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Editorial

Growth and Development of Short-Rotation Woody Crops for Rural and Urban Applications

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Citation: Zalesny, R.S., Jr.; Pilipović, A. Growth and Development of Short-Rotation Woody Crops for Rural and Urban Applications. *Forests* **2022**, *13*, 867. https://doi.org/10.3390/f13060867

Received: 26 May 2022
Accepted: 28 May 2022
Published: 31 May 2022

1. Introduction

Woody biomass from short-rotation woody crops (SRWCs) plays a substantial role in feedstock production for alternative energy sources throughout the world, thus helping to mitigate climate change driven by excessive use of fossil fuels. The establishment of these biomass production systems presents the basis for more efficient development of renewable energy sources while avoiding impacts (e.g., additional emissions of carbon dioxide (CO_2) into the atmosphere) on essential ecosystem services such as clean water and healthy soils. In addition to these bioenergy-related uses, the increase of degraded land such as industrial brownfields and municipal landfills has prompted the integration of biomass production with phytotechnologies to produce income, sequester carbon, and clean the environment. Recognizing the need for information linking the silviculture of intensive forestry with the provision of ecosystem services, this Special Issue focused on the growth and development of SRWCs grown for numerous applications in rural and urban areas.

There are a total of 20 papers in the Special Issue representing 13 countries and four genera (*Phalaris* L., *Populus* L., *Robinia* L., *Salix* L.) (Figure 1; Table 1). In addition to the development and management of a *Salix* cultivar database [1], rural and urban applications represented in the Special Issue include: (a) *forest buffers* [2], (b) *forest health screening* [3,4], (c) *phytoremediation* [5–7], (d) *short rotation coppice* [8–15], (e) *volume production* [16–18], and (f) *wastewater reuse* [19,20] (Table 1). There were >130 genotypes from 27 genomic groups tested across all studies (Table 2), representing the importance of phyto-recurrent selection and other methods to choose clones for local and regional biomass production systems whose methodologies and approaches are relevant worldwide. Our objective in this editorial was to summarize each of the studies included in the Special Issue, which is included in the following section.

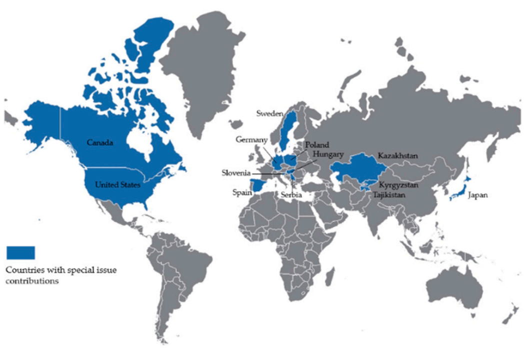

Figure 1. Countries with manuscript contributions in the Special Issue on the Growth and Development of Short-Rotation Woody Crops for Rural and Urban Applications (https://www.mdpi.com/journal/forests/special_issues/growth_development_woody_crops; accessed on 25 May 2022).

Table 1. Applications of short-rotation woody crops tested worldwide and described in the contributions of the Special Issue on the Growth and Development of Short-Rotation Woody Crops for Rural and Urban Applications (https://www.mdpi.com/journal/forests/special_issues/growth_development_woody_crops; accessed on 25 May 2022).

