Wetland management to reduce Baltic Sea eutrophication

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Abstract Seven regions with coastal eutrophication problems in the Baltic Sea, including the Kattegat, constitute the BERNET project (Baltic Eutrophication Regional Network). To counteract eutrophication and associated severe biological conditions the countries around this large brackish water body must all cooperate. The regions are characterized by large differences in land use, e.g. agricultural intensity, and losses of retention capacity in the catchments due to wetland reclamation. Initially it has been necessary to identify nutrient sources – especially nitrogen – and technical, economical and even administrative obstacles to initiate eutrophication management measures. Nitrogen retention in different types of wetlands in the Baltic Sea Region has been analysed. The wetlands generally have a positive effect on reduced nitrogen transport to aquatic environments and it is generally accepted that measures leading to decreased losses of nutrients to the aquatic environment must be combined with measures leading to increased retention of nutrients in catchments. Data analysed in the BERNET project show that the potential for such a measure is large. Therefore, conservation and restoration initiatives for wetlands is an essential part of the work in the BERNET project. Wetlands have been drained or totally eliminated due to intensive agriculture in some regions while large scale rehabilitation of wetlands occurs in regions with less intensive agriculture. Based on land use data from the seven regions, the working group for wetland management within the BERNET project has identified the possible use of wetlands as building blocks as a contribution to the management of the Baltic Sea eutrophication. Several recommendations are presented on the wise use of existing and constructed wetlands for water quality management in relation to non-point nutrient pollution.

Keywords Baltic Sea; eutrophication; retention capacity; wetlands

Introduction

The BERNET (Baltic Eutrophication Regional NETwork) (Figure 1) was established as a contribution to reduce the eutrophication of the Baltic Sea, including the Kattegat, and to support the aim of the Helsinki Convention (HELCOM, 1988) in assuring the ecological restoration of the Baltic Sea. The Helsinki Convention is signed by the nine coastal countries around the Baltic Sea as well as the European Community, and sets up a number of criteria for the contracting parties to follow in order to prevent pollution from land based sources and activities at sea – including the excess loading with nutrients leading to serious eutrophication problems in the Baltic Sea. The aim of BERNET is to describe regional eutrophication problems in the Baltic Sea Region, evaluate the initiatives towards solutions of these problems, and to suggest improvements. The BERNET also attempts to create political awareness of the problems on a regional level, and point to the international obligations to seek solutions.

The fulfilment of the HELCOM 1988 Ministerial Declaration on reducing both nitrogen (N) and phosphorus (P) loads of coastal waters by 50% from 1985 to 1995 has not been approved by any of the contracting regions (Bernet, 2000a). In some of the Baltic regions

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the main problem to be solved is reduction of the diffuse nutrient loads from agriculture and forestry. Due to the breakdown of the Eastern European agricultural sector, the main eutrophication problem in these regions at present arises from point sources. However, when agricultural production again increases, it will be important to implement environmentally sustainable agriculture.

The aim of this contribution is to describe the importance of wetlands to the ecological balance in the aquatic environment and identify central problems regarding the role of wetlands in relation to eutrophication of the aquatic environment in the Baltic Sea Region. Further, wetland physical planning and management practices will be compared and recommendations for the use of wetlands for water quality management in watersheds are presented.

Why are wetlands important?

The BERNET project defines a wetland as a fresh water body where different transformation processes favour the removal or retention of nutrients, resulting in decreased nutrient transport to the coastal waters. Thus, the BERNET project considers ponds, lakes, fens and wet meadows in relation to water quality management to counteract diffuse pollution of coastal waters with nutrients. Wetlands are part of the bufferzone concept, and wetlands are an important part of the retention capacity of drainage basins (Fleischer and Stibe, 1991).

In aquatic buffer zones processes occur, which in most cases result in the removal and retention of plant nutrients from the water entering the wetland. In wetlands, nutrients, e.g. N and P, are retained from the water by uptake into living material such as plants, algae, and bacteria. Nutrients are also retained by sedimentation of particulate material, including dead plant material which is buried in the sediments. This is important for P removal. With respect to N, bacterial processes (denitrification) are responsible for the conversion of nitrate to harmless atmospheric N which in most cases is unavailable for algae growth in coastal waters.

