GROUP PROJECT BRIEF

BREN SCHOOL OF ENVIRONMENTAL SCIENCE & MANAGEMENT
UNIVERSITY OF CALIFORNIA SANTA BARBARA

Incorporating Land Use Impacts on Biodiversity into Life Cycle Assessment for the Apparel Industry

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Project Significance & Overview

The global textile and apparel industry requires massive inputs of land for raw material production and fabric manufacturing. Such land use has significant implications for biodiversity—the diversity of Earth's species, which provide critical services such as pollination, water purification, and climate regulation. Although land use is a major driver of biodiversity loss, there is no easily applicable method for incorporating land use impacts on biodiversity into life cycle assessment (LCA)—a widely-used tool for evaluating potential environmental impacts of a product system.

Patagonia Inc., an outdoor apparel and gear company with a reputation for sustainability, commissioned a Bren Group Project to identify and evaluate emerging methodologies for quantifying land use impacts on biodiversity using LCA. We selected and evaluated a promising new model created by de Baan et al. (2013), which provides a relatively complete set of biodiversity characterization factors, used to convert a quantity of occupied land into an absolute, regionally-specific measure of potential species loss. Our practical application of the model to four Patagonia products highlights operational limitations and areas for refinement of the model to improve its utility within the apparel industry. Developing a robust and accessible method for incorporating biodiversity impacts into LCA will greatly improve the ability of companies to make environmentally-informed decisions about product systems.

Objectives

1. Review methodologies for incorporating land use impacts on biodiversity into LCA, and select a model with high potential for use within the apparel industry
2. Apply the selected model to four Patagonia product systems to quantify the potential land use impacts on biodiversity of common textiles
3. Evaluate the effectiveness of the model for measuring regional land use impacts on biodiversity using LCA, and identify limitations and recommendations for refinement
4. Assess the potential for Patagonia and the apparel industry to use the model to evaluate the impact of a product's land use on biodiversity within LCAs

Assessed T-Shirts & Textiles

COTTON
The studied t-shirt is made from 100% organic cotton, which is grown and ginned in Texas. The fiber is spun into yarn, knit into a fabric, dyed, finished, cut and sewn into a t-shirt in Mexico.

WOOL
Wool is shorn from sustainably-grazed sheep and turned into fiber top in Argentina. Top is spun into yarn in China, the fabric is knit in Thailand, and the fabric is cut and sewn into a t-shirt in Vietnam.

POLYESTER
Petroleum-based polymers and staple fiber are produced in South Carolina, and the Polyester fiber is spun into yarn in North Carolina. The fabric is knit in Los Angeles, and cut and sewn in El Salvador.

LYOCELL
Lyocell is made from eucalyptus, beech and spruce trees grown in South Africa and Europe. Wool is pulped and fiber processed in the Czech Republic, U.K., South Africa and U.S. Yarn is spun in Thailand. Fabric is knit in S. Korea, and the shirt is cut and sewn in Sri Lanka.

Methods

We evaluated the biodiversity impact of four Patagonia t-shirts, made from cotton, wool, polyester, and lyocell, to compare the biodiversity impacts arising from the unique land use requirements of each textile. Primary data from Patagonia's suppliers was used to complete a life cycle inventory analysis (LCI) of each t-shirt. The LCI quantifies the amount of land occupied (in m^2*years) for each unit process from raw material production through manufacturing (the system boundary is cradle to factory gate). Land occupation prevents the recovery of biodiversity after land has been converted for human use. Each unit process was then assigned a characterization factor, as provided by de Baan et al., based on its location and land use type. The land occupation and characterization factor were multiplied together to convert land occupation into an absolute measure of biodiversity loss. The result is a biodiversity impact, measured in potentially lost non-endemic species, for each product system.

Inventory Result X Characterization Factor = Biodiversity Impact

Inventory Analysis

For each textile we calculated how much land occupation a particular unit process requires to make one million t-shirts (our functional unit; f.u.). Using the cotton t-shirt as an example (Figure 1), we first calculated how much agricultural land is required to produce one functional unit. We divided the total property size by the annual amount of raw cotton produced, then multiplied this output by the inverse yield of each subsequent unit process. The inverse yield is the output from Unit Process A (e.g. raw cotton) required to make a specific output of Unit Process B (e.g. fiber). The specific output is the amount required to make a specific output of the next unit process (e.g. yarn), through to the production of one million t-shirts. The same calculation was done for each unit process, and the results were summed to produce the total land occupation of the product system.

