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Review

Ecosystem services from turfgrass landscapes☆

José A. Monteiro

Faculdade de Ciências e Tecnologia & Centro de Estudos em Património, Paisagem e Construção, Campus de Gambelas, Universidade do Algarve, 8005-139 Faro, Portugal

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ABSTRACT

Turf is an important component of the urban and rural landscape. The natural plant formations/biomes that it mimics are the tropical savanna, the temperate grasslands (steppe and the prairies) and the tundra. Turf in a higher or lower degree provides all the ecosystem services of the other types of vegetation. Vegetation ecosystem services that have been previously emphasized include functional, aesthetical, recreational, social, and economic services as well as services related to people psychological or physical health. The purpose of this review is to gather updated information on turf ecosystem services, mainly on how they compare to other types of vegetation, or substitutes, and to suggest some future trends/areas of research.

Turf has a unique role in aesthetics and, definitely, provides an irreplaceable surface for recreational sports/activities. From the available information, turf seems to have a higher potential than other types of vegetation for reducing runoff, increasing infiltration, purifying water from sediments and pollutants, controlling erosion, improving soil quality and reducing fire hazards. For the lawn owners the main turf benefits are: first the enhanced property aesthetics, second the increment in property value and third the provision of a recreation area. Turf, as all vegetation, uses water. Without the water its benefits may be reduced or annihilated. Mimicking nature may offer some solutions for saving water: summer brown lawns that green up in the fall, although losing some of the turf benefits, may be an appropriate choice where irrigation is not feasible and are worth some research. Research, should also be done on lawns using a mix of grasses and legumes: the presence of legumes may avoid N fertilization and, possibly allows for clippings removal and usage as biofuel, while keeping the soil accumulation of carbon, preventing N leaching and turning turf's carbon footprint even more positive.

1. Introduction

Turf is an important component of the anthropogenic landscape as grasslands are important in natural landscapes. In geobotany, herbaceous plants make most of the pioneer stages in ecological succession (Wang et al., 2010). In natural landscapes, grass also appears in the clearings in the middle of the woods or as the lower strata in sparse woods. The plant formations/biomes that turf mimics are the tropical savanna, the temperate grasslands (steppe and the prairies) and the tundra. In the tundra, trees and tall plants are excluded because of the low temperature or the short growing season. In the tropical savanna, it is the long dry season that benefits grasses, leaving the trees small and spaced out. The temperate grasslands appear in temperate, seasonal, dry climates (deep organic soils develop and organic matter accumulates) (Colinvaux, 1986). In many of these biomes, the above ground part, if not the entire plant, dies in the unfavorable season (due to drought or cold) and re-sprouts or germinates from seed, when the weather becomes favorable.

The environmental benefits of turf have been listed in several places, often in sites with an academic origin but, except for the review of Beard and Green (1994), most of them present very few supporting references. The ecosystem services of gardens and parks, in which turf is included, have been more recently reviewed (Brethour et al., 2007; Cameron et al., 2012) and many benefits have been presented (environmental, aesthetic, recreational, economic, sociologic and psychological/physiological) but the specific role of turf has not been differentiated. Controversial issues about lawns include high water consumption, incorrect use of fertilizers, herbicides and pesticides (Helfand et al., 2006) and, production of volatile organic compounds (VOC) that could affect the environment and human health (Harvey et al., 2014).

The purpose of this work is to take stock of the information supporting turf ecosystem services/controversial issues, focusing on how it compares with other types of vegetation or elements of the landscape. The objective is not to present a systematic or exhaustive review, on so many and so diverse topics, but to summarize the actual state of the art, based on what

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E-mail address: jmontei@ualg.pt.

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is considered to be the best evidence. With decision support in mind, possible turf substitutes in the landscape are discussed. Gaps in the knowledge needing further research are identified and, some personal opinions on future trends for lawns, are presented.

2. Methods

For the different topics, searches by keywords, using Boolean expressions were performed using b-on (http://www.b-on.pt/), the online library of knowledge from the Portuguese Consortium of Universities, Research Institutions and Public Entities. The most relevant search systems it includes are: EBSCO-Academic Search Complete, THOMSON REUTERS-Current Contents, MEDLINE, ProQuest Science Journals, THOMSON REUTERS Web of Science (Web of Knowledge), …; and the providers of information include: Science Direct, General OneFile, Academic OneFile, Expanded Academic ASAP, Literature Resource Center, MEDLINE with Full Text, Science In Context, Science Citation Index, Scopus®, Social Sciences Citation Index, Directory of Open Access Journals, … (http://www.ualg.pt/pt/content/bases-dados-1). The searches were limited to academic, peer-reviewed papers, published from January 1995 to March 2016 (i.e. after Beard & Green, 1994). The expressions used followed the type: (turf OR lawn) AND (variable keywords or expression). The variable keywords or expressions included: "urban temperature", "net primary production", carbon, "air quality", "soil quality", "water quality", pollution, particulate matter, infiltration, runoff, "filter strips", rain interception, noise, reflectance, albedo, aesthetics, maintenance, savings, "VOC", (fertilizer AND leach*)….among others. In some of the searches, when the number of records was too high or diverse, the key words were restricted to the titles (ex: (TI turf OR TI lawn) AND (TI carbon)).

