Reconciling Environment and Production in Managed Ecosystems: Is Ecological Intensification a Solution?

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The overall demand for both agricultural and forest goods and services has strongly increased and is likely to continue to rise in the future, leading to more intensive practices in many managed ecosystems with potential negative effects for biodiversity and the environment (Cassman 1999; Tilman et al. 2002; Brussaard et al. 2010; Verkerk et al. 2014). Regarding agriculture, the challenge is to feed increasing numbers of people (food security) as well as to contribute to the development of bioenergy (Valentine et al. 2012). In the same vein, more forest products are required to satisfy new ambitious energy and construction policies (Jonsson 2013). Meanwhile, the concept of ecosystem services (ESs) has emerged and has been established in the environmental research and public spheres, exemplifying the complexity of ecosystems and their multiple relationships with human needs, including provisioning and regulating as well as social and cultural services (Tilman et al. 2002; Messier et al. 2015). Although conflicts or trade-offs between ESs have often been emphasized, positive interactions between, for example, regulating and provisioning ESs have paved the way to designing new management systems promoting ecological processes and reducing practices based on heavy mechanical or chemical means (Gaba et al. 2015). Overall, this is creating possibilities to reconcile production and the environment through a new type of ecologically driven intensification.

According to Doré et al. (2011), ecological intensification (EI) consists in reducing artificial inputs while maintaining high production levels through biological regulation. It can thus be related to all practices that consist in intensifying the use of natural functions provided by ecosystems to support production (Chevassus au Louis and Griffon 2008). By nature, EI is closely related to biodiversity, which can directly or indirectly support production and other ESs through functional processes (Bommarco et al. 2013; Gaba et al. 2014). Although to date it has for the most part been mentioned in discussions on crop systems in agriculture, with some adjustments it can be generalized to other managed ecosystems dedicated to production (Rey et al. 2015). For instance, in forest science, concepts such as close-to-nature forestry, which explicitly integrates the reduction of inputs using natural processes, can fall under EI (Bauhus et al. 2013). As highlighted by Tittonell (2014), EI must be considered as designing ecosystem-based “[...] multifunctional agroecosystems that are both sustained by nature and sustainable in their nature.” From all these principles, it appears that EI contains all the ingredients to reconcile production and the environment (Fig. 1): (1) it aims at supporting and maximizing production; (2) it promotes practices that are based on functional ecological processes and that favor synergies between ESs (especially between regulating and provisioning ESs); and (3) it aims at reducing negative impacts of intensive management practices designed to increase productivity.

So far, some important steps have been taken toward EI in both forestry and agriculture. For instance, in forestry, favoring species mixture in planted or natural forest stands may increase ecosystem productivity through temporal and spatial species niche complementarities (Forrester 2014). Silviculture practices based on natural processes (natural

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Fig. 1 Influence of ecological intensification (EI) on links between production practices, environment, and ecosystem services (ESs). Practices aim at enhancing benefits through changes of the physical environment, biodiversity, and ESs: they usually add anthropogenic inputs to natural capital under two broad different circumstances: either they initiate a bio-based production system (new crop or plantation) with its associated ESs, or they manage or use existing ESs (harvest, restoration, conservation...). The figure seeks to

separate what concerns more Society or Nature. Potential actions and effects of EI are represented using mathematical symbols: “−” means a reduction, “+” an increase, “≠” a change in nature more than in quantity, and “=” a maintenance or an increase. The overall idea is to promote ecological processes particularly against heavy mechanical and chemical inputs while maintaining or even increasing production levels (provisioning ESs); the result is likely to enhance regulating ESs, probably together with cultural ones

regeneration, disturbance-based processes) have also been developed to limit anthropogenic inputs and strengthen the adaptability of ecosystems to global change, an essential feature to support production in the long term (Drever et al. 2006; Brang et al. 2014). In agriculture, several approaches such as nature mimicry, mixed cropping, diversified crop rotations, and cover crops, and increasing the quantity of semi-natural habitats in the landscape (Bommarco et al. 2013; Titttonell 2014) are considered to maintain productivity while decreasing the use of anthropogenic inputs.