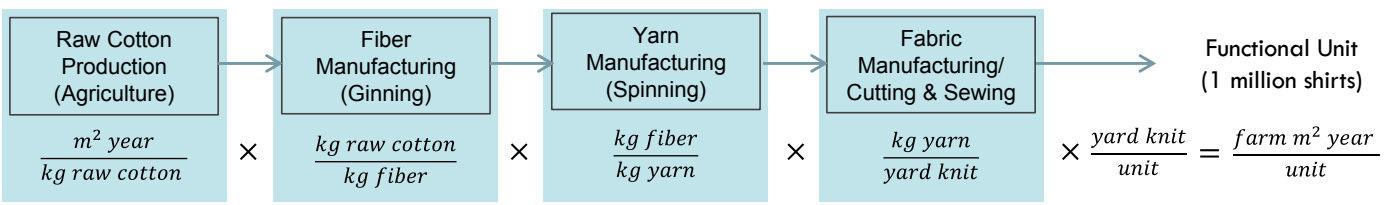


Figure 1. Inventory analysis calculation methods for the cotton product system

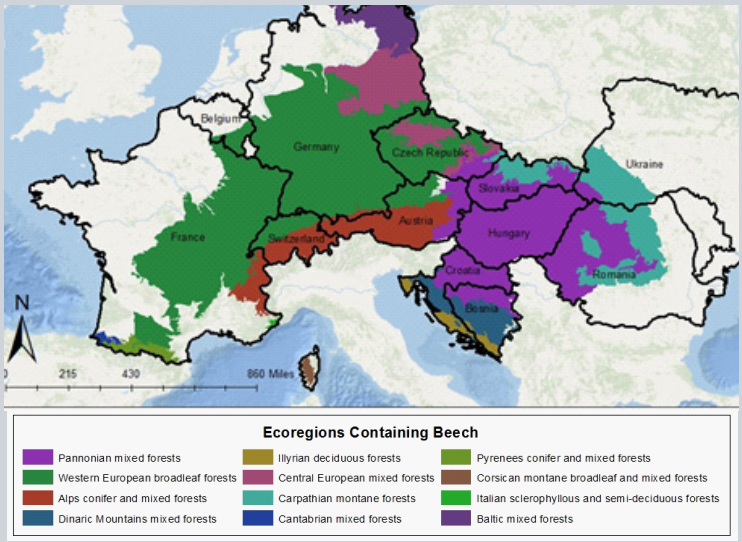
Characterization Factors

The characterization factors used in this study are based on the spatial classification *ecoregion*, a large area with distinct species and environmental conditions. Ecoregions provide more ecologically-relevant characterization factors than those calculated at larger spatial scales. For all 867 ecoregions, de Baan et al. provide a characterization factor for every combination of 4 broad land use types (agriculture, pasture, managed forest, and urban) and 5 taxa (birds, mammals, reptiles, plants, and amphibians). We used aggregated characterization factors, which are a weighted average of the taxon-specific characterization factors.

Adapting the Characterization Factors

For processes in which the ecoregion was unknown (e.g. a source country rather than address was provided for lyocell raw materials) or which take place in multiple ecoregions (e.g. raw wool production), we created a single adapted characterization factor. For wool, we used a simple weighted average of the characterization factors for each grazing operation. For each lyocell wood, we used ArcGIS software to map all ecoregions partially contained by sourcing countries, but eliminated ecoregions that do not grow the wood (Figure 2 shows this map for beech). A weighted average of these ecoregions was calculated for each country based on the portion of ecoregion falling within that country. These adapted country-specific characterization factors were converted to a single characterization factor based on the percent contribution of that country to lyocell production.

Figure 2. Map of beech-containing ecoregions in beech-supplying countries



Results & Discussion

High Biodiversity Impact of Wool

The wool t-shirt evaluated in our study has by far the greatest total biodiversity impact of the four textiles. As shown in Table 1, wool's total biodiversity impact is roughly 20x greater than cotton, 160x greater than lyocell, and more than 9,000x greater than polyester. Taking our results at face value, we find that the production of one million wool t-shirts leads to the potential loss of roughly 4.8% of a non-endemic species regionally, while all other textiles produce a loss of less than 1%. These results can be attributed to the low yield, and thus high land requirements, of wool grazing. However, the broad classification scheme used in the model may overestimate the negative biodiversity impact of Patagonia's wool, because it cannot capture the sustainable grazing strategies used by the t-shirt's suppliers. Sheep are moved between pastures to decrease pressure on the land, which explains the particularly high land occupation, and is intended to reverse habitat damage to South American grasslands.

Table 1. Total land occupation and biodiversity impact of the four textiles. Land occupation is measured in meters squared*years; biodiversity impact is measured in potentially lost non-endemic species per f.u.