It is important to stress that wetlands do not decrease N leaching from agricultural or forest areas and do not protect the groundwater from nutrient loading. The function of wetlands with respect to N, is partly to remove that N which has already entered surface waters

Figure 1 The seven BERNET administrative regions (dark) and the total catchment (light grey) of the Baltic Sea

after diffuse leaching from the agricultural or forest fields. Therefore, a prerequisite for the use of wetlands for water quality management is, that created wetlands are located in the catchments where the N leaching is high.

Water can be considered as a transport medium which carries nutrients to wetlands and distributes the nutrients within the wetlands. Therefore, hydrological processes play a key role in relation to the general ability of wetlands to retain nutrients (Hoffmann, 1998). An overall prerequisite for successful use of ponds as bufferzones is that the hydrological conditions favour deposition of organic material, that is, running water conditions do not exist. This is not only needed with respect to sedimentation of material containing nutrients but also for creation of the special conditions needed for e. g. denitrification. These conditions may not be difficult to create in ponds/wetlands in the agricultural landscape (Figure 2a, b), but more difficult to create in sites used for stormwater treatment (Figure 2c). In other types of created wetlands, e.g. wet meadows, nutrient rich drainage water from the catchment is forced to infiltrate the soil (Fuglsang, 1998; Hoffmann, 1998). In the waterlogged soil, the water flow pattern determines if nutrients are carried to soil layers where nutrient transformation occurs. The retention capacity of catchments can also be increased outside wetlands, for example by regulated drainage on agricultural fields which, at the same time, also increases yields. This is practiced in Ostrobothnia, Finland (Bernet, 2000b).

It is difficult to predict nutrient retention in wetlands since the physical conditions vary. However, in absolute terms, wetlands can only remove much N if loaded with much N (Figure 3), although the nutrient removal efficiency decreases with increasing load. This dose/response relationship makes it possible also to estimate the cost efficiency and include restoration of wetlands into overall packet solutions to counteract coastal eutrophication. The costs for removal of N and P depend on several conditions, including investment costs, interest rates, writing off period, opportunity costs and costs for maintenance. Different

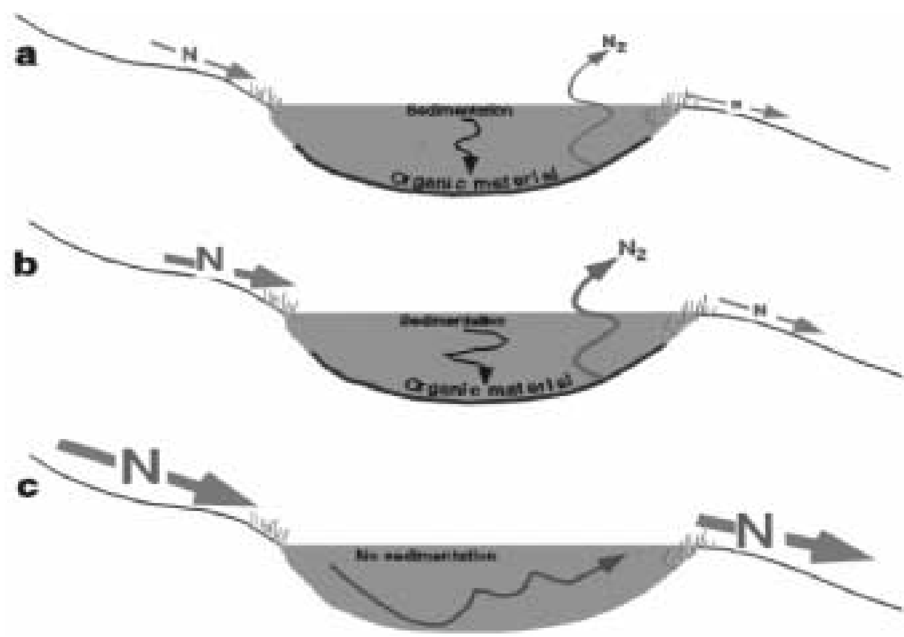

Figure 2 Schematic presentation of the same pond under varying loading conditions. a) Low water discharge and low N load into the pond. The low N load limits the N removal. b) High water discharge implies high transport of N into the pond and high areal N removal is favoured (a high areal N-dose implies a high areal N-removal). c) Very high hydrological loads cause running water conditions and no organic sediment is deposited. Denitrification is not favoured and N removal is very low

