this paper, the feasibility of such a knowledge-availability has been demonstrated: 1) for earthworms among all ecological, agronomical and environmental actions at the level of the objective data (DICs) today immediately accessible on simple requests in ECORDRE, a Relational Data Base (proximately connected in a Network Relational Data Base), 2) for earthworms at the level of the interpretation of facts, including the assessment of our actions on them; the relative knowledge we have is available and critizable in ROLUMBRIC, a prototype of Explained Knowledge Dispenser. Such improvment could be made by all scientists or technicians dealing with ecosystems and among them all soil zoologists.

1. Introduction

The International Biological Programme was proposed in 1963 to improve our understanding of the biological basis of productivity and human welfare, and presented during its execution 1964–1974 a great opportunity to improve both fundamental ecological knowledge and cooperation between the numerous disciplines contributing to ecosystem analysis (Worthington 1975). That was for us soil zoologists a great opportunity to move from descriptive studies of the soil fauna (always needed) to the study of animal rôles in soil, and then to the integration of this knowledge into an ecosystem understanding. In fact a great task has been made (see Petersen & Luxton 1982), soil zoology was taken in account in cooperative field works as the Solling Projekt (Ellenberg 1971) or the Grassland biome study (Van Dyne 1969). Apparently the scientific community converged on a common language, "the energetics of ecosystems", with which everybody described the contribution of certain animal groups in ecosystems. Also, it was important to improve synthetic tools, particularly modeling, and finally the "integration" was accepted as an aim.

The IBP was obviously a success by combining many previously isolated disciplines, sometimes to coordinate studies in the same ecosystems and to promote the aim to make synthesis with the help of new concepts. But the IBP reached its limits by the lack of both conceptual and technical tools to really integrate the various peculiar knowledges gathered by the various disciplines contributing individually to the description of some ecosystem properties.

As soil zoologists we met at the "IBP end" in Uppsala (VI. Int. Soil Zool. Coll., 1976) where it was possible to see both our achievnments and our limitations. There, I was obliged, about the rôle of soil organisms in nutrient cycling, to conclude (translated) "The faunal contribution to biogeochemical cycles could not yet be estimated", "It is necessary to improve techiques allowing field measures of phenomenon actually proper to this field and to integrate these measures in models which tackle all faunal properties" (including mechanical properties) (Bouché 1978a).

In fact, these limitations illustrated the lack of ecological concepts shared by all contributing disciplines. These concepts must fit exactly and fully the definition of ecology (translated from Haeckel 1866, see Bouché 1990) "We mean by Ecology the global science of the relations of the organisms with their surrounding external world in which we include, in the widest sense, all existence conditions".

I wont to stress some usually forgotten requirements:

1) The object(s) of this science is (are) ecosystem(s), i.e. system(s) including relations between organisms and other components of their surrouning world: abiotic components as most soil, atmosphere or hydrosphere. Consequently, ecology is devoted to biophysicochemical systems as a whole.

2) To be efficient and qualified, each specialist restricts his field of study (= his speciality) and cannot alone make ecology. He can only contribute to global ecosystem studies

if his knowledge is fully available to all other ecosystem researchers.

3) Ecology is grounded on observation (data gathering) of biological and abiotic (physico-chemical) compartments, i.e. depends of exact sciences (biology, physics, chemistry) and logic (mathematics, basic epistemology). Ecology *sensu stricto* is inherently an exact science.

4) Based on exact sciences, being ecosystemic at all scales related to this definition, the so-called inherently "fuzzy nature" of ecology and confusions for reason of scaling or hierarchy results in too restricted ecological approaches (for example, see Allen & Starr 1982 and, in contrast, Bouché 1990).

2. Need to integrate and use the soil zoology knowledge in ecology

There are thousands of animal species living in soil. There are many types of soil with gradients between them. There is an infinite number of biological (e.g. plants, microorganisms), chemical (e.g. humus compounds), physical (e.g. climatic) variables and anthropogenic actions (e.g. pollutions, yield, use of fertilizers) acting on soil systems.

We are, as soil zoologists, working, step by step, usually on a precise and very restricted topic, generally on a few species, on one or a few soils and under some natural and anthropic conditions. Consequently, we are producing: 1) a restricted number of objective data observed on some ecosystem parts and conditions, and 2) focused interpretations restricted to some topics.

