Strategic overview of influences of biomass crop production on biodiversity and ecosystems services in Ireland

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Key Messages
• *Miscanthus* is the most widely planted biomass crop in Ireland although willow has also been established.
• Increased commercial-scale biomass crop cultivation may affect biodiversity and the delivery of ecosystem services in unpredictable ways. There is currently not enough evidence to make firm conclusions on impacts.
• During the early years after planting, the number of species of birds, invertebrates and plants varies with biomass crop type and management. However, long term effects are unknown.
• Pest control measures, vegetation structure, and heterogeneity at the field scale will influence within-crop biodiversity.
• The location and size of biomass plantations will influence landscape level biodiversity and the delivery of ecosystem services.
• Regionally, the location of plantations in relation to processing infrastructure, along with other socio-economic factors, will affect impacts on the environment, and biomass production should be subject to EIA and be part of regional SEAs.
• The prospects for biomass production depend on the relative economics of other farming enterprises as well as the price of fossil fuels and carbon. As long as energy prices rise, energy crop production should be economically sustainable. If food becomes relatively more valuable, it might be more profitable for farmers to stay in food production.

Glossary of terms	
Biodiversity	Variation of life at genetic, species and ecosystem level
Bioenergy	Renewable energy made available from materials derived from biological sources
Biofuel	Fuel derived from biological sources
Biomass crops	Biological material derived from living, or recently living organisms such as wood. Biomass is commonly plant matter grown to generate electricity or produce heat or liquid fuels. In this paper the focus is on second generation dedicated biomass crops not on first generation "conventional" crops rededicated for biomass
Ecosystem services	Resources and processes that are supplied by ecosystems that benefit humankind
First generation energy crops	The basic feedstocks for the production of first generation biofuels: seeds or grains are pressed to yield vegetable oil used in biodiesel; or cereals which yield starch that is fermented into bioethanol
Perennial rhizomatous grass	Long lived (>2 years) grasses with rhizome, an underground stem (abbreviated to PRG)
Second generation energy crops	Non food crops (such as *Miscanthus* and willow) produced for biomass to generate heat and power.
Short Rotation Coppice (SRC)	Traditional method of woodland management which takes advantage of the fact that many trees reshoot from the stump or roots if cut down, e.g. willows or poplars in short rotation for energy crop purposes.

1. Rationale

To mitigate global climate change and substitute fossil fuels, bioenergy will become an important component of global and national energy portfolios. Thus several countries, including Ireland, have introduced policies and targets to increase the contribution of bioenergy (biomass in particular) to the national energy supply and to promote the increasing application of bioenergy generation (Donnelly et al., 2011). At the same time, there are major concerns about the introduction of a large land-use sector that could further accelerate land-use change and associated biodiversity loss (Eggers et al., 2009; Beringer et al., 2011). Furthermore, the large-scale cultivation of energy crops may actually increase greenhouse gas (GHG) emissions and environmental degradation, or introduce risks for food security, if not managed correctly (Robertson *et al.*, 2008; WBGU, 2009).

The expansion of biomass production will induce complex interactions among a large number of important ecological processes that are poorly understood (Dale et al., 2010). The conversion of existing crops or of relatively unmanaged and "marginal" land to biomass will be accompanied by changes in land management, including altered fertilization, irrigation, cultivation, and harvesting regimes (Dale et al., 2010). These changes will affect biodiversity and ecosystem functioning and thus the ecological services those ecosystems provide (Dale et al., 2010). This represents a challenge for decision making to ensure strategic and sustainable bioenergy production.

To reach the climate change mitigation targets, large areas would have to be converted to biomass crops. The spatial layout and distribution of these areas in landscapes and regions will influence their effects on biodiversity and ecosystem services. Thus risk assessment procedures and strategic landscape planning should include effects on biodiversity and ecosystem services to ensure sustainable and environmentally friendly energy crop production (Donnelly et al., 2010).

The aim of this paper is to highlight the effects commercial biomass production could have on biodiversity and ecosystem services and to raise issues for decision makers regarding mitigation to promote sustainable biomass production in Ireland.