Table 1 Marginal costs for nitrogen (N) and phosphorus (P) removal in wetlands near the coast of the Laholm Bay (Sweden [S]), in Schleswig-Holstein (Germany [D]), and on Fyn (Denmark [DK]). Costs are calculated for assumed maximum and minimum duration periods (Bernet, 2000b)

Regional	Wetland type	Estimated duration (yrs max/min)	P-max duration (EUR kg^{-1} P)	P-min duration (EUR kg^{-1} P)	N-max duration (EUR kg^{-1} N)	N-min duration (EUR kg^{-1} N)
L. Böslid (S)	Agricultural	30/20	2.4	3.6	1.2	1.9
Möllegård (S)	Agricultural	50/20	15.4	38.5	0.3	0.8
Vallås (S)	Stormwater	20/20	NR	NR	24.9	24.9
Pond (D)	Municipal	30/30	40.8	40.8	13.3	13.3
Pond (D)	Stormwater	30/30	486.2	486.2	79.6	79.6
Hundstrup River (DK)	Agricultural	5/5	NE	NE	6.9*	6.9*

NE: not estimated, NR: no retention. * Landowners have been compensated economically for all income decreases

prerequisites, e. g. the period of function after creation of a wetland as well as the contracting period with landowners, can be assumed, and this will influence the estimated marginal cost (Table 1). The most cost efficient situation appears in those situations where the wetland is highly loaded, implying low percent removal, but a high retention per unit area (Figure 3) although such a situation may be undesirable for other reasons as discussed below.

Wetlands in a historical perspective in the Bernet regions

In the 19th and 20th centuries, wetlands in Baltic Sea catchments have been reclaimed for agriculture, forestry and peat mining far beyond the limit for stable ecosystems (Figure 4). In very intense agricultural regions such as Schleswig-Holstein and Fyn only 20% to 25% of the original wetland area remains. In Gdansk Region the wetland loss is less but many of the remaining wetlands are in a seminatural state because of partial drainage. In Laholm Bay Drainage Basin the loss has been almost total in the coastal zone, while in the Swedish uplands, the wetland area reclaimed for forestry has been partly compensated through establishment of dams for hydroelectric power. This trend of decreasing wetland area is shared by many other European countries (EC, 1995).

Because of soil subsidence after drainage, many reclaimed wetland areas are no longer used for intensive agriculture, but, for example, for set aside soils. It is therefore reasonable to conclude that reclamation of wetlands in most cases has been highly unsustainable.

Wetland reclamation has resulted in increasing transport of nutrients to watercourses even without additional application of nutrients in the catchments (Fleischer and Stibe,

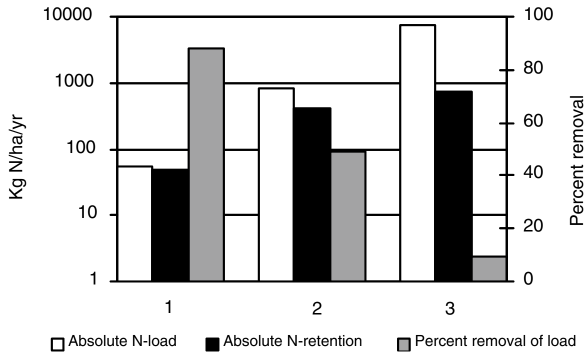

Figure 3 Schematic presentation of the functioning of nitrogen retention in three wetlands. High nitrogen retention in absolute terms can only be achieved if the wetland has a high nitrogen load (3). Low load will result in a low areal retention, but a high retention when expressed relatively (1). The situation (3) with a low relative removal implies lower costs and will remove more nitrogen per unit area. However, to fulfil the objectives for a reduced nitrogen load of the Baltic Sea, the situation with higher relative removal and a low retention in absolute terms (3) should be promoted