Application	Genus	Location	Contribution	DOI
Cultivar Database [1]	*Salix*	Global	McGovern et al. [1]	https://doi.org/10.3390/f12050631
Forest Buffers	*Populus*	Canada	Fortier et al. [2]	https://doi.org/10.3390/f12020122
Forest Health Screening	*Populus*	Serbia	Zlatković et al. [3]	https://doi.org/10.3390/f11101080
	Populus	Serbia	Galović et al. [4]	https://doi.org/10.3390/f12050636
Phytoremediation	*Populus*	United States	Zalesny et al. [5]	https://doi.org/10.3390/f12040430
	Populus	United States	Pilipović et al. [6]	https://doi.org/10.3390/f12040474
	Populus	Canada	Hu et al. [7]	https://doi.org/10.3390/f12050572
Short Rotation Coppice	*Salix*	Japan	Han et al. [8]	https://doi.org/10.3390/f11050505
	Salix	Japan	Harayama et al. [9]	https://doi.org/10.3390/f11080809
	Populus	Canada	Thiffault et al. [10]	https://doi.org/10.3390/f11070785
	Populus	Spain	González et al. [11]	https://doi.org/10.3390/f11111133
	Robinia	Spain	González et al. [11]	https://doi.org/10.3390/f11111133
	Populus	Spain	Oliveira et al. [12]	https://doi.org/10.3390/f11121352
	Populus	Germany	Landgraf et al. [13]	https://doi.org/10.3390/f11101048
	Populus	Kazakhstan	Thevs et al. [14]	https://doi.org/10.3390/f12030373
	Populus	Kyrgyzstan	Thevs et al. [14]	https://doi.org/10.3390/f12030373
	Populus	Tajikistan	Thevs et al. [14]	https://doi.org/10.3390/f12030373
	Populus	Hungary	Schiberna et al. [15]	https://doi.org/10.3390/f12050623
Volume Production	*Robinia*	Poland	Kraszkiewicz [16]	https://doi.org/10.3390/f12040470
	Populus	United States	Ghezehei et al. [17]	https://doi.org/10.3390/f12070869
	Phalaris	Sweden	Mola-Yudego et al. [18]	https://doi.org/10.3390/f12070897
Wastewater Reuse	*Salix*	Hungary	Kolozsvári et al. [19]	https://doi.org/10.3390/f12040457
	Salix	Slovenia	Istenič and Božič [20]	https://doi.org/10.3390/f12050554

[1] McGovern et al. [1] did not describe the growth and development of short-rotation woody crops for rural and urban applications but rather a database of *Salix* cultivars that can be used globally for genotype management and selection.

Table 2. Genomic groups, taxonomic sections, and genotypes of *Populus*, *Robinia*, and *Salix* tested worldwide and described in the contributions of the Special Issue on the Growth and Development of Short-Rotation Woody Crops for Rural and Urban Applications (https://www.mdpi.com/journal/forests/special_issues/growth_development_woody_crops, accessed on 25 May 2022).

Genomic Group [1,2]	Section [3]	Genotype [4]	Contribution
P. alba 'A'	*Populus*	'111PK', 'Ozolin'	[11,14]
P. balsamifera 'B'	*Tacamahaca*	See [7]	[7]
P. deltoides 'D'	*Aigeiros*	'7300502', '89M060', 'Antonije', 'Bora', 'Lux', 'PE19/66', 'Samsun', 'Viriato'	[4–6,12,14]
P. nigra 'N'	*Aigeiros*	'Tr 56/75', 'Bordils', 'Lombardo Ieones', 'Mirza Terek', 'Pyramidalis'	[12,14]
P. pamirica 'P'	*Tacamahaca*	Not specified	[14]
P. simonii 'S'	*Tacamahaca*	Not specified	[14]
P. trichocarpa 'T'	*Tacamahaca*	'Fritzi Pauley', 'Muhle Larsen', 'Trichobel', 'Weser 6'	[13,14]
P. alba × *P. tremula* '$AT_{tremula}$'	*Populus* × *Populus*	'4×Göttingen', 'P1'	[13]
P. deltoides × *P. deltoides* 'DD'	*Aigeiros* × *Aigeiros*	'140', '356'	[17]
P. deltoides × *P. maximowiczii* 'DM'	*Aigeiros* × *Tacamahaca*	'230', 'DM114', 'NC14106'	[5,6,17]
P. deltoides × *P. nigra* 'DN'	*Aigeiros* × *Aigeiros*	'9732-11', '9732-24', '9732-31', '9732-36', '99038022', '99059016', '2000 Verde', 'AF2', 'AF13', 'AF15', 'AF16', 'AF17', 'AF18', 'AF19', 'AF20', 'AF24', 'AF24', 'AF28', 'Agathe-F', 'BL Constanzo', 'Bellini', 'Blanc du Poitou', 'Branagesi', 'B-1M', 'Campeador', 'Canadá Blanco', 'DN2', 'DN5', 'DN34', 'DN177', 'Dorskamp', 'E-298', 'Flevo', 'Guardi', 'H-8', 'H-11', 'H-17', 'H-33', 'H-328', 'Harff', 'Heidemij', 'I-214', 'I-45/51', 'I-454/40', 'Isières', 'Jacometti 78 B', 'Koltay', 'Kopecky', 'Kornik-21', 'Luisa Avanzo', 'MC', 'Oudenberg', 'Orion', 'Pannonia', 'Robusta', 'Tiepolo', 'Triplo', 'Veronese', 'Vesten'	[3–6,12–15]
P. maximowiczii × *P. nigra* 'MN'	*Tacamahaca* × *Aigeiros*	'Rochester'	[13]
P. maximowiczii × *P. trichocarpa* 'MT'	*Tacamahaca* × *Tacamahaca*	'Androscoggin', 'Fastwood-1', 'Fastwood-2', 'Matrix-11', 'Matrix-24', 'Matrix-49', 'NE42'	[13,14]