2. Biomass crops in Ireland

Currently, the end use for biomass in Ireland is heat or combined heat and power (CHP), but might be biorefinery in the future. A viable market and secure supply chains for biomass have not yet been established in Ireland. This may deter farmer uptake of biomass production. Potential biomass crops for Ireland include perennial rhizomatous grasses (PRGs) such as *Miscanthus*, short rotation coppice (SRC) willow, hemp, oilseed rape and sugar beet (Teagasc, 2008). Among the biomass crops, *Miscanthus* and willow have attracted most interest from farmers, with commercial *Miscanthus* production established in 2004. Under commercial conditions *Miscanthus* yields are expected to be approximately 8 to 15 t d.m. $ha^{-1}yr^{-1}$ (Teagasc, 2008). At present, there are approximately 2500 hectares of land planted with energy crops in Ireland, 2100 ha of *Miscanthus*, 360 ha of willow but very little hemp (McDonagh, 2010). As SRC willow is suitable for cultivation on wetter and more marginal soils than *Miscanthus*, these two crops can be regarded as complementary rather than competitors (Styles & Jones, 2007). Hemp is envisaged as a potential bioenergy crop for Ireland by Teagasc (2008), but at present only about 35 farmers are growing hemp on a total area of approximately100 ha (Dieterich et al., 2008). Reed canary grass (RCG) and switchgrass may provide further options but there is currently no commercial production of these crops in Ireland.

3. Influence of biomass crops on biodiversity and ecosystem services

Effects depend greatly on the crop and its management, how production is integrated into existing landscapes and farming systems, how much land is converted to biomass crops and whether intensively managed agricultural land, marginal agricultural land or natural areas are planted (Ranney & Mann, 1994). As a consequence, impacts operate over a range of spatial scales.

Given the comparatively slow uptake of biomass crops by farmers in Ireland, surveys of landscape-scale impacts of biomass crops are difficult to make. Apart from the studies currently undertaken in *Miscanthus* crops within the SIMBIOSYS project and a few MSc and BSc projects (Fennelly, 2007 [birds, ground beetles, rove beetles]; McCabe, 2008 [beetles]; Crowley, 2009 [pollinating insects]; Hennessy, 2010 [spiders]), only a very limited number of studies exist on birds (Kavanagh, 1990; Sage & Robertson, 1996), canopy invertebrates (Sage & Tucker, 1997) and plants (Sage, 1995) in SRC willow in Ireland. This limited number of studies makes it currently difficult to generalize impacts on biodiversity in an Irish context.

This section is therefore based on a review of studies from north-temperate regions (Dauber et al., 2010). There has been a general decline in biodiversity in European agricultural landscapes over the last decades. Not only are rare and threatened species declining, but also common ones which are often ecological generalists, and are responsible for most of the regulating and supporting services in agri-ecosystems. This review does not focus on species of high conservation value, but the overall number of species in biomass crops and fields of traditional land use. Species-specific impacts are detailed in the original literature cited in Dauber et al. (2010).

3.1 Comparison of biomass crops and traditional land use

Biomass crops vs. arable food crops:

Biomass crops are often perceived as being beneficial for biodiversity as opposed to arable food crops. This may be because they have longer rotation periods, low fertilizer and pesticide requirements, provide better soil protection, a greater richness of spatial structures, are exposed to fewer disturbances during the growing period, and harvesting is carried out in winter or can be done after the breeding period of birds, which again causes less disturbance (EEA, 2007). SRC crops (willow and poplar) and PRGs (*Miscanthus sp.* and Reed canary-grass), in comparison to arable crops (wheat, barley, maize, oilseed rape), tend to harbour more species of birds, mammals, plants, butterflies and spiders. Only ground beetles and a few other ground dwelling arthropods have more species in annual arable crops (Dauber et al., 2010, Emmerson et al., 2011).

Given the infancy of the bioenergy sector, most of these comparisons were made in biomass crops during their first few years after planting. During their establishment phase, biomass crop fields are often characterised by open patches which become colonized by weeds. The positive effect of biomass crops on biodiversity may therefore be due to high plant species richness in the gaps, with associated high invertebrate diversity, which provides good food availability (seeds and insect prey) for birds (Dauber et al., 2010). These positive impacts might diminish with age of the crop and the closure of the crop cover.

Biomass crops vs. grassland and set aside:

The number of studies comparing of biomass crops to grasslands or set-aside land is very limited, findings are ambiguous and no general patterns emerge (Dauber et al., 2010). In pastoral landscapes of Wales, Valentine et al. (2009) showed that SRC crops create a pseudo-arable environment for weeds during the establishment phase but create early succession woodland conditions when mature. In consequence, plant species richness and proportions of annuals and short-lived perennials can be higher in recently planted SRC crops compared with grasslands, but will likely decline again with increasing age of the plantations. For birds no clear differences between biomass crops and grassland have been established so far (Dauber et al., 2010).