Soil zoologists' work is only a contribution to the understanding of the soil subecosystems, themselves parts of ecosystems. Our knowledge must be integrated in these bio-physico-chemical systems and must be applied to all kinds of terrestrial ecosystems. Consequently we need integration and interpolation between studied conditions and non-studied conditions.

1) Integration is a fashionable "key-word", usually expressing our aim to integrate. As an example Ellenberg (1971), used this word to describe the Solling Project — a cooperative and well managed local programme — without integration between partners: that was only co-ordination of researchers, not true integration. We need to really integrate, i.e. to incorporate our specialists' contributions into a sole global description at all stages of knowledge.

2) Interpolation. Knowledge between observed "points", on which we have related our data (cf. section 3.3), must be interpolated to intermediate or similar non-observed points in space, time and composition (e.g. composition of the soil fauna, soil components, natural and anthropic factors).

Interpolation gives a) the ability to generalize, b) the possibility to focuse, to some extent, information from various fields to one selected for key-position, and c) the falsiability of our interpretations. Each interpretation, based on facts and hypotheses, must lead to a prediction which could be assessed in other time, space or conditions, thanks to interpolation.

3) Availability of the knowledge is an other prerequisite of modern ecology. All ecosystem studies, comparison of knowledge, and various views to interprete, need access to all objective data and all types of interpretation from all types of specialists. Presently, a minor part of our knowledge is available and its availability is often in very restricted contributions. These contributions give generally only few interpreted facts and conclusions, only devoted to an initial aim of each isolated study. In contrary, we must increase the instantaneous access to all objective facts (data) and all interpretation stages. We must aggregate, or conversely analyze at all time, space and composition scales the two types of knowledge: objective facts (as DICs, see below) and interpretations (see, for example, scaling problems in Coleman et al. 1992).

3. Modern concepts and tools allowing a full use of the knowledge of soil fauna

3.1. The present situation

Soil zoology is a vast field where in fact each soil zoologist is gathering a restricted number of data on a limited taxonomic group and few soil types, human managements, etc. We accumulate a great amount of individual data, called DICs (DIC = Datum Initial and Controlled = Donnée Initiale Contrôlée, see Bouché 1990). Each DIC is directly a fact from one peculiar object (called prelevat) analyzed in an ecosystem (example: 0,02, green, large, 4322). DICs are not pre-interpreted, i.e. 0,02 could not be the mean of two values. Usually only a synthesis of the observed data are published. Publications present a selection, eliminating non-useful DICs (i.e. not convenient for the researcher's aim). Generally, only means, standard deviations, parameters of mathematical models, i.e. "results" are available. These results reflect both objective facts (= DICs) from ecosystems and hypotheses of interpretations (as selection of useful DICs; as the choice of the set limits for a mean, as the acceptance of a mathematical fitting, as, more widely, the selection of data types).

In ecology, excluding here artificial devices or microcosms, the unlimited number of DIC types and the great diversity of interpretations lead to an infinite diversity of publications describing almost always a new habitat, an original sampling of data and an original interpretation choice, often with various concepts for one word and with concepts, each described by various words. Traditionally, we work individually, including cooperative and multidisciplinary projects and multi-author papers, trying to "integrate" by exchanging, as best as possible, our contributions. These cumulative practices have been promoted for years (at least 1964, with the IBP launching) and produce only an enormous amount of papers where practically all facts (DICs) are lost, where intepretation rules are obscure and where the knowledge availability is poor. The traditional management of DICs (saving, description and access) is almost nil and the communication of interpretation procedures, always closely linked to a peculiar topic, lack of flexibility, accessibility, congruence and conviviality.

Today, we have fortunately concepts and tools: both are jointly needed. Without tools we cannot change our Gutenberg's paper transmission and its sclerosis. Without share of ecological and technical concepts, we cannot use modern conservation-communication tools.

To describe, conserve and communicate all knowledge, we have two tools: 1) the Related Data Base giving access instantaneously to all kinds of DICs (the objective observations), 2) the Explained Knowledge Dispenser (EKD) giving access to all interpretation procedures based on explained and falsifiable hypotheses.