Table 2. *Cont.*

Genomic Group [1,2]	Section [3]	Genotype [4]	Contribution
P. nigra × *P. maximowiczii* 'NM'	*Aigeiros* × *Tacamahaca*	'Max-1', 'Max-3', 'Max-4', 'NM2', 'NM5', 'NM6'	[5,6,13,14]
P. trichocarpa × *P. deltoides* 'TD'	*Tacamahaca* × *Aigeiros*	'Beaupre', 'Boelare', 'Raspalje', 'Unal', '185', '49-177'	[12,17]
P. tremula × *P. tremuloides* '$T_{tremula}T_{tremuloides}$'	*Populus* × *Populus*	'Esch5'	[13]
(*P. deltoides* × *P. nigra*) × *P. maximowiczii* 'DN×M'	(*Aigeiros* × *Aigeiros*) × *Tacamahaca*	'DN × M-915508'	[2]
P. laurifolia × (*P. deltoides* × *P. nigra*) 'L×DN'	*Tacamahaca* × (*Aigeiros* × *Aigeiros*)	'Kazakhstani', 'Kyzyl-Tan'	[14]
(*P. maximowiczii* × *P. deltoides*) × *P. trichocarpa* 'MD×T'	(*Tacamahaca* × *Aigeiros*) × *Tacamahaca*	Not specified	[10]
P. trichocarpa × (*P. trichocarpa* × *P. deltoides*) 'T×TD'	*Tacamahaca* × (*Tacamahaca* × *Aigeiros*)	'AF8'	[13]
(*P. trichocarpa* × *P. deltoides*) × *P. alba* 'TD×A'	(*Tacamahaca* × *Aigeiros*) × *Populus*	'I-114/69'	[12]
(*P. trichocarpa* × *P. deltoides*) × *P. nigra* 'TD×N'	(*Tacamahaca* × *Aigeiros*) × *Aigeiros*	'AF6', 'Monviso'	[13]
R. pseudoacacia '$P_{robinia}$'	na [5]	'Nyirsegy'	[11]
S. alba 'A_{salix}'	na	'Naperti', 'V-160'	[19,20]
S. pet-susu 'P_{salix}'	na	'P.C.51', 'P.G.12', 'P.G.D', 'P.I.62', 'P.I.81', 'P.I.82', 'P.T.59'	[8,9]
S. sachalinensis 'S_{salix}'	na	'S.I.27', 'S.I.44', 'S.I.67', 'S.S.3', 'S.T.27'	[8,9]
S. alba × *S. alba* '$A_{salix}A_{salix}$'	na	'V-052', 'V-093'	[20]

[1] Species authorities (*Populus*, *Robinia*, *Salix*): *P. alba* L.; *P. balsamifera* L.; *P. deltoides* Bartr. Ex Marsh; *P. laurifolia* Ledeb.; *P. maximowiczii* A. Henry; *P. nigra* L.; *P. pamirica* Komarov; *P. simonii* Carrière; *P. tremula* L.; *P. tremuloides* Michx.; *P. trichocarpa* Torr. et. Gray; *R. pseudoacacia* L.; *S. alba* L.; *S. pet-susu* Kimura; *S. sachalinensis* F. Schmidt. [2] Genomic group synonyms (*Populus*): *P. alba* × *P. tremula* = *P.* × *canescens* (Aiton) Sm.; *P. deltoides* × *P. nigra* = *P.* × *canadensis* Mönch = *P.* × *euramericana* (Dode) Guinier; *P. trichocarpa* × *P. deltoides* = *P.* × *generosa* Henry. [3] Section authorities (*Populus*): Aigeiros Duby; *Populus* L.; *Tacamahaca* Spach. [4] Genotype synonyms: *Populus*: 'Agathe F' = 'E-298'; 'Antonije' = '182/81'; 'Bora' = 'B229'; 'DN34' = 'Eugenei'; 'I-214' = 'Campeador', 'NE42' = 'Hybride 275' = 'H-275'; 'Pannonia' = 'M1', 'Pyramidalis' may be 'Mirza Terek'. *Salix*: 'P.I.81' = 'P81'; 'P.I.82' = 'P82'; 'S.I.27' = 'S27'; 'S.I.67' = 'S67'.
[5] na = not applicable.