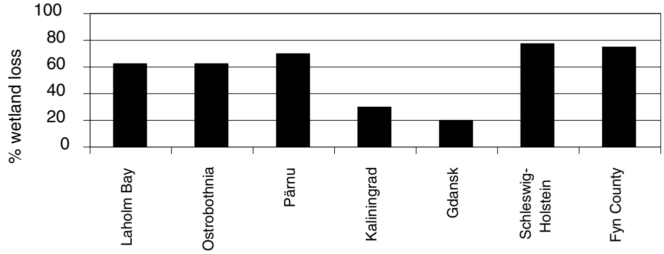

Figure 4 The relative loss of wetland areas within the seven BERNET catchments during the last 150 years. Gdansk and Kaliningrad data are rough estimates

1991). Thus, drainage activities imply a short circuit of the hydrological cycle, giving rise to nutrient losses from the previously water logged soils as well as production of ochre and acidification. Former wetland areas have lost the hydrological contact with drainage water from the watersheds since this water – together with nutrients – in most cases is directed directly to the watercourses. In addition, subsoil drainage in agricultural soils results in reduced contact between infiltrating water and the soil contributing to additional nutrient losses (Bernet, 2000c).

Comprehensive programmes to reduce nutrient emissions from cities and municipalities have been successful as far as fresh waters are concerned, where P alone is the limiting nutrient. In coastal waters, where N loading also must be decreased, a positive effect from solely reducing point sources has failed to appear, or, very often, the situation has even become more serious. However, this is logical as non-point sources, especially agricultural land, are the predominating causes of coastal eutrophication in many of the regions surrounding the Baltic Sea. Thus, a large fraction of the land area is occupied by intensive agriculture and forestry (Figure 5).

Wetland reclamation results in decreased retention capacity of the catchments, and application of nitrogen on agricultural areas increases nitrogen run-off from the catchments (Figure 6). A higher efficiency in the use of nitrogen and other nutrients is an overall pre-requisite for decreasing eutrophication of terrestrial and aquatic environments. To improve the environmental situation of the Baltic Sea such measures must be combined with reduced emissions from point sources and increased retention of N during run-off, implying restoration or creation of wetlands

Wetlands as building blocks in water quality management

Lakes, ponds, wet meadows, and fens are all valuable in the context of aquatic eutrophication management because they trap N from incoming water (Figure 7). Common to natural and constructed wetlands is, that those wetlands which have the highest absolute areal N removal are those wetlands which have the highest areal load. This, however, does not

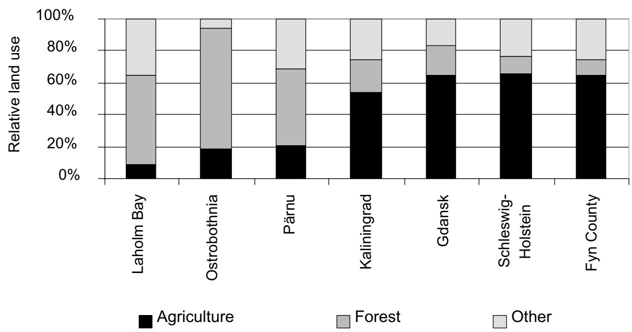

Figure 5 Land use in the catchments within the BERNET regions. Kaliningrad data is a rough estimate. "Other" is urban structures, freshwater areas and nature areas

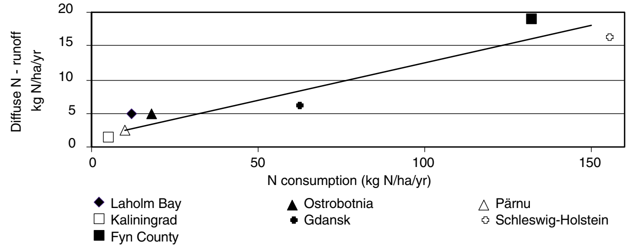

Figure 6 Diffuse N-transport in BERNET region watercourses compared to total applied N-fertilizers (manure + artificial) within the total catchment of the watercourses ($Y = 0.1022X + 2.323$, $r^2 = 0.90$)

imply that high loaded wetlands should always be preferred. There is a risk that high loaded wetlands become unstable habitats with a poor diversity of flora and fauna and fragile ecosystems with respect to nutrient processing (Hoffmann, 1998). Wetlands should therefore only be loaded with nutrients in respect of their natural trophic state.