Despite this progress, there are still major knowledge gaps that deserve to be investigated in order to assess whether EI can be considered an efficient and practical concept for managed ecosystems (Gaba et al. 2014; Caron et al. 2014). First, the impact of some current and past practices on ecosystem functioning, key ecological components, and their interactions at different spatial scales deserves further investigation (Hole et al. 2005; Bouget et al. 2012; Lamers et al. 2013). Knowledge gaps in this field limit our ability to generate hypotheses on the potential effects on the environment of new management actions based on EI principles. Second, the efficiency of new practices or scenarios based on such EI principles is not always rigorously assessed or monitored, which impedes continuous learning through adaptive management approaches (Williams 2011; Duru et al. 2015). Finally, the

qualitative and quantitative relationships between ESs and the way they are modulated by management actions are usually partially assessed, calling for more conceptual or integrated studies (Bennett et al. 2009; Gaba et al. 2015; Rey et al. 2015).

The objective of this special issue is to present some of the progress made in EI and closely related concepts for both agriculture (crops and grasslands) and forestry. It contains innovative scientific research focusing on the following topics related to EI: (1) the relationships between specific practices and key functional ecological components or biodiversity (Kershaw et al. 2015); (2) the efficiency of practices according to EI principles (Lemaire et al. 2015; Levain et al. 2015; Mattioli et al. 2015; Petit et al. 2015; Podadera et al. 2015); and (3) the analysis of trade-offs and synergies between production and biodiversity conservation (Lafond et al. 2015; Loucogaray et al. 2015; Magda et al. 2015; Marusak et al. 2015; Mathias et al. 2015; Tittler et al. 2015).

The contributions to this special issue in *Environmental Management* provide constructive messages for future research on EI. As underlined by several authors (Bommarco et al. 2013; Titttonell 2014), the diversification of practices or farming systems in space and time is an avenue to reconcile production and the environment. Such diversification can be directly based on EI principles (Levain

et al. 2015; Petit et al. 2015) or principles attempting to minimize environmental impacts of intensive crop systems (Lemaire et al. 2015). Another key point is the possibility to further intensify production (although this term can hide different meanings in forestry and agriculture) at the farm or forest management unit level without harmful effects on species or functional biodiversity (Loucougaray et al. 2015; Lafond et al. 2015; Mathias et al. 2015; Mattioli et al. 2015). Of course, such EI pathways may depend not only on practices but also on the ecological situation itself (Kershaw et al. 2015; Podadera et al. 2015), calling for multisite experiments and evidence-based approaches such as meta-analyses (Doré et al. 2011). Two studies also demonstrate that compromises between intensive production and biodiversity conservation (including forest landscape connectivity) or environmental parameter preservation are possible at the landscape scale (Marusak et al. 2015; Tittler et al. 2015), which strengthens the idea of implementing EI at different spatial scales (Tittonell 2014). Finally, it appears that the possibility of reconciling production and the environment requires avoiding opposing these two elements in concepts and speech; building interactive and reflexive interactions between researchers, owners, and managers; and building landscape agroecosystem designs based on innovation, cooperation, and intensive knowledge sharing (Lemaire et al. 2015; Levain et al. 2015; Magda et al. 2015; see also Tittonell (2014) and Caron et al. (2014)).

The final aim of this special issue is to stimulate research on the relationship between practices and their effect on production, biodiversity, and ESs, either using the EI concept or other frameworks specifying the cascading effects from practices to ecosystem functions and ultimately to ESs (Rey et al. 2015).