The results were ordered by publication date and positive selection started with the most recently published. Papers, including literature reviews, were selected for having estimates of the topics discussed, either coming from empiric experiments or generally accepted models. After having a few, good quality, recent, relevant and concordant papers for a specific topic the search was considered completed for that topic. If some discrepant papers were found, they were carefully inspected for the cause of the disagreement and if a final synthesis was not possible the different types of information were presented. When convenient, the reference lists of the selected papers were used as sources of other relevant papers.

3. Ecosystem services

3.1. Moderation of urban temperature extremes

Plants decrease temperatures through evaporative cooling (evapotranspiration), reflection and shading. Tan et al. (2015) found good correlations between vegetation evapotranspiration or albedo and cooling capacity. On the other hand, plant canopies may alleviate low temperatures by not allowing radiation to escape to the atmosphere, as well as, by avoiding the mixing of cold air with warmer air, as in shelter beds or windbreaks. Turf cooling capacity is then related with its evapotranspiration and albedo which depends on several factors, including water availability. It is not expected that mowed turf will have significant shading, radiation trap or windbreak effect on temperature. The vegetation effect on temperature varies with the time of the day. Trees are the best vegetation type to mitigate the high temperatures (Brom et al., 2009; Wu et al., 2007) and in urban squares trees were shown to reduce the temperature by 1.9 °C, on average (Wu et al., 2007). "Mown meadows" have the highest surface temperature among the studied types of vegetation (Brom et al., 2009) but in urban environments the presence of lawns (compared to absence of vegetation) was shown to decrease temperature peaks, in the middle of the day, by approximately 1 °C, on average (Wu et al., 2007). Also, growing turf surface maximum temperatures (31 °C) are known to be much lower than maximum temperatures for brown-summer-dormant turf (52 °C), bare soil (39 °C) or synthetic artificial turf (70 °C) (Beard and Green 1994). Yaghoobian et al. (2010) modeling the thermal effects of artificial/natural turf found that natural grass is by far the coolest surface (around 20 °C less than artificial turf, at noon) and that artificial turf can raise air temperature by 4 °C compared to irrigated grass but, ultimately concluded that natural turf landscapes use more energy than the artificial turf, due to the embodied energy of irrigation water. However, they did not perform a full energy balance for the two systems: artificial turf has embodied energy on its own, and has energy requiring maintenance – brushing, wet cleaning, weed killing, decompaction, irrigation to stabilize the infill,… (FIFA, 2001) which were not included. More recently, Wang et al. (2016) modeled the thermal effects of trees and lawns in a desert city, concluding that trees allow higher energy (and monetary) savings than lawns, but lawns alone save energy and money. Wang et al. (2016) pointed out the importance of the outdoor thermal comfort as having an impact on other (non-building) energy and monetary savings (like car air conditioning or time of suspended outdoor work).

3.2. Oxygen production

Plant photosynthesis produces oxygen and uses carbon dioxide. Oxygen production is then positively correlated with photosynthesis which is often referred, in ecology studies, as net primary production (NPP). Photosynthesis depends on an enormity of factors, including irradiance, plant species/clone, water and nutrient availability. For China, Gao and Liu (2008), using several different models, estimated that grasslands were the vegetation type with the lowest annual NPP, which makes sense since grasslands in China (or in the world) are mostly in arid or semi-arid zones. Taking world's biomes net production as estimates for urban landscapes may be misleading since they refer to different climates. Considering the ecological succession in a Chinese forest, i.e. under the same climate (mid-temperate continental monsoon), Wang et al. (2010) found the higher productivity – and expectedly the highest oxygen production – during the shrub (intermediate) succession stages: the latest grassland stages being more productive than the forest stages. Wu and Bauer (2012), using a remote sensing based model, obtained an higher annual NPP for golf course grass (1,100.5 $g\ C\ m^{-2}$) than for regular lawn grass (771.2 $g\ C\ m^{-2}$), confirming the NPP value obtained by Falk (1980) for lawns (i.e 1650 g Dry Matter $m^{-2} \approx 792\ g\ C\ m^{-2}$) who stated that "at temperate latitudes, lawns surpass prairies, coniferous forests, pine plantations and approach deciduous forests in annual net primary production." (Falk, 1980, p.694), which is oxygen production.

3.3. Carbon sequestration

The carbon sequestered by a biome, ultimately, is the biomass present in the system (live and dead organic matter). Using the same Chinese example (Wang et al., 2010), the highest aboveground biomass was found in the shrub and forest succession stages. The grassland stages had a much lower biomass compared to the other stages. Wang et al. (2010) did not measured below ground biomass and it is known that it is important in grasses. Whittinghill et al. (2014), quantifying carbon sequestration in several shrub and herbaceous landscape types, found the highest below ground carbon content (Kg/m^2) in a Kentucky blue grass lawn although the total carbon content, due to the above ground parts, was much higher in other landscapes types such as: Broad leaf evergreen shrubs, Deciduous shrubs, Herbaceous perennials and grasses, a Native prairie mix, Needle leaf evergreen shrubs or a Vegetable and herb garden. The total carbon content of the Kentucky blue grass lawn was similar to the content of a Succulent rock garden or Woody ground covers.

In lawns, carbon sequestration has been considered positive