Biomass crops v forest and woodlands:
Compared with woodland habitats, SRC crops have fewer species or are not different, particularly with respect to bird diversity (Dauber et al., 2010). Most importantly, bird species composition of SRC crops often does not resemble forest bird communities but is rather indicative of open farmland or transitional scrubland. Positive effects were recorded for ground beetles and other ground living invertebrates. Areas planted with fast growing trees are extremely dynamic and within four years they can change from being open habitat to being young forest-like habitat, with trees reaching 10–15 m in height. Consequently, with increasing age of the plantations, plants and birds that are more commonly associated with forests become more abundant in the SRC plots.

Questions for policy consideration:

- To what extent are different aspects of biodiversity (at all levels – genetic, species, habitat) affected and what are the knock-on impacts on the delivery of ecosystem services (other than provisioning) at the field scale?
- How can biomass crops be effectively monitored to determine impacts over longer-time frames, particularly in comparison to traditional cropping systems? Can biodiversity indicators be used?
- Should conversion of sites of high wildlife value and clearing of natural or protected sites be prohibited?
- High wildlife value is not necessarily confined to designated sites (Special Areas of Conservation, Special Protection Areas, Natural Heritage Areas) and therefore should “no-go-areas” for biomass crops be defined, based on biodiversity conservation values?
- Is cultivation of biomass compatible with High Nature Value farming (HNV) and should support for HNV farming systems be part of the post-2013 CAP reform ?

3.2 Biomass crop management

Differences between biomass plantations, in terms of their biodiversity value, may be mainly due to differences in weed and pest control measures, vegetation structure, crop heterogeneity and harvesting patterns. Recent studies at a pan European scale have shown that the application of pesticides continues to be the single most important driver of biodiversity declines in agroecosystems (Geiger et al., 2010).

3.2.1 Pest control and waste application

The development of ground vegetation within the plantations increases richness of associated invertebrate communities and provides food and shelter for birds (Semere & Slater, 2007a,b; Valentine et al., 2009; Bellamy et al., 2009). To maximise yield, weed control is essential for SRC and perennial grass crops (e.g. *Miscanthus*) during establishment, and during seasonal regrowth in the latter (Clay & Dixon, 1995; Bullard et al., 1995). With maturation of the crops, a stable perennial ground flora in energy crops may be desirable, both from an ecological and agro-economical viewpoint (Sage, 1999), and weed control applications may be limited.

SRC plantations support a diverse community of invertebrate species (Sage & Tucker, 1997), many of which are pests such as leaf-eating beetles (Coleoptera: Chrysomelidae), and these can reach damaging numbers in the plantations (Sage, 2008). In non-native perennial grass crops, impacts of invertebrate pests are less severe, at least in the short term. To prevent yield losses, pest control in SRC plantations could become necessary, but may also affect non-pest invertebrates. Given this, and the small economic profit margins of energy crop cultivation, application of insecticides might not be a viable option in SRC crops (Björkman et al., 2004). Biological control may be a realistic alternative, but requires satisfactory risk assessment and strategic management, including a longer period between harvests to enable natural enemies to fully respond numerically and/or to disperse from refuges, or harvesting neighbouring plantations asynchronously (Björkman et al., 2004).

Waste management may be a very viable option for biomass plantations. Waste water remediation offers a local way of dealing with waste water and providing energy at the same time. Greater benefits may be available from sewage sludge disposal. Disposal of waste water from farm, urban or industrial sources to biomass plantations could secure the return of nutrients into the soil, irrigate plantations and further enhances the economic feasibility of biomass production systems. However, sewage sludge can also contain undesirable elements, such as heavy metals. At present, sewage sludge either goes to landfill or is applied to food crops (grass, cereals etc) but EU legislation and public concerns are closing off these two disposal routes. Biomass crops offer a disposal route which does not involve the food chain and which offers economic opportunities for the farmer (avoidance of fertilizer costs, a possible gate fee). Bioremediation could represent a very important driver for expansion of biomass crops, as important as energy production. This practise however becomes questionable if biomass plantations are later re-converted to food production.

Although waste disposal in biomass crops might be expected to have significant effects on the flora and fauna within the crop, an extensive review by Britt (2002) revealed almost no evidence of research that looked directly at the ecological effects of this practice. On one hand, thick applications of waste materials may suppress ground flora and could also run-off into watercourses with subsequent negative impacts on biodiversity. On the other, organic wastes may provide a valuable additional food source for soil and ground-dwelling microorganisms and invertebrates, which may have positive 'knock-on' effects up through the food chain (Britt, 2002). High application rates of sewage sludge however have been shown to cause a considerable reduction in earthworm and spring tail numbers in soil (Artuso et al., 2010).