	Wool	Cotton	Lyocell	Polyester
Land occupation	1.77×10^{9}	1.59×10^{7}	9.77×10^{5}	1.92×10^{4}
Biodiversity impact	0.0475	0.0023	0.0003	0.00001
Biodiversity impact relative to wool	*1:1*	*1:21*	*1:157*	*1:9461*

Importance of Raw Material Production

Raw material production contributes more than 99% of the total biodiversity impact and land occupation for the cotton and wool t-shirts, and 92% of the lyocell t-shirt. These textiles require agriculture- and pasture-based land use, which have significantly lower yields, and thus require more land per functional unit, than the urban manufacturing processes. As examples, Tables 2a and 2b show the relative contributions of each unit process to the total land occupation and biodiversity impact of cotton and wool.

Table 2a. Results of inventory analysis and impact assessment of the cotton t-shirt product system

COTTON	Raw Material Production	Fiber Production (Ginning)	Spinning	Knitting/ Sewing	Total
Land Occupation	1.59×10^{7}	1.00×10^{3}	1.82×10^{2}	$4.72E\times10^{3}$	**1.59×10^{7}**
Percent of Total	*99.96%*	*0.01%*	*0.00%*	*0.03%*	
Character. Factor	1.44×10^{-10}	7.65×10^{-11}	0.00	4.86×10^{-10}	
Biodiversity Impact	**2.28×10^{-3}**	**7.67×10^{-8}**	**0.00**	**2.29×10^{-6}**	**2.29×10^{-3}**
Percent of Total	*99.90%*	*0.00%*	*0.00%*	*0.10%*	

Table 2b. Results of inventory analysis and impact assessment of the wool t-shirt product system

WOOL	Raw Material Production	Fiber Production	Spinning	Knitting/ Finish	Cutting/ Sewing	Total
Land Occupation	**1.77×10^{9}**	**2.85×10^{3}**	**1.09×10^{3}**	**4.39×10^{5}**	**1.55×10^{3}**	**1.77×10^{9}**
Percent of Total	*99.97%*	*0.00%*	*0.00%*	*0.02%*	*0.00%*	
Character. Factor	2.66×10^{-11}	2.38×10^{-11}	1.13×10^{-10}	1.04×10^{-9}	1.67×10^{-10}	
Biodiversity Impact	**4.71×10^{-2}**	**6.77×10^{-8}**	**1.23×10^{-7}**	**4.58×10^{-4}**	**2.59×10^{-7}**	**4.75×10^{-2}**
Percent of Total	*99.04%*	*0.00%*	*0.00%*	*0.96%*	*0.00%*	

Influence of Characterization Factors

Polyester - All polyester production processes are classified as urban land use, which leads to a more even distribution of land occupation and biodiversity impact than the other textiles. As shown in Figure 3, the pattern of the unit processes' percent contribution to land occupation differs from contribution to total impact, indicating that the location of the process as captured by the characterization factor influences the total biodiversity impact. The polyester raw material process calculations used industry data from the Ecoinvent database and a world average characterization factor, because specific source locations cannot be identified for commodity products such as the petroleum used to manufacture polyester.

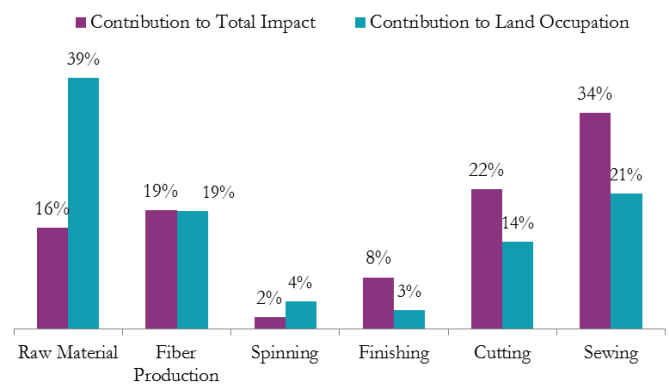


Figure 3. Contribution of polyester unit processes to total impact and land occupation

Lyocell - As shown in Table 3, beech requires 3.5 times more land than eucalyptus to produce a ton of dry output because it is harvested from managed forests rather than plantations, yet the biodiversity impact of eucalyptus per oven dried ton is 4.75 times greater than beech. This difference is partially due to eucalyptus' classification as agriculture rather than managed forest, but is also impacted by location—eucalyptus is grown in South Africa while beech is harvested from Central Europe. Using a managed forest characterization factor for eucalyptus in the same ecoregion still produces a 2.26 times greater impact than beech. Despite its relatively low land occupation, eucalyptus has a high biodiversity impact, and contributes 81% of lyocell's total biodiversity impact.