3.2. Concepts

To share our knowledge we need about one hundred concepts strictly known, each indicated by an univocal word. We are here in an exact science, and word-concepts, such as ecology or ecosystem, must be known with a very *stricto sensu* acceptance, and not as fuzzy approximations as in the mundane "ecology". In chemistry, calcium is not lead or barium, while in "ecology" biocenoses are often ecosystems or biotopes or niches. To communicate efficiently these fuzzy practices must be discarded. Ecosystems are studied at various levels, with various topics, and operationally related DICs and interpretations. They could be exactly described as such, with a very great economy of precise concepts.

The concepts needed are about 60 in ecology *sensu stricto,* with *an* additional 20 systemic word-concepts (needed by the ecosystemics) and 20 word-concepts devoted to handling-sharing procedures and tools. Almost all of them are strictly described in Bouché (1990) with a few exceptions about the Explained Knowledge Dispensers which are always today in conceptual improvements.

3.3. Tools

ECORDRE

ECORDRE is a Relational Data Base now used for 8 years in soil zoology and applied also to all ecological objective data (DICs) including soil, plants, pesticides, birds, fishes, parasites, soil treatment such as ploughing, and so on.

In ECORDRE all data are related together by described relations in such a way that any scientist can describe and request any kind of DICs and their relations or to get any recombined selection of DICs in its desired order. In this relational data base data are independent of the "reasons" of their initial gathering and could be used for this initial aim but also for any other re-interpretation for which some of the data managed in ECORDRE are convenient.

Data are presented following five "referendaires" or protocols. A protocol constitutes an obligatory link for each data. There are three ecological protocols, a technical one and a socio-economical one.

The first ecological protocol is "time" with only two dimensions: 1) the date (in absolute time including, if needed, fractions of seconds), and 2) the duration (between two dates or expressed *versus* time as velocity: e.g. 20 cm/s).

The second protocol is "space", which in ecology, where we work with newtonian physics, is the three euclidian dimensions (length, width, depth). A geodesic system relates all data from the smallest to the widest: the World.

The third protocol is "composition". It is multidimensional with all "analyses" of any component belonging to any "prelevat" or sample described methodically. Any kind of quantitative, qualitative or fuzzy data could be described. The sample is by definition the "object" containing the value of one variable, and it is itself described (e.g. size, shape) in ECORDRE.

The technical protocol gives access to the technique of observation: the Technical Description which describes how each DIC is observed (measured, qualified).

The socio-economical protocol is the "motivation". It gives description of the human intellectual, administrative and financial "reasons" which justified the data gathering in ecosystems. In other words, this multidimensional protocol contains the technician or scientist responsible for the research, the institution paying for or coordinating it.

Each datum is obligatorily related to its five protocols. By the motivation it is possible, if needed, to judge the quality of data (as in taxonomy for the identificator), the initial property and, if needed, to create an automatic control of the data availability, etc. Thanks to the technical protocol we know the exact significance of the observation (example: in chemical analyses). Not only each datum is related to each other and to its ecosystems, but also to its scientific-technical context of sampling.

EK-Dispensers

Explained Knowledge Dispensers are still in under development. The latest computer improvments are quickly giving us the ability to apply the very simple concepts related to interpretation.

In knowledge "interpretations" are the complement of DICs. DICs are objective facts while interpretations are our "opinions" of them. To interprete we use a multitude of hypotheses, including these of statistical tests, of sampling procedures, of modelling, of vague opinions, ... Conceptually, those hypotheses can be described, step by step, ordered by categories and very simply explained *if* scientific rules are followed.

As far as ecology (and soil zoology) is not a wordly-minded mundane exercise but scientifically restricted to its aim, concepts needed are very restricted (see Bouché 1990). Only two interpretation types occur and are complementary: the comparison of "objects" and the systematics of them as ecosystem components.

Typological comparisons, using descriptive statistics, are today widely used in multivariate analysis.

System studies are 1) ecologically described in component terms, related to the physical, chemical and biological states or kinetic variables, 2) aggregated in compartments linked by kinetics if the connection occurs, 3°) described in conceptual and particular mathematical models: the infosystems, 4) explored in artificial models (microcosms), 5) mathematically fitted by mathematical functions. Finally infosystems are validated on ecosystems ("ecovalidation") by means of interpolations.

