

NUTRIENT LEVELS IN A CONSTRUCTED WETLAND SYSTEM GLOŽAN (VOJVODINA PROVINCE)

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Abstract

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The constructed wetland system (CWS) located near the village of Gložan is the first system for wastewater treatment built in the Vojvodina Province (Serbia). The CWS at Gložan has been designed to treat municipal wastewater. The CWS uses the reed (*Phragmites australis* (Cav.) Trin. Ex Steud.) as a biofilter, the plant species that had grown naturally at the site prior to the construction of the CWS. In the study period, the Gložan CWS proved to be capable of effectively removing nutrients from wastewater. Removal rates for nitrogen compounds ranged from 47.3% for nitrates, 47.5% for ammonium, to 78.3% for nitrites, while the phosphorus removal rate was 29.1%. The efficiency of the system is clearly a result of a combined action of microbes and the reed residing in the CWS. The analysis of the chemical composition of the reed confirmed that it acted as a biofilter, i.e., nutrients were found to accumulate in its parts. Reed leaves accumulated largest amounts of nitrogen (up to 42.7 g kg⁻¹ DM), while the inflorescence accumulated largest amounts of phosphorus (up to 2.1 g kg⁻¹ DM). The Gložan CWS retained on average 292 kg P year⁻¹ and 2920 kg N year⁻¹.

Key words: wastewater, constructed wetland, *Phragmites australis*, nitrogen, phosphorus, purification, Vojvodina

Abbreviations: CWS - constructed wetland system, DM - dry matter

Introduction

Wetlands have been recognised as a natural resource throughout human history. Their importance is appreciated in their natural state by such people as the Marsh Arabs around the confluence of the rivers Tigris and Euphrates in southern Iraq, as well as in managed forms; e.g., rice pad-

dies, particularly in South East Asia (Mitsch and Gosselink, 2000). The natural water purification processes occurring within these systems have become increasingly relevant to practical use of constructed or even semi-natural wetlands for water and wastewater treatment (Scholz, 2006).

Wastewaters are often discharged into the recipients without any pretreatment, which rep-

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resents a serious threat to the quality of water and its further usability. As a consequence, many water resources have been brought to the state of unsatisfactory water quality, which affects the health of people and all living world in the environment. A first step in preserving a satisfactory quality of water resources is certainly an appropriate treatment of wastewaters. Various methods have been used to achieve this, and a special place among them occupies constructed wetland systems (CWS). These systems represent a combination of biological, chemical and physical processes, and their remarkable characteristics are practicality, economic, and simplicity of exploitation (Lakatos, 1998). The essence of the CWS method is in the utilization of phytofiltration and phytoaccumulation capacities of marsh plants (Brix, 1994a; Ellis et al., 1994; Urbanc-Berčić, 1997; Nikolić et al., 2003 and Nikolić et al., 2007). Besides, due to the favorable conditions, the root zones of these plants are amply populated with microorganisms, which are of essential importance in the transformation of nitrogen and its compounds, through the processes of ammonification, nitrification and denitrification (Greenway, 2007), as well as in the mineralization of organic matter (Jarak and Čolo, 2007).

Nutall et al. (1998) presented a list of aquatic plants that are suitable for the application in the CWS, and among them a special place occupies the emergent species like *Phragmites australis* (Cav.) Trin. ex Steud, *Typha latifolia* L. and *T. angustifolia* L., as the species which bear well high organic loads. Brix (1994a, 1994b) also mentioned the importance and manifold functions of reed in the functioning of CWSs.

CWSs can be applied in the different stages of water treatment (primary, secondary, tertiary), to treat municipal wastewaters, wastewaters from the different industries and farms, runoffs from the agricultural, urban and traffic areas, as well as of landfill leachates (Cooper and Clarke, 2001). Lakatos (1998) pointed out that CWSs are most suitable to treat wastewaters of smaller rural settlements.

The Vojvodina's population of more than two millions of inhabitants lives in 467 settlements. Of this number, 404 are settlements with less than 5000 inhabitants, having no systems for collecting and treating local wastewaters. The main reason for such a situation is the shortage of financial resources. Hence, in these settlements use is made of septic tanks, so that their leaks contaminate ground waters, whose level in this region is rather high. Contents of septic tanks are disposed on the fertile soil or to water bodies. Thus the soil and water resources are constantly contaminated. A promising solution to this problem would be to construct low-pressure sewerage systems for collecting used waters and treating them in CWSs.