Analysing the effect of wetland restoration on nutrient transport (Figure 7) clearly demonstrates that wetland restoration, in combination with other measures, can function as a tool in Baltic Sea water quality management. Constructed ponds generally show a N retention in the range from 200 to 1,000 kg N/yr/ha, although higher retention rates have been observed. In constructed wet meadows irrigated with drainage water the N retention ranges from 180 to 650 kg N/yr/ha. Monitoring shows that many natural lakes retain nitrogen in the range from 70 to 500 kg N/yr/ha which is also the case for natural fens and meadows.

Existing wetlands have a definite capacity to transform nutrients which is reflected in the size of the present total discharge of nutrients to coastal waters. In Laholm Bay Drainage Basin and in Fyn County it has been estimated that present wetlands retain approximately 20% and 5–10%, respectively, of the N leached from terrestrial diffuse sources (Bernet, 2000b). Also P has been shown to be effectively trapped in, for example, lakes (Bernet, 2000b). The environmental effect of this P retention is more unknown than the effect of N retention. This is because many lakes have accumulated an anthropogenic pool of P in their sediments originating from household and industrial waste waters and from agriculture. The internal P pool can be available for algae growth for many years in the same way as P leached from agricultural soils.

To counteract eutrophication of the Baltic Sea one measure is to increase the retention of substances in the watersheds. By restoring reclaimed wetland areas the speed of runoff water is reduced and water with its associated substances is retained. Typically, wetlands are constructed as ponds and lakes or as wet irrigated meadows in river valleys (Figure 7).

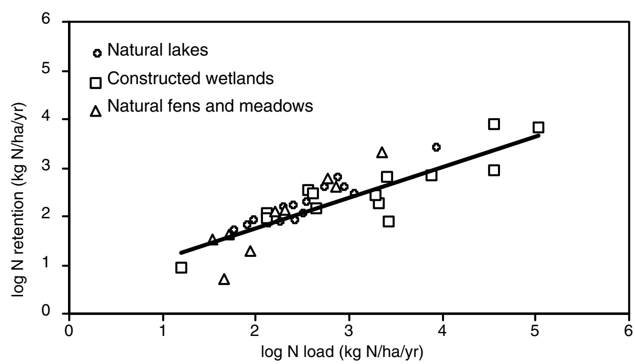

Figure 7 The areal retention of nitrogen is significantly ($p<0.001$) related to the areal specific nitrogen load of wetlands in the BERNET regions ($n = 40$; $Y = 0.6887X + 0.4255$; $r^2 = 0.78$). Constructed wetlands are ponds and irrigated wet meadows

In Kaliningrad, the background for wetland re-establishment is connected more to recession in the agricultural sector than to the need for increased retention capacity. Thus, the drainage of lowlands is simply abandoned.

Removal of nutrients in wetlands can only be changed through changes in wetland area, wetland use, nutrient load, and catchment hydrology. To increase the nutrient retention capacity of catchments it is important to locate restored wetlands strategically, i.e. where the most intense nutrient transport occurs. In the coastal zone of Laholm Bay Drainage Basin and in Ostrobothnia concrete action plans for wetland restoration exist in relation to water quality management (Table 2). In Fyn County, wetland restoration is even part of the regional plan for spatial planning and as such associated with legal guidelines (Paludan and Fuglsang, 2000). If these ambitious measures are fulfilled N retention in wetlands can be increased by almost 100% as compared to the present situation.

Obstacles to wetland restoration

With regard to implementation of wetland restoration programmes, the outcome of scientific results does not seem to be the main problem. Economic and legal problems as well as landowner and authority traditions are more difficult to overcome. An administrative frame with specific guidelines for environmental administration can benefit the process of wetland restoration and conservation. Conservation and restoration initiatives require that the landowners entering a project are compensated economically. This is linked to the competition for land and space and to the agricultural structure. Different kinds of subsidies exist. Most of the existing agricultural subsidies from the EC counteract the possibilities for another land use, because the subsidies are directed towards production aid. This will probably be changed since future EC agricultural subsidy programmes will be directed towards integration of production and environmental measures.

Further, decisions can be difficult to make if the administrative structure is too multi-levelled. Many bureaucratic administrative levels slow down the decision making. If the information level is low it may be difficult for the landowners to accept a restoration project. Thus, it is crucial that the landowners are informed about the necessity for the projects and are informed about the future perspectives (agricultural, economic, etc.) if they join a project. In Kaliningrad the situation is different. In this region the land is state property and 370 km^2 of wetlands and agricultural soils have been conserved by the local government in 1999, induced by BERNET.