Both in typological comparisons and systematic interpretations choices could be aided by probabilistic statistics.

All these interpretations could be described using mathematical models (algorithms) or non-algorithmic descriptions (heuristics).

The EK-Dispenser gives this knowledge in a very simple way in microcomputers.

Two kinds of workers use it: 1) the developers who are obliged to give "all" the knowledge available in a logic order, and 2) the users who request knowledge in the EK-Dispenser and evaluate it.

As a prototype we are developing the EK-Dispenser "ROLUMBRIC" which gives access to the knowledge about the various earthworm functions (physical as soil "workers", chemical as nitrogen or carbon flux regulators, biological as prey, ecosystemic as global soil properties, e.g. humus, erosion) for ecological, agronomical or environmental assessments.

We use various types of knowledge (Table 1). Some are, in spite of quantification, at the conceptual stage from an ecosystemic point of view. For example, because of lack of data, the kinetic relation between prey and predators could not be quantitatively described for most of the time. Some are, at the stage of modelling based on ecological data, e.g. the *Millsonia anomala* demography model, while falsifiable, not yet ecovalidated. Some are ecovalidated, i.e. after conceptual and then mathematical modelling and fitting, checked in ecosystems, as for the Nitrogen assimilation-emanation fluxes of earthworms.

To describe all these steps the EK-Dispenser uses presently the TPW computer language, a Windows software, and a microcomputer.

Then knowledge is described (Fig. 1) with, 1) words and locutions (in a semantic logic: locutions (L), listed in a lexic in an alphabetic order), 2) predicates (P) which are sentences or mathematical formulae, or both (i.e. heuristic and algorithmic descriptions), 3) references (R), which are, as in a scientific paper, the limit of the explanation directly given. A classical bibliographical list is available.

Each predicate could be connected to other predicates, uses locutions, and sometimes references. The graph-system used (Fig. 1) connects automatically each component (predicate, locution, reference).

A menu gives users access. If they want an assessment of some earthworm rôle a selection of these rôles is made by the user. The EK-Dispenser asks for local data if the user asks for local evaluations. If the user does not understand

Table 1. ECORDRE and ROLUMBRIC describe information scattered in various papers and is related to data. This EK-Dispenser is related to various stages of knowledge: DICs, conceptual, modelled and ecovalidated stages leading to an integration based on biological (earthworm) information and ecological rôles allowing an integration used to assess anthropic actions.

Study types	Data (DICs) 1st year	Conceptual	Modelling (= prediction)	(Eco)validation	Integration
Biological					
Population	1967	Bouché & Gardner 1984	Lavelle 1971	—	*
Ecol. category	1970	Bouché 1971	Sims & Bouché 1980	—	*
(Paleo)geography	1965	Bouché 1972	Bouché 1983	Lin et al. 1985	*
Functional					
Activity regulation	1967	Bouché 1975	Heidet & Bouché 1991	Al Addan 1990	*
Biological rôles					
ex.: predators	19?	Granval & Aliaga 1988	—	—	*
Chemical rôles					
ex.: N cycle	1978	Gounot & Bouché 1974	Ferriere 1986	Hameed 1989	*
Physical rôles					
ex.: water infiltration	1983	Duret 1983	Al Addan et al. 1991	—	*
Ecosystem rôles	1967	**Darwin 1881**	**Darwin 1881**	**Darwin 1881**	
Anthropic				(for evaluation)	
Man actions					
ex.: pesticides	1972	Numerous papers	Ferriere et al. 1981	—	
Man uses					
ex.: garbage disposal	(1976)	Bouché 1979	Only prototypes	Bouché in press	
Man control					
ex.: hevy metal ecotoxicology	1979	Ireland 1975	Jay 1979	Abdul Rida 1992	
Soft- + hardware computer tools	RDB to NDB ECORDRE	algorithms + heuristic aggregated in the EK-Dispenser ROLUMBRIC			