In the studied CWS located near Gložan (in the vicinity of Novi Sad, the Vojvodina Province, Serbia), the dominant emergent species was the reed - *Phragmites australis* (Cav.) Trin. ex Steud.. The paper presents multi-year results of analyses of nutrient contents in reeds and wastewater from the CWS near Gložan. It shows that differences existed in the chemical composition of nitrogen compounds and total phosphorus at the entrance and exit of the CWS indicating a high efficiency of the system in purifying municipal wastewater. The objective of the paper was to consider the applicability of CWSs for the removal of nutrients from municipal waste water, using the extraction of nitrogen and phosphorus as an example.

Study area

In the fall of 2004 in the village of Gložan, a facility for purification of municipal wastewater was put in operation in whose technological process the cane was the main bio-purifier. The geographic position of Gložan is 45° 17' north latitude and 19° 33' east longitude. It is situated between 80 and 82 m above sea level. Surface water courses in the area are the Danube River and several drainage canals. The Danube is 6 km away from the village and in this part it makes a meander (Figure 1). Between the village and the Danube River, there is a



Fig. 1. A map of the studied area

deep floodplain protected from high waters with a levee and it is drained by a man-made melioration system. The floodplain is situated at 76.5 m above sea level and it has several ditches that represent the former branches of the river.

According to its geographical position, the village of Gložan is located in a zone of temperate continental climate. The fall is warmer than the spring, and the temperature change from winter to summer is somewhat more sudden than that from summer to winter. The precipitation has a distribution pattern characteristic for regions along the Danube River, with large differences between months. The Gložan population is 2275 inhabitants. The waterworks are constructed in 1973, and to the construction of the sewerage system in 2004 use was made of septic tanks.

The studied CWS is located in an alluvial

floodplain of the Danube, south of the village of Gložan, between two drainage canals. The altitude of the CWS site is 76.50 m asl, and the terrain is practically horizontal. The CWS site has features of a swamp. The CWS comprises three fields with a total area of 9400 m². The constructed CWS is a horizontal sub-surface flow (Cooper and Clarke, 2001). The substrate consists of gravel strips 0.6 m wide and 0.6 m thick, which alternate with strips of natural soil 1.0 m wide (Figure 2). The surface layer is gravel mixed with soil and planted with reeds. The lining is the impermeable clay layer that underlies the field. Wastewater purification proceeds through three fields in a row. In field I, the wastewater remains for 24 hours, in field II for 48 hours and in field III for 33 hours. The technological process can be divided to the collection and transportation of wastewater, purification in the



Fig. 2. CWS in construction (2004) and after several years of operation

CWS and the discharge of the purified water into a channel which empties into the Danube (Belić et al., 2004).

Materials and Methods

Measurements at the Gložan CWS included the taking of samples for laboratory analyses of nitrogen compounds and total phosphorus in wastewater and biological research/investigation/observations in the multi-year. Measurements were made at distinctive points of the CWS (Figure 3): the entrance to field I (measurement point 1), the entrance to field II (measurement point 2), the entrance to field III (measurement point 3), and the exit, between field III and the discharge canal (measurement point 4).

The following methods were applied: water sampling according to JUS ISO 5667-1, for chemical analyses of ammonium (ISO 7150-1), nitrites

and nitrates (SEV 1973), and total phosphorus (ISO 6878/1). Samples were formed on the basis of a series of measurements at the measurement points in the CWS. The samples were numerically expressed in the form of average values.