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References

- Bauhus J, Puettmann KJ, Kühne C (2013) Close-to-nature forest management in Europe. Compatible with managing forests as complex adaptive forest ecosystems? In: Messier C, Klaus Puettmann J, Coates KD (eds) Managing forests as complex adaptive systems: building resilience to the challenge of global change. The earthscan forest library Routledge, London, pp 187–213
- Bennett EM, Peterson GD, Gordon LJ (2009) Understanding relationships among multiple ecosystem services. *Ecol Lett* 12:1394–1404
- Bommarco R, Kleijn D, Potts SG (2013) Ecological intensification: harnessing ecosystem services for food security. *Trends Ecol Evol* 28:230–238
- Bouget C, Lassauce A, Jonsell M (2012) Effects of fuelwood harvesting on biodiversity: a review focused on the situation in Europe. *Can J For Res* 42:1421–1432
- Brang P, Spathelf P, Larsen JB, Bauhus J, Bončina A, Chauvin C, Drössler L, García-Güemes C, Heiri C, Kerr G, Lexer MJ, Mason B, Mohren F, Mühlethaler U, Nocentini S, Svoboda M (2014) Suitability of close-to-nature silviculture for adapting temperate European forests to climate change. *Forestry* 87:492–503
- Brussaard L, Caron P, Campbell B, Lipper L, Mainka S, Rabbinge R, Babin D, Pulleman M (2010) Reconciling biodiversity conservation and food security: scientific challenges for a new agriculture. *Curr Opin Environ Sustain* 2:34–42
- Caron P, Biénabe E, Hainzelin E (2014) Making transition towards ecological intensification of agriculture a reality: the gaps in and the role of scientific knowledge. *Curr Opin Environ Sustain* 8:44–52
- Cassman KG (1999) Ecological intensification of cereal production systems: yield potential, soil quality, and precision agriculture. *Proc Natl Acad Sci USA* 96:5952–5959
- Chevassus au Louis B, Griffon M (2008) La nouvelle modernité: une agriculture productive à haute valeur écologique. *Déméter* 14:7–48
- Doré T, Makowski D, Malézieux E, Munier-Jolain N, Tchatmitchian M, Tittonell P (2011) Facing up to the paradigm of ecological intensification in agronomy: revisiting methods, concepts and knowledge. *Eur J Agron* 34:197–210
- Drever CR, Peterson G, Messier C, Bergeron Y, Flannigan M (2006) Can forest management based on natural disturbances maintain ecological resilience? *Can J For Res* 36:2285–2299
- Duru M, Therond O, Martin G, Martin-Clouaire R, Magne MA, Justes E, Journet EP, Aubertot JN, Savary S, Bergez JE, Sarthou JP (2015) How to implement biodiversity-based agriculture to enhance ecosystem services: a review. *Agron Sustain Dev*. doi:10.1007/s13593-015-0306-1
- Forrester DI (2014) The spatial and temporal dynamics of species interactions in mixed-species forests: from pattern to process. *For Ecol Manag* 312:282–292
- Gaba S, Bretagnolle F, Rigaud T, Philippot L (2014) Managing biotic interactions for ecological intensification of agroecosystems. *Front Ecol Evol* 2:28. doi:10.3389/fevo.2014.00029
- Gaba S, Lescouret F, Boudsocq S, Enjalbert J, Hinsinger P, Journet EP, Navas M-L, Wery J, Louarn G, Malézieux E, Pelzer E, Prudent M, Ozier-Lafontaine H (2015) Multiple cropping systems as drivers for providing multiple ecosystem services: from concepts to design. *Agron Sustain Dev* 35:607–623
- Hole DG, Perkins AJ, Wilson JD, Alexander IH, Grice PV, Evans AD (2005) Does organic farming benefit biodiversity? *Biol Cons* 122:113–130
- Jonsson R (2013) How to cope with changing demand conditions: the Swedish forest sector as a case study—an analysis of major drivers of change in the use of wood resources. *Can J For Res* 43(4):405–418
- Kershaw HM, Morris DM, Fleming RL, Luckai NJ (2015) Reconciling harvest intensity and plant diversity in boreal ecosystems: does intensification influence understorey plant diversity? *Environ Manag*. doi:10.1007/s00267-015-0551-8
- Lafond V, Cordonnier T, Courbaud B (2015) Reconciling biodiversity conservation and timber production in mixed uneven-aged