2. Applications from Around the Globe

McGovern et al. [1] described a proof-of-concept of an SQL database to store existing information on *Salix* cultivars and to allow users to compare and submit new *Salix* cultivar entries. The development and management of this ***cultivar database*** have the potential to enhance an existing checklist for *Salix* cultivars that includes 968 epithet records in a Microsoft Excel spreadsheet format. This existing checklist has been maintained since 2015 by the International Commission on Poplars and Other Fast-Growing Trees Sustaining People and the Environment of the Food and Agriculture Organization of the United Nations (UN FAO) (https://www.fao.org/ipc/en/; accessed on 25 May 2022), highlighting the global reach of their work.

Fortier et al. [2] conducted a study in Canada on the use of hybrid poplars in ***forest buffers*** to reduce firewood harvest pressure in woodlots while improving ecosystem services related to soils, water, and carbon. They evaluated the natural drying and chemical characteristics of hybrid poplar firewood produced from bioenergy buffers and then compared those results to *Populus tremuloides* Michx., *Acer rubrum* L., and *Fraxinus americana* L. from adjacent woodlots. They determined that hybrid poplar buffers could be used as firewood feedstock in the fall and spring when heat demand is less intense than in the colder winter months.

Zlatković et al. [3] used a ***forest health screening*** approach to identify a bacterial pathogen (*Lonsdalea populi*) causing cankering of two-year-old hybrid poplar in the Vojvodina province in Serbia. This was the first report of *L. populi* causing bacterial canker disease in the country as well as throughout southeastern Europe. The cankering was observed on stems and branches and consisted of a soft, watery, colorless fluid that smelled rotten and flowed from bark fissures. Two weeks after being observed, the cankers caused crown dieback. These results are important for the region and Serbia, given the implications for the potential need to screen for *L. populi* in poplar breeding and testing programs.

Galović et al. [4] used a ***forest health screening*** approach to test the variability among three hybrid poplar genotypes in their ability to tolerate salts in halomorphic soils such as those in the Vojvodina province in Serbia. The clones were hydroponically subjected to NaCl concentrations ranging from 150 to 450 mM, and biochemical responses were quantified in the leaves via estimation of radical scavenging capacities and accumulation of total phenolic content and flavonoids. Using molecular genetic approaches, they reported that two of the three clones were highly salt-tolerant and exhibited potential for phytoremediation of halomorphic soils and other saline environments.

Zalesny et al. [5] evaluated the genotype × environment interactions of hybrid poplars growing at sixteen ***phytoremediation*** buffer systems (i.e., phyto buffers) in the Great Lakes Basin in the United States (Figure 2). They tested health, growth, and volume during establishment (i.e., ages one to four years) and identified generalist clones exhibiting superior performance across a broad range of phyto buffers as well as specialist genotypes that were adapted to local soil and climate conditions. They concluded that a combination of these response groups would enhance the potential for phytoremediation best management practices that are regionally developed and yet globally relevant.

Pilipović et al. [6] studied hybrid poplars at the ***phytoremediation*** buffer systems (i.e., phyto buffers) described by Zalesny et al. [5]. They compared the establishment potential of promising hybrid poplar clones developed at the University of Minnesota Duluth's Natural Resources Research Institute (NRRI) with experimental genotypes with a rich history of testing and common genotypes used for commercial and/or research purposes in the midwestern United States. Overall, certain NRRI clones had exceptional survival and growth relative to experimental or common clones across at least ten phyto buffers, indicating their potential for use in geographically robust phytotechnologies.

Figure 2. Poplar phytoremediation buffer system in the Great Lakes Basin, United States. From Zalesny et al. [5]. Photo courtesy of Paul Manley, Missouri University of Science and Technology.

Hu et al. [7] described field testing of salt-tolerant balsam poplar (*Populus balsamifera* L.) clones used for reclamation around end-pit lakes associated with bitumen extraction in northern Alberta, Canada. They used ***phytoremediation*** approaches to select genetically suitable native balsam poplar clones screened in the greenhouse and at field sites with a tolerance to salty process-affected water resulting from the hot-water bitumen extraction process at oil sands mine sites. Overall, their work elucidated an integrated system for choosing balsam poplar for oil sand reclamation, providing information showing the advantage of deploying selected native material versus unselected genotypes.