Standard methods (APHA 1995) were used to collect and analyze plant material from the CWS. Plant material was collected at the end of vegetation, in all three ponds of the CWS. Content of nutrients (N and P) was determined in vegetative and generative parts of the reed (leaf, stem, rhizome with roots and inflorescence). The collected plant material was rinsed with distilled water, dried at 100 °C and ground. Total nitrogen in dry weight was determined by the standard microkjeldahl method (Nelson and Sommers, 1973). Content of total phosphorus was determined after ashing and treatment with HCl, spectrophotometrically, by the ammonium molybdate-vanadate method (Gericke and Kurmies, 1952). All analyses were

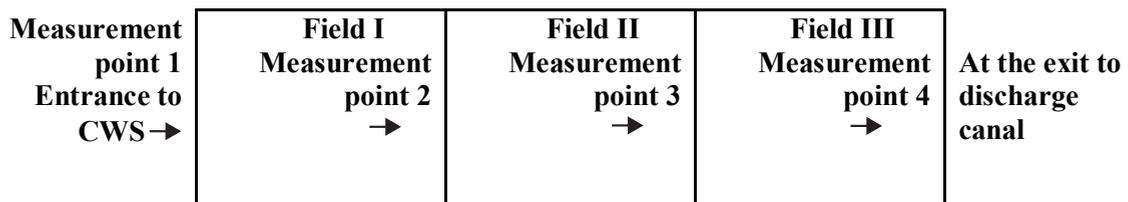


Fig. 3. A diagram of sampling sites in the CWS

done in three replications.

To determine significance of differences in nutrients content in dry weight of the reed, data for plant parts and CWS ponds were subjected to the analysis of variance (ANOVA). The least significant difference (LSD) test was done at the significance levels of 0.05 and 0.01.

Total inorganic nitrogen (ammonium, nitrite and nitrate) and total phosphorus, which are collected on the CWS, were estimated by hydraulic load. The average hydraulic load was determined by volumetric method. The average yearly flow for the Gložan CWS working period amounts to 2.25 l s^{-1} .

Results

Previous literature results indicated the differences in the efficiency of wetland functioning, which can be ascribed to a great number of variables. These are: natural conditions (geographic, climatic, hydrological) of the region, amount and quality of treated water, required quality of the effluent, characteristics of the substrate, hydrological system, type and characteristics of the aquatic plants, etc (Kadlec and Wallace, 2008).

The measurement carried out on the Gložan CWS gave results regarding to satisfied chemical indicators. Based on the influent (measuring point 1) and effluent (measuring point 4) data it was possible to calculate the overall removal efficiencies, and they were used to estimate the effects of the treatment (Table 1). The Gložan CWS retained on average $292 \text{ kg P year}^{-1}$ and $2920 \text{ kg N year}^{-1}$ (Table

2). The bioaccumulation of nutrients in the plant organs are confirmed by the results of chemical composition of the reed (Table 3).

Discussion

Nitrogen extraction from wastewater

Raw municipal wastewater of the Gložan settlement has a high content of inorganic nitrogen, mostly in the form of ammonium, but nitrates and nitrites are also present. The efficiency of ammonium removal in the CWS was 47.5% (Table 1). While the content of ammonium in field I decreased, in fields II and III it was transformed in the other forms and/or taken up by plants, which was significantly less pronounced.

The processes occurring most in the CWS are nitrification and ammonification. The former process takes place in fields I and II, while ammonification is characteristic of field III.

Nitrogen transformation in the CWS was closely associated with the activity of microorganisms present in the water and substrate, and it proceeded through the processes of denitrification and ammonification (Lund et al., 2000 and Greenway, 2007). The activity of individual groups of microorganisms depends on the aerobic and/or anaerobic conditions prevailing in the CWS. Based on the monitoring of ammonium, nitrites and nitrates, nitrification is in due process in the Gložan CWS. Denitrification and ammonification are also in evidence (Belić et al., 2006).

Based on average values, the total inorganic nitrogen load in the Gložan CWS is 8.0 kg day^{-1} ,

Table 1
Effects of wastewater treatment in the Gložan CWS (2005-2007)

Parameter/indicator of water quality	Meas. point 1, mg L^{-1}	Meas. point 2, mg L^{-1}	Meas. point 3, mg L^{-1}	Meas. point 4, mg L^{-1}	Treatment efficiency, %
Ammonium	86.25	56.98	51.54	45.28	47.5
Nitrite	0.092	0.244	0.182	0.020	78.3
Nitrate	0.230	0.410	0.210	0.120	47.3
Total phosphorus	14.46	10.58	8.72	10.25	29.1

Table 2
The average nutrients load at the Gložan CWS (2005-2007)

Parameter	Meas.point 1, kg day ⁻¹	Meas.point 4, kg day ⁻¹	Difference, kg day ⁻¹	Nutrients load at the CWS, kg year ⁻¹
Total inorganic nitrogen	16.8	8.8	8.0	2920.0
Total phosphorus	12.8	2.0	0.8	292.0

or 2920.0 kg year⁻¹ (Table 2), of which amount a certain portion of nitrogen is taken up by the dense reed population. Ammonium/or nitrates taken up by plants are also stored in reed phytomass.