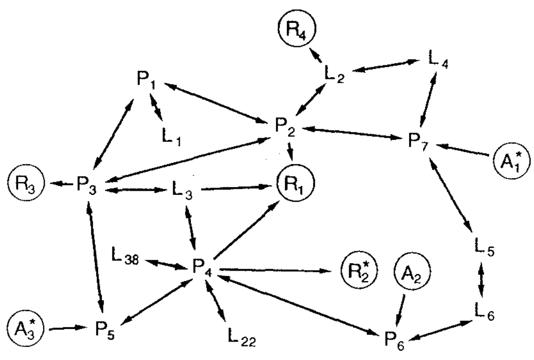

Fig. 1. The Explained Knowledge Dispenser graph. This graph relates between them predicates (P) (= sentence, formulae) and locutions (L) (= words and locutions in the semantic meaning) used to describe interpretations. References (R) are interpretation given outside the EK-Dispenser and Annotations are remarks made by users. Example: predicates describe by sentences and formulae together (P-P-P) the earthworm N-cycle rôle in anecics. The anecic is defined by a relation with a specific L and more details is accessible in references R_1 ... R_n (see Table 1, N-cycle).

one word (L) an automatic connection gives its meaning, everywhere in the EK-Dispenser. If the user disagrees with some explanations or needs more explanations (or better explanations) than available, he can make an "annotation" (A) inscribing a comment in the programme. The annotation is temporarily created by users and developers update them regularly to improve the EK-Dispenser.

In conclusion:

The ROLUMBRIC EK-Dispenser gives, theoretically, all knowledge-unknowledge (= relative knowledge) about earthworm rôles in a way which could be applied to all local conditions.

It gives an up-to-date state-of-the-art. It is a kind of scientific or technical manuscript "just written".

It gives to users the needed knowledge, i.e. not all but only what is needed, including explanations, general, or if requested detailed, and this following the wish of users (and not the developer's). It is a kind of scientific or technical multi-paper where the choice of the text is made by the user at his convenience.

It is adaptable to both the criticism of users and the every-day improvement of knowledge.

References

Abdul Rida, A. M. 1992: Biosurveillance de la contamination du sol: apport de l'étude des lombriciens à l'évaluation des risques liés aux éléments traces. — Thèse Univ. Montpellier II, 2/07/92, 233 pp.

Al Addan, F. 1990: Biophysique du sol. Etude quantitative de la régulation, par le travail lombricien, des propriétés structurales en milieux méditerranéens. — Thèse doct. 3ème cycle, USTL Montpellier, 291 pp + Ann.

Al Addan, F., Aliaga, R. & Bouché, M. B. 1991: Relations entre peuplements lombriciens et propriétés physiques de sols méditerranéens. — In: Veeresh, G. K., Rajagopal, D. & Viraktamah, C. A. (eds.), Advances in management and conservation of soil fauna: 525–537. Oxford and IBH Publ. Co. Ltd, New-Delhi.

Allen, T. F. H. & Starr, T. B. 1982: Hierarchy, perspectives for ecological complexity. — Ed. Univ. Chicago Press, Chicago, 310 pp.

Bouché, M. B. 1971: Relations entre les structures spatiales et fonctionnelles des écosystèmes illustrées par le rôle pédobiologique des vers de terre. — In: Pesson, "La vie dans les sols": 187–209. Ed. Gauthier-Villars, Paris.

— 1972: Lombriciens de France. Ecologie et systématique. — Ed. INRA, Ann. Zool. — Écol. Anim., Num. Spécial 72-2: 1–671.

— 1975: Fonctions des lombriciens. IV. Corrections et utilisations des distorsions causées par les méthodes de capture. — In: "Progress in soil zoology", C. R. Vème Coll. Int. Zool. Sol, Ed. Academia, Prague, 583–592.

— 1977: Ecologie et paraécologie; peut-on estimer la contribution de la faune aux cycles des éléments biogènes? — In: Lohm, U. & Persson, T. (eds.), Soil organisms as components of ecosystems. Ecol. Bull. (Stockholm) 25: 402–408.

— 1979: Valorisation des déchets organiques par les lombriciens. — In: C. R. Comité Sci. Sol Déchets Dolides, Orléans 15-17/03/1977. Ed. La Documentation Française, Coll. Rech. Environ. 11: 401.

— 1980: L'interprétation morphologique des lombriciens: un commentaire de l'évaluation numérique de R. W. Sims. — Pedobiologia 20(4): 227–229.