Han et al. [8] tested the influence of mulching and cutback (i.e., coppicing) on the suppression of weed competition and their interactive effects on biomass productivity of ***short-rotation coppice (SRC)*** willow in northern boreal Hokkaido, Japan. Trees were harvested after three years of growth following cutback, and those grown with mulch exhibited 1130% greater biomass production than those exposed to weed competition. In these non-mulched plots, weed biomass was 800% greater than willows. Overall, their results showed that SRC willow is a biomass feedstock alternative in the region if used with mulching to sustain complete weed control.

Harayama et al. [9] estimated the yield loss of ***short-rotation coppice (SRC)*** willow from deer browse in northern boreal Hokkaido, Japan. They allowed deer browsing to occur after the first summer of the second coppice cycle and subsequently recorded the number of sprouting stems and the number of deer-browsed stems. Then, after three years, they quantified yield losses and reported 80% reductions in yield after browsing of only a single stem per parent root system. At the stand scale, these yield losses were as high as 6 tons ha^{-1} $year^{-1}$ (dry biomass), suggesting the need for silvicultural prescriptions that include control of deer browsing.

Thiffault et al. [10] tested two intensive mechanical site preparation treatments versus a control with no site preparation to assess the survival, growth, and nutritional status of ***short-rotation coppice (SRC)*** poplars in Québec, Canada. They also assessed differences among treatments for inorganic soil N. After four growing seasons, survival was nearly twice as high for both treatments (mounding = 99%; V-blade = 91%) relative to the control (48%), and trees exhibited 155% (mounding) and 91% (V-blade) greater diameter than control trees. Overall, they reported mounding as being the best treatment given higher survival and growth along with the lowest erosion potential.

González et al. [11] quantified mid-rotation nutrient contributions from leaf litter of ***short-rotation coppice (SRC)*** of white poplar, black locust, and an even mix of both species on the Iberian Peninsula of Spain. They reported white poplar exhibited 32% and 20%

greater leaf biomass than black locust and the species mix, respectively. White poplar had 15% more leaf carbon than the other two treatments, which did not differ from one another. Contributions of individual macronutrients were highly variable across species and the mix, leading to their results recommending deploying mixtures of species to achieve a potential reduction in the amount of mineral fertilization required at the stand level.

Oliveira et al. [12] reviewed the potential of ***short-rotation coppice (SRC)*** poplars in Mediterranean conditions and in Spain as sustainable biomass feedstock production systems for a circular bioeconomy that is robust to global change. They reviewed these SRCs for their abilities to provide quality biomass with predictable yield and periodicity across the landscape. In their analysis, they considered: genetic plant material, planting designs, site maintenance activities, yield prediction, biomass characterization, and ecosystem services. Despite recent advances, they concluded more work on these components is necessary to develop a circular bioeconomy at regional and national levels.

Landgraf et al. [13] tested the survival, growth, and biomass production of 37 poplar genotypes grown as ***short-rotation coppice (SRC)*** in northeastern Germany. In addition to first-year survival, they reported results after the first and second coppice cycles, with three years for each cycle. Overall, their varieties exhibited broad variation in all traits, with the top seven clones having at least 11 Mg ha^{-1} $year^{-1}$ of aboveground dry biomass after the second coppice cycle being recommended for commercial use. Six varieties had less than 4 Mg ha^{-1} $year^{-1}$. In general, biomass yield increased from the first to the second harvest, although some varieties produced less biomass in subsequent years.

Thevs et al. [14] estimated the growth rates and biomass production of 30 poplar genotypes grown as ***short-rotation coppice (SRC)*** across nine sites in Kyrgyzstan, Kazakhstan, and Tajikistan in central Asia. There was a difference in genomic group performance based on elevation, with *P. deltoides* × *P. nigra* and *P. nigra* × *P. maximowiczii* clones exhibiting the greatest stem volumes and biomass yields at lower elevations, and *P. maximowiczii* × *P. trichocarpa* and pure *P. trichocarpa* genotypes performing the best at higher elevations. They concluded that many of the cultivars tested could be incorporated into SRC and agroforestry applications.

Schiberna et al. [15] reviewed the biomass production potential of ***short-rotation coppice (SRC)*** poplars in Hungary. Based on the literature-derived values for site characteristics, yield, and costs, they developed an economic model to predict the financial performance of these biomass feedstock production systems. They reported break-even yields ranging between 6 and 8 Mg ha^{-1} $year^{-1}$ of aboveground dry biomass on shorter rotations with an evenly distributed cash flow. In addition to SRC applications, they also discussed the potential of extending industrial rotations to range from 20 to 25 years to produce high-quality veneer logs, which are currently limited to rotations of up to 15 years.