Reed leaves contained highest nitrogen levels, which was expected from the physiological point. The N content ranged from 29.3 g kg⁻¹ DM (2005, field II), up to 42.7 g kg⁻¹ DM (2007, field I) (Table 3). Our results are consistent with the data recorded by Dinka (1986), but are slightly higher than the results for reed leaves from Koviljski Rit (Pajević et al., 2002). The increased nitrogen content in leaves of the reeds growing in the municipal wastewater purification systems can be explained by the quality of the municipal water entering the CWS (Belić and Josimov-Dunderski, 2007). Substantial

concentrations of nitrogen were accumulated in inflorescences and rhizomes with roots, while the lowest concentration of nitrogen accumulated in reed stems (Table 3).

Studies of Mitsch and Gosselink (2000) confirmed that the anoxic conditions that prevail in most CWSs cause the process of denitrification to release gaseous nitrogen from lithosphere and hydrosphere into the atmosphere. Ammonium bound in the soil can be absorbed by root systems of macrophytic plants and again transformed into organic matter. This process can also be performed by anaerobic microorganisms. Scholz (2006) reported that studies carried out in southern California had shown that denitrification is the most likely pathway for the loss of nitrogen from CWSs.

Table 3
Nutrients content in reed (g kg⁻¹ DM) (2005-2007)

Plant organ	Field	2005		2006		2007	
		N	P	N	P	N	P
Bloom	I	24.7	1.6	28.2	2.1	27.1	1.9
	II	25.8	1.7	30.1	2.0	27.6	1.5
	III	24.8	1.5	32.9	1.6	23.9	0.9
Leaf	I	34.2	1.1	31.0	1.3	42.7	1.2
	II	29.3	0.8	36.5	1.4	32.1	0.9
	III	34.2	0.9	36.7	1.4	28.3	0.7
Stem	I	10.5	0.4	9.4	0.7	11.7	0.3
	II	7.0	0.3	10.2	0.7	9.9	0.2
	III	8.6	0.2	10.5	0.9	8.0	0.5
Rhizome + root	I	11.5	0.4	8.5	0.4	21.5	0.8
	II	8.7	0.2	11.4	0.4	10.2	0.2
	III	8.2	0.2	13.9	0.6	8.5	0.2

Furthermore, the nitrogen removal from influent wastewater is generally less intensive in CWSs than in swamp systems and waterlogged land. There is considerable interest to increase bacterial denitrification in CWSs, in order to reduce the eutrophication rate in the recipient water body. Further support to the importance of denitrification was given by Lund et al. (2000).

Phosphorus removal from wastewater

According to the obtained average values, the efficiency of phosphorus removal in the CWS was 29.1% (Table 1).

Based on average values, the total phosphorus load at the Gložan CWS is 0.8 kg day^{-1} or $292.0 \text{ kg year}^{-1}$ (Table 2). Phosphorus sedimentation and sorption of soluble phosphorus are the two physical processes that remove phosphorus. In the Gložan CWS, the former process is predominant in the phosphorus cycle in the substrate.

The lowest values of phosphorus (0.2 g kg^{-1} DM) were recorded in the rhizomes with roots and stems (fields II and III, 2005 and 2007), while the highest value was found in the inflorescence (2.1 g kg^{-1} DM, 2006, field I) (Table 3). Such distribution is characteristic for the accumulation of phosphorus in the different parts of the reed (Pajević et al., 2002 and Nikolić et al., 2003). Regarding the phosphorus content, which is present in the substrate of wetlands in the forms of soluble and insoluble organic and inorganic complexes, the reed is a good bio-accumulator of this element, especially in the phase of intensive growth.

To achieve the necessary efficiency in the removal of phosphorus in the Gložan CWS, it is necessary to timely harvest the reeds (after the formation of inflorescences) and remove the harvested biomass from the ponds, which had not been done during the examined period.