Conclusions

Existing wetlands should be protected by law and any kind of reclamation must be stopped. Legislation should make restoration of wetlands possible including an efficient economic

Table 2 Upscale of expected nitrogen retention in planned restored wetlands in three catchments of the Baltic Sea

Bernet region	Action plan	Area involved (ha)	Estimated N ret (tons N yr^{-1})	Total costs mill. EUR	National share of costs (%)	Retention relative to diffuse load of coastal waters (%)
Laholm Bay Drainage Basin, Sweden	Regional wetland restoration plan	240	180**	3.8	69	2.8
Ostrobothnia, Finland	Söderfjärden Project***	1,600	32*	0.95	50	0.5
Fyn County, Denmark	Action plan on the Aquatic Environment II	1,600	560	12.1	47	7.3

* Estimated from decrease in use of fertilizer and manure. Denitrification not included. ** Assuming that ponds retain 750 kg N ha^{-1} yr^{-1}. *** Realized project

framework and consideration of wetlands as building blocks in regional action plans for water quality management. An administrative framework with legal guidelines and necessary resources must be available to enforce wetland protection and restoration. Economic compensation must be paid to landowners entering wetland restoration projects. Economic subsidies that guarantee sustainability must be established and these subsidies must be more attractive than – and competitive than – existing subsidies. The success of these initiatives depends on public awareness and education about wetland values.

Wetland restoration should be considered in all areas with intensive land-use and the wetlands should be located strategically. Intensive use of land areas (agriculture and forestry) is connected to leaching of nutrients. Wetlands can only retain nutrients which have entered surface waters after leaching if the wetlands are located where the nutrient transport to coastal waters occurs.

Wetland restoration should be used to reduce the nutrient load of coastal waters in combination with other measures to reduce leaching. Wetland restoration must be permanent and nutrient loading must only occur in respect of the multi-functioning of this ecosystem type. In some BERNET regions wetland restoration shall be realized to fulfil national and international obligations for eutrophication management. To secure long term stability and the highest cost efficiency mature wetlands must be preferred. This is true not only with respect to nutrient retention but also with respect to maintenance of biodiversity and recreational possibilities. Hence, loading of wetlands with waste waters should be avoided in general.

It should be more widely accepted that environmental authorities are allowed to acquire areas suitable for wetland restoration under compulsory powers. Due to complex property structures and private interests many potential wetlands are unavailable for the environmental authorities to restore.

An expert system should be developed. The system should locate the right position and find the right wetland type to secure the most cost efficient solution for the region. This also requires up-to-date knowledge of present land-use. The system will form the basis for political decisions and increase the awareness of monitoring and applied research.

Acknowledgements

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References

Bernet (2000a). *Aquatic Monitoring and Assessment. Vol. 1. Synthesis. BERNET theme report*. Fyn County, Odense, Denmark (ISBN 87-7343-430-2). 50 pp.

Bernet (2000b). Wetland Management. BERNET theme report. Fyn County, Odense, Denmark (ISBN 87-7343-429-9). 45 pp.

Bernet (2000c). *Sustainable Agriculture and Forestry. BERNET theme report.* Fyn County, Odense, Denmark (ISBN 87-7343-427-2).143 pp.

EC (1995). *Wise use and conservation of wetlands*. Commission Communication to the council and the European Parliament. 79 pp.

Fleischer, S. and Stibe, L. (1991). Drainage basin management – reducing river transported nitrogen. Verh. *Internat. Verein. Limnol*. **24**, 1753–1755.

Fuglsang, A. (1998). Rehabilitation of rivers using wet meadows as nutrient filters. In: *Rehabilitation of rivers – principles and implementation*, L.C. de Wall (ed.), Wiley, pp. 97–111.

HELCOM (1988). Declaration of the Helsinki Convention.

Hoffmann, C.C. (1998). Nutrient retention in wet meadows and fens. Ph.D. Thesis. NERI, Denmark. 134 pp.

Paludan, C. and Fuglsang, A. (2000). Hydrological restoration to improve nitrogen retention in Danish wetlands. *Nordic Hydrology Programme. Report no.* **46**, pp. 101–108.