Kraszkiewicz [16] quantified the growth and ***volume production*** of 14 black locust stands varying in soil and climate conditions in Małopolska Kraina, southeastern Poland. The biomass volume of the stands was similar to that of natural forests. In addition, four of these stands were 4 to 8 years old and exhibited a stand height (2 to 8 m) and diameter (4.5 to 12.0 cm) consistent with short-rotation poplar and willow systems in the region. Based on his results, he concluded that black locusts can be complementary to poplars and willows as bioenergy feedstocks to produce medium-sized timber on marginal lands not suitable for most tree species.

Ghezehei et al. [17] estimated the ***volume production*** and profitability of poplars grown with different planting densities and fertilization treatments across three sandy coastal sites in North Carolina in the United States. Overall, survival ranged from 62 to 93%, and the mean annual increment of green stem biomass of six-year-old trees ranged from 9 to 25 Mg ha^{-1} $year^{-1}$ across densities. Fertilization increased volume production on fertile soils but not at marginal sites. Given economic barriers of establishment costs and weed control with higher planting densities, their calculated break-even price was 27 USD Mg^{-1} (delivered). Weed control was more important than fertilizer for determining this threshold.

Mola-Yudego et al. [18] compared the ***volume production***, land-use patterns, and climatic profiles of reed canary grass versus traditional energy crops (i.e., poplars and willows) in Sweden. Reed canary grass is grown in colder climates in areas that have lower agricultural productivity than poplars and willows, yet they found its mean yields of 6 Mg ha^{-1} $year^{-1}$ (experimental) and 3.5 Mg ha^{-1} $year^{-1}$ (commercial) to be similar. Nevertheless, they concluded that broad-scale application of reed canary grass may be hindered as its land area for production is more sensitive to policy incentives than short rotation woody crops (i.e., due to insufficient markets and lack of compensation for ecosystem services).

Kolozsvári et al. [19] conducted a ***wastewater reuse*** project utilizing fish farm effluent as irrigation and fertilization for the production of short-rotation energy willow in Hungary. Comparing two fertigation sources (i.e., effluent water and freshwater), they reported that effluent water increased willow yield. The phytoextraction of nutrients was tissue-specific, with nitrogen and sodium being taken up into leaves and phosphorus accumulating in the stems. There was an inverse relationship between phosphorus uptake and irrigation volume. Trees irrigated with effluent water were healthier than those with freshwater, indicating the potential for wastewater reuse to increase willow production.

Istenič and Božič [20] tested the potential for ***wastewater reuse*** in an evaporative willow system (EWS) accepting primary treated municipal wastewater in a sub-Mediterranean climate in Slovenia. Willows receiving wastewater exhibited greater growth and biomass than untreated controls. The nutrient recovery potential of the EWS was high, with the uptake of nitrogen (48%) and phosphorus (45%) being greater in willows than in other plants used for wastewater treatment. Trees from one genotype had the least biomass and the greatest nutrient uptake, leading to the need for clonal selection to maximize the biomass production of EWS while mitigating discharge to surface and groundwater.

3. Concluding Remarks

As highlighted above, there is great potential for SRWCs to be included in biomass feedstock portfolios and environmental applications in rural and urban areas. Coupled with engineering approaches, the green solutions presented in this Special Issue offer an opportunity to sustainably produce biomass for bioenergy, biofuels, and bioproducts while reducing impacts from anthropogenic activities on local- and landscape-level ecosystem services. In addition, integrating biomass production with phytotechnologies offers potential pollution solutions for increasing community health and livelihoods.

Author Contributions: Conceptualization, A.P. and R.S.Z.J.; writing—original draft preparation, R.S.Z.J.; writing—review and editing, A.P. and R.S.Z.J.; visualization, R.S.Z.J.; funding acquisition, R.S.Z.J. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the Great Lakes Restoration Initiative (GLRI; Template #738 Landfill Runoff Reduction).

Acknowledgments: The findings and conclusions in this publication are those of the authors and should not be construed to represent any official USDA or United States Government determination or policy. We are grateful to all of the authors and reviewers of the individual manuscripts; without you this Special Issue would not be possible. We thank E.R. Rogers and R.A. Vinhal for reviewing earlier versions of this manuscript.

Conflicts of Interest: The authors declare no conflict of interest.

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