According to Wang and Mitsch (2000), previous research has shown that the dominant way to retain phosphorus in CWSs is by physical sedimentation. Reddy et al. (1999) noted a tendency of phosphorus to be deposited with certain ions,

depending on the acidity/alkalinity of the substrate. According to Molle et al. (2004), although laboratory tests using the jar test achieved phosphorus reduction of almost 85%, the results of phosphorus removal in a CWS did not exceed 40%.

A pilot CWS in north-eastern Illinois has shown an increase of total phosphorus in water, in the presence of quiescent macrophytes and the period of their initial growth. Most of the phosphorus that macrophytes take up from the substrate returns to the substrate in the form of dead plant material. By harvesting macrophytes at the end of vegetation season, phosphorus can be removed from its internal cycle in the CWS (Wang and Mitsch, 2000).

Conclusions

The results presented for the Gložan CWS demonstrate the usability of such systems under the conditions of moderate continental climate, which could be an essential contribution to the sustainable development and environmental protection. The obtained results indicated that the rate of removal of nitrogen compounds ranged from 47.3 to 78.3% while the rate of phosphorus removal was 29.1%. On average, the CWS retains $292 \text{ kg P year}^{-1}$ and $2920 \text{ kg N year}^{-1}$. A considerable portion of these macronutrients is taken up by the dense reed population which thrives and grows intensively in the examined CWS (Josimov-Dunderski, 2010).

The analysis of variance, at the significance level of 0.05 and 0.01, indicated that there existed highly significant differences in the contents of N and P among the analyzed plant parts, as well as among the three ponds in the examined system for treatment of municipal wastewater. These observations may be due to the physiological specificity of individual plant parts, but also due to different contents of these nutrients in the wastewater entering the system and different eco-hydrological conditions at the times the wastewater is let into the system.

In the process of nutrients extraction from municipal wastewater, in addition to the physical and

chemical actions of the CWS, we place emphasis on the biological action of the reed. The relatively high N and P contents in the reed indicate that it a very successful biological accumulator of nutrients. The Gložan CWS successfully retains nutrients and thus reduces their concentration in wastewater, which after treatment flows into the Danube as the final recipient.

The system for purification of municipal wastewater should be permanently monitored and maintained. These activities involve, in the first place, a timely reed harvesting and removal of plant residues, which are done in order to avoid their decay that causes a secondary pollution of the system.

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References

- APHA, 1995. Standard Methods for the Examination of Water and Wastewater. Franson M.H. (Editor), 19th Edition American Public Health Association, Washington.
- Belić, A. and J. Josimov-Dunderski, 2007. Biosystems in wastewater treatment. *University of Novi Sad Faculty of Agriculture*, Novi Sad, 84 pp.
- Belić, A., J. Josimov-Dunderski and M. Jarak, 2006. Efficiency of the Glozan Constructed Wetland. 10th International Conference on Wetland Systems for Water Pollution Control, (Proceedings of Symposium, Lisbon, 23-29 September, 2006. IWA) Lisbon, pp. 777-784.
- Belić, A., V. Ratković, J. Josimov-Dunderski and P. Ivković, 2004. Glozan – the first constructed wetland in Vojvodina Province. 9th International Conference on Wetland Systems. (Proceedings of Symposium, Avignon, 26-30 September, 2004. IWA and ASTEE), Avignon PC12HS01 on Compact Disc.
- Brix, H., 1994a. Functions of Macrophytes in constructed Wetlands. *Water Science and Technology*, **29** (4): 71-78.
- Brix, H., 1994b. Use of constructed wetlands in water pollution control: Historical development, present status, and future perspectives. *Water Science and Technology*, **30** (8): 209-233.
- Cooper, P. and T. Clarke, 2001. Reed Bed and Constructed Wetland Wastewater Treatment Systems. *Aqua Enviro Technology Transfer*, Leeds.
- Dinka, M., 1986. Accumulation and distribution of elements in cattail species (*Typha latifolia* L., *Typha angustifolia* L.) and reed (*Phragmites communis* (Cav.) Trin. ex Steudel) living in lake Balaton. 7th Symposium on Aquatic Weeds. (Proceedings of Symposium EWRS/AAB, 15-19 September, 1986.), Quorn Selected Repro., Loughborough, pp. 82-85.
- Ellis, J. B., D. M. Revitt, R. B. E. Shutes and J. M. Langley, 1994. The performance of vegetated bio-filters for highway runoff control. *The Science of the Total Environment*, **146/147**: 543-550.
- Gericke, S. and B. Kurmies, 1952. Die kolorimetrische Phosphorsäurebestimmung mit Ammonium-Vanadat-Molybdat und ihre Anwendung in der Pflanzenanalyse. *Z. Pflanzenernährung, Düngung, Bodenkunde*, **59** (3): 32-35.
- Greenway, M., 2007. The Role of Macrophytes in Nutrient Removal using Constructed Wetlands. *Environmental Bioremediation Technologies*, pp. 331-351.
- Jarak, M. and J. Čolo, 2007. Soil Microbiology. *University of Novi Sad Faculty of Agriculture*, Novi Sad, 209 pp.
- Josimov-Dunderski, J., 2010. Eco-hydrological conditions for the application of constructed wetlands in Vojvodina. Thesis (PhD), *University of Novi Sad Faculty of Agriculture*, Novi Sad, 193 pp. (Sr).
- Lakatos, G., 1998. Hungary. In: J. Vymazal et al. (Editors), *Constructed Wetlands for Wastewater Treatment in Europe*. M.B.Green & R.Haberl, Backhuyis Publishers, Leiden, pp. 191-206.
- Lund, L. J., A. J. Horne and A. E. Williams, 2000.