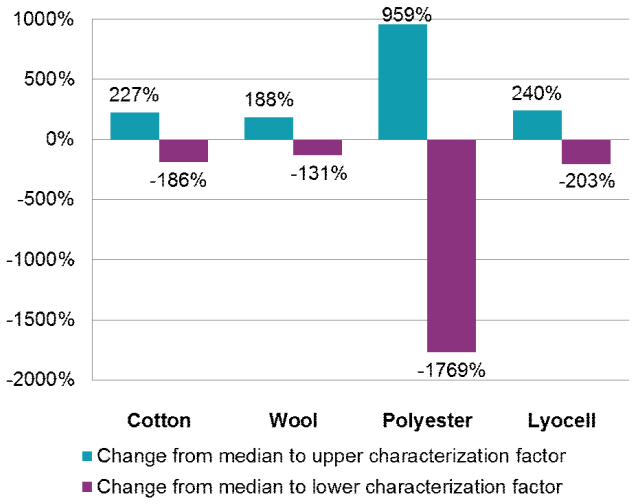
Table 3. Beech and eucalyptus biodiversity impact per oven dried ton.

	Beech Production	Eucalyptus Production	Eucalyptus Production
Land use type	Forest	Agriculture	Forest
Annual yield (odt/ha)	3.4	12	
Hectares per oven dried ton	2.94×10^{-1}	8.33×10^{-2}	
Characterization factor	5.01×10^{-11}	8.40×10^{-10}	3.72×10^{-10}
Biodiversity impact of an oven dried ton	1.47×10^{-11}	7.00×10^{-11}	3.10×10^{-11}

Uncertainty Analysis

It is important to note in considering the results of this study that de Baan et al. (2013) found high uncertainty when using Monte Carlo simulations to propagate parameter uncertainty into the characterization. Calculating our results using characterization factors for the upper and lower bounds of a 95% confidence interval, we find the biodiversity impact for all materials changes by more than 100%—and in the case of polyester by more than 1700%. The results of each also range from a positive to a negative impact value, with a negative value representing a potential benefit to biodiversity. This uncertainty is due to a lack of taxa- and ecoregion-specific data, which required that some values be aggregated across larger spatial units than ecoregions, such as biomes or the globe.

Figure 4. Percent change in total biodiversity impact from a median to high (blue) and low (purple) characterization factor.



Model Limitations

1. High uncertainty of characterization factors resulting from incomplete taxa- and ecoregion-specific data

2. Required knowledge of specific process locations in order to obtain regional resolution, which may be difficult for companies with complex or non-transparent supply chains to aquire

3. Inability to differentiate between land management strategies, such as organic and conventional cotton growing, due to the broad land classification scheme, which considers only four land use types

Conclusions

Although this model has potential for future use in LCAs alongside other indicators, we find that currently it is better suited for providing generalizations about relative biodiversity impacts rather than for conducting refined product system assessments. However, application of these characterization factors to product systems, as done in this case study, reveals interesting information regarding land use impacts on biodiversity. In particular, agricultural and pastoral land occupations contribute significantly to the overall biodiversity impact of a t-shirt. Thus, it may be possible for companies producing products dependent on agriculture or grazing, such as Patagonia, to approximate total biodiversity impacts without characterization factors and without looking beyond those raw material processes.

At first glance, increasing raw material process yields might reduce the per-unit biodiversity impact of a product system. However, increasing yields often requires more intensive land use, putting greater pressure on a particular ecosystem, and requiring greater inputs of fertilizer, pesticides, and water, among others. Moving to higher-yield land management (e.g. conventional cotton farming from organic) may shift land occupation impacts to other environmental categories. Alternatively, sustainable agriculture and grazing methods can be investigated as opportunities to minimize biodiversity loss. The benefits of such methods are not captured by the model as it exists, and thus would need to be measured using other, possibly qualitative methods.

Recommendations for Patagonia

- Look qualitatively at supply chain land use, with a particular focus on identifying methods for reducing habitat impacts of agricultural and pastoral processes.
- Continue to develop partnerships with NGOs and suppliers that expand and develop innovative sustainable land management strategies.
- Keep up-to-date on sustainable land management practices and strategies, and support and source from suppliers using such practices.
- Work with suppliers to minimize inputs that may have harmful effects on biodiversity. Decreasing water use, chemical use, water pollution, and fertilizer may all help to minimize impacts on biodiversity.

Acknowledgements:

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References:

de Baan, Laura, Christopher L. Mutel, Michael Curran, Stefanie Hellweg, and Thomas Koellner. "Land use in life cycle assessment: global characterization factors based on regional and global potential species extinction." *Environmental science & technology 47*, no. 16 (2013): 9281-9290.