— 1983: The establishment of earthworm communities. — In: Satchell J. E. (ed.), Earthworm ecology from Darwin to vermiculture: 431–448. Chapman and Hall (London).

— 1990: Ecologie opérationnelle assistée par ordinateur. — Ed. Masson, Paris. 572 pp.

Bouché, M. B. & Gardner, R. H. 1984: Earthworm functions (Fonctions des Lombriciens). VII. Population estimation techniques. — Rev. Écol. Biol. Sol 21(1): 37–63.

Bouché, M. B. sous presse: Le lombricompostage industriel des déchets.

Coleman, D. C., Odum, E. P. & Crossley, Jr., D. A. 1982: Soil biology, soil ecology and global change. — Biol. Fertil. Soils 14(2): 104–111.

Darwin, C. 1881: The formation of vegetable mould through the action of worms with observations on their habits. — John Murray and Co. Publ., London. 326 pp.

Ellenberg, H. 1971: Integrated experimental ecology. — Springer-Verlag, Berlin, Ecol. Stud. 2: 1–214.

Ferrière, G. 1986: Mouvements naturels des éléments dans une prairie: quantification des échanges d'azote entre lombriciens, sol et plantes. — Thèse doct. d'Etat ès-Sciences, Univ. Lyon I, 23/06/86, 148 pp + Ann.

Ferrière, G., Fayolle L. & Bouché, M. B. 1981: Un nouvel outil, essentiel pour l'écophysiologie et l'écotoxicologie, l'élevage des lombriciens en sol artificiel. — Pedobiologia 22(3): 196–201.

Gounot, J. & Bouché, M. B. 1974: Modélisation de l'écosystème prairial: objectifs et méthodes. — Bull. Écol. 5(4): 309–338.

Granval, Ph. & Aliaga, R. 1988: Analyse critique des connaissances sur les prédateurs de lombriciens. — Gibier et Faune Sauvage 5: 71–94.

Hameed, R. 1989: Transformation et translocation de l'azote sous influence lombricienne et microbienne: modèles et validation écologiques. — Thèse doct. 3ème cycle, USTL, Montpellier, 18/12/89, 156 pp.

Heidet, J. — C. & Bouché, M. B. 1991: Régulation de l'activité lombricienne: influence de la température, de la photopériode et de l'humidité in situ sur l'indice de mobilité de Nicodrilus longus longus (Ude) (Lumbricidae, Oligochaeta). — In: Veeresh, G. K., Rajagopal, D., Vircktamah, C. A. (eds), Advances in management and conservation of soil fauna: 643–655. Oxford & IBH Publ. Co. PVT Ltd. New-Delhi.

Ireland, M. P. 1975: The effect of earthworm Dendrobaena rubida (Oligochaeta) on the solubility of lead, zinc and calcium in heavy metal contaminated soil in Wales. — J. Soil Sci. 26(3): 313–318.

Jay, S. 1979: Mesure de l'écotoxicité de quelques métaux lourds sur le chaînon lombricien. — Mémoire-thèse ENITA, Dijon, 1979. 91 pp.

Lavelle, P. 1971: Recherches sur la démographie d'un ver de terre d'Afrique Millsonia anomala Omodeo (Oligochaeta, Acanthodrilidae). — Bull. Soc. Écol. 2(4): 302–312.

Lin, Jin-Lu, Fuller, M. & Wen-You Zhang, 1985: Preliminary phanerozoic polar wander paths for the North and South China blocks. — Nature 313: 444–449.

Petersen, H. & Luxton, M. 1982: A comparative analysis of soil fauna populations and their role in decomposition processes. — Oikos 39(3): 288–388.

Sims, R. W. 1980: A preliminary numerical evaluation of the taxonomic characters of Allolobophora auct. and some allies (Lumbricidae, Oligochaeta) occuring in France. — Pedobiologia 20(3): 212–226.

Van Dyne, G. M. 1969: Some mathematical models of grassland ecosystems. — In: Dix, R. L. & Beidleman, R. G. (eds), The grassland ecosystem: a preliminary synthesis: 3–26. Publ. Range Sci. Dept. Sci. ser. rep. 3. Colorado State Univ.

Worthington, E. B. 1975: The evolution of IBP. — Cambridge University Press. Int. Biol. Prog. (1). 268 pp.