- mountain forests: identification of ecological intensification pathways. *Environ Manag.* doi:[10.1007/s00267-015-0557-2](https://doi.org/10.1007/s00267-015-0557-2)
- Lamers P, Thiffault E, Pare D, Junginger M (2013) Feedstock specific environmental risk levels related to biomass extraction for energy from boreal and temperate forests. *Biomass Bioenergy* 55:212–226
- Lemaire G, Gastal F, Franzluebbers A, Chabbi A (2015) Grassland-cropping rotations: an avenue for agricultural diversification to reconcile high production with environmental quality. *Environ Manag.* doi:[10.1007/s00267-015-0561-6](https://doi.org/10.1007/s00267-015-0561-6)
- Levain A, Vertès F, Ruiz L, Delaby L, Gascuel-Oudou C, Barbier M (2015) “A am an intensive guy”: the possibility and conditions of reconciliation through the ecological intensification framework. *Environ Manag.* doi:[10.1007/s00267-015-0548-3](https://doi.org/10.1007/s00267-015-0548-3)
- Loucougaray G, Dobremez L, Gos P, Pauthenet Y, Nettièr B, Lavorel S (2015) Assessing the effects of grassland management on forage production and environmental quality to identify paths to ecological intensification in mountain grasslands. *Environ Manag.* doi:[10.1007/s00267-015-0550-9](https://doi.org/10.1007/s00267-015-0550-9)
- Magda D, de Sainte-Marie C, Plantureux S, Agreil C, Amiaud B, Mestelan P, Mihout S (2015) Integrating agricultural and ecological goals into management of species-rich grasslands: learning from the flowering meadows competition in France. *Environ Manag.* doi:[10.1007/s00267-015-0553-6](https://doi.org/10.1007/s00267-015-0553-6)
- Marusak R, Kaspar J, Hlavaty R, Kotek V, Kuzelka K, Vopenka P (2015) Alternative modelling approach to spatial harvesting scheduling with respect to fragmentation of forest ecosystem. *Environ Manag.* doi:[10.1007/s00267-015-0558-1](https://doi.org/10.1007/s00267-015-0558-1)
- Mathias JD, Bonte B, Cordonnier T, de Morogues F (2015) Using the viability theory to assess the flexibility of forest managers under ecological intensification. *Environ Manag.* doi:[10.1007/s00267-015-0555-4](https://doi.org/10.1007/s00267-015-0555-4)
- Mattioli W, Ferrari B, Giularelli D, Mancini LD, Portoghesi L, Corona P (2015) Conversion of mountain beech coppices into high forest: an example for ecological intensification. *Environ Manag.* doi:[10.1007/s00267-015-0549-2](https://doi.org/10.1007/s00267-015-0549-2)
- Messier C, Puettmann K, Chazdon R, Andersson KP, Angers VA, Brotons L, Filotas E, Tittler R, Parrott L, Levin SA (2015) From management to stewardship: viewing forests as complex adaptive systems in an uncertain world. *Conserv Lett.* doi:[10.1111/conl.12156](https://doi.org/10.1111/conl.12156)
- Petit S, Munier-Jolain N, Bretagnolle V, Bockstaller C, Gaba S, Cordeau S, Lechenet M, Mézière D, Colbach N (2015) Ecological intensification through pesticide reduction: weed control, weed biodiversity and sustainability in arable farming. *Environ Manag.* doi:[10.1007/s00267-015-0554-5](https://doi.org/10.1007/s00267-015-0554-5)
- Podadera DS, Engel VL, Parrotta JA, Machado DL, Sato LM, Durigan G (2015) Influence of a non-native tree species *Mimosa caesalpinifolia* Benth. on the regenerating plant communities in a tropical semideciduous forest under restoration in Brazil. *Environ Manag.* doi:[10.1007/s00267-015-0560-7](https://doi.org/10.1007/s00267-015-0560-7)
- Rey F, Cécillon L, Cordonnier T, Jaunatre R, Loucougaray G (2015) Integrating ecological engineering and ecological intensification from management practices to ecosystem services into a generic framework: a review. *Agron Sustain Dev.* doi:[10.1007/s13593-015-0320-3](https://doi.org/10.1007/s13593-015-0320-3)
- Tilman D, Cassman KG, Matson PA, Naylor R, Polasky S (2002) Agricultural sustainability and intensive production practices. *Nature* 418:671–677
- Tittler R, Filotas E, Kroese J, Messier C (2015) Maximizing conservation and production with intensive forest management: it’s all about location. *Environ Manag.* doi:[10.1007/s00267-015-0556-3](https://doi.org/10.1007/s00267-015-0556-3)
- Tittonell P (2014) Ecological intensification of agriculture-sustainable by nature. *Curr Opin Environ Sustain* 8:53–61
- Valentine J, Clifton-Brown J, Hastings A, Robson P, Allison G, Smith P (2012) Food vs. fuel: the use of land for lignocellulosic ‘next generation’ energy crops that minimize competition with primary food production. *GCB Bioenergy* 4:1–19
- Verkerk PJ, Mavsar R, Giergiczny M, Lindner M, Edwards D, Schelhaas MJ (2014) Assessing impacts of intensified biomass production and biodiversity protection on ecosystem services provided by European forests. *Ecosyst Serv* 9:155–165
- Williams BK (2011) Adaptive management of natural resources—framework and issues. *J Environ Manag* 92:1346–1353