- Estimating denitrification in a large constructed wetland using stable nitrogen isotope ratios. *Ecological Engineering*, **14** (1-2): 67-76.
- Mitsch, W. J. and J. G. Gosselink**, 2000. Wetlands. *John Wiley & Sons*, New York, 920 pp.
- Molle, P., A. Cenare, C. Boutin, G. Merlin and A. Iwerna**, 2004. How to treat raw sewage with constructed wetlands: an overview of the French systems. *9th International Conference on Wetland Systems*. (Proceedings of Simposium, Avignon, 26-30 September, 2004. IWA and ASTEE), Avignon, pp. 11-19.
- Nikolić, Lj., S. Stojanović and Ž. Stanković**, 2003. Content of macro- (N, P, K) and micronutrients (Fe, Mn, Zn) in four promising emergent macrophytic species. *Large Rivers*, **14**, 3-4, *Archiv Hydrobiol Supplement*, **147** (3-4): 297-306.
- Nikolić, Lj., S. Stojanović and D. Lazić**, 2007. Role of reed (*Phragmites australis* (Cav.) Trin. ex Steud.) in the process of treatment of municipal wastewaters using constructed wetland systems. *Contemporary Agriculture*, **51** (3-4): 230-235
- Nelson, D. W. and L. E. Sommers**, 1973. Determination of total nitrogen in plant material. *Agronomy Journal*, **65**: 109-112.
- Nuttall, P. M., A. G. Boon and M. R. Rowell**, 1998. Review of the design and management of constructed wetlands. *Construction Industry Research and Information association (CIRIA), CIRIA Publications, Report R180*, London.
- Pajević, S., M. Vučković, Ž. Stanković, B. Krstić, Ž. Kevrešan and S. Radulović**, 2002. The content of some macronutrients and heavy metals in aquatic macrophytes of three ecosystems connected to the Danube in Yugoslavia. *Large Rivers*, **13**, 1-2, *Archiv Hydrobiol Supplement*, **141** (1-2): 73-83.
- Reddy, K. R., R. H. Kadlec, E. Flaig and P. M. Gale**, 1999. Phosphorus retention in streams and wetlands: a review. *Critical Reviews in Environmental Science and Technology*, **29** (1): 83-146.
- Scholz, M.**, 2006. Wetland Systems to Control Urban Runoff. *Elsevier*, Amsterdam, 333 pp.
- Urbanc-Berčić, O.**, 1997. Constructed wetlands for the treatment of landfill leachates: the Slovenian experience. *Wetlands Ecology and Management*, **4**: 189-197.
- Wang, N. and W. J. Mitsch**, 2000. A detailed ecosystem model of phosphorus dynamics in created riparian wetlands. *Ecological Modeling*, **126** (2-3): 101-130.

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