Questions for policy consideration:

- Can biomass crops be grown with low fertilizer, pesticide, and energy inputs in most settings and can biocontrol agents be promoted?
- Are there advantages to encouraging growth of perennial ground flora in crops after the establishment phase?
- Are applications of wastewater or other waste materials compatible with the nutrient uptake of the crop, the soil and hydrological situation of the site and what are the effects on biodiversity?

3.2.2 Age structure and heterogeneity

Asynchronous harvest and/or establishment patterns of both SRC and grass crops would increase habitat diversity and species turnover, and thus overall biodiversity. Harvesting some fields and leaving other fields unharvested increases the heterogeneity of vegetation structure in the landscape. This can affect biodiversity because different species prefer different growth stages and an ecological succession from harvested to mature crops can be observed (Dauber et al., 2010). As many bird species prefer tall willow plants for nesting, relatively long periods between harvests would be beneficial for many bird species (Berg, 2002), whereas short periods would be beneficial from the perspective of plant conservation, because the reduced light intensity in older stands would reduce the species that could survive there (Gustafsson, 1987).

Planting more than one clone and, if possible, species in a SRC stand would also increase the vegetation heterogeneity and hence the diversity of associated species (Londo et al., 2005). This may also increase the resistance of the plantations to pests and diseases (McCracken et al., 2005). Planting willow species and clones with varying flowering times would extend the flowering season and could provide a more continuous resource for flower visiting insects (Reddersen, 2001). Furthermore, planting both male (nectar and pollen producing) and female (nectar and seed producing) willow and poplar trees provides a more diverse food resource for pollinators and other invertebrates (Reddersen, 2001).

In SRC and *Miscanthus* plantations, headlands and rides provide access to crops for harvesting and other management operations. Those small non-crop areas in the fields are an important feature for biodiversity. In intensively managed farmland they present an opportunity for rough grassland and wood-edge communities to exist (Sage, 1998). In particular, butterfly abundance and occurrence has been shown to be positively influenced by the presence of these habitats (Haughton *et al.*, 2009).

Questions for policy consideration:

- Does polyculture and/or growth of a mixture of varieties (preferably of different gender) increase within crop heterogeneity and thus biodiversity? Similarly, in large plantations, can variation in harvest cycles in individual plots, and establishment of plots in different years diversify the age structure (mixed-age stands) and hence biodiversity?
- Does promotion of rides and headlands increase biodiversity in biomass crops, particularly if they include native nectar sources for flower-feeding insects? Can use of willow clones with a range of flowering times promote resource availability for flower visiting insects?
- The primary goal of biomass crop cultivation is provision of feedstock for energy production. Management actions for biodiversity conservation in biomass plantations will most likely result in reduced yields and farming income. How and to what extent should society pay for biodiversity and ecosystem services other than provision of energy feedstock? Are national subsidies or CAP payments combined with cross-compliance issues appropriate?

3.3 Integration of energy crops into existing land-use systems

3.3.1 Plantation size and shape

The absolute size, the shape of a stand and the relative edge-to-stand area relationship can affect biodiversity. In general, biodiversity tends to be higher at edges of plantations, particularly larger ones, compared with the centres (Dauber et al., 2010). The size and shape of plantations also affect interactions between biomass crops and other land use in the vicinity, and affect whether biomass crops can act as temporal habitat or shelter for species. Many birds move from adjacent habitats into small SRC plantations (Hanowski et al., 1997) and arthropods, including potential biocontrol agents, from surrounding arable crops overwinter in *Miscanthus sinensis* plantations (Loeffel & Nentwig, 1997). Therefore energy crop plantations could also have a positive feedback effect on landscape scale biodiversity and on ecosystem service delivery in neighbouring habitats (EEA, 2007). An optimization of biomass crop field sizes, with a larger number of smaller plantations interspersed in the landscape, may therefore be desirable from a biodiversity and ecosystem service perspective (Smeets et al., 2009).

Questions for policy consideration:

- Should plantations be designed to be small (< 15 ha) with large edge to interior ratios?
- Should it be mandatory to carry out an Environmental Impact Assessment (EIA) for large schemes and at what size should an EIA be required?
- Can plantations be interspersed with other farmed habitats in the landscape?
- How can plantations be located to maximize variation in habitat type and function as buffer, corridor or stepping stone habitat?

3.3.2 Landscape scale impacts of biomass crops

Biomass crop production has the potential to change the diversity of land use. Either it can make it more uniform in the case of extensive, large scale monocultures, or more diverse, in the case of smaller polyculture plantations interspersed in a previously homogeneous landscape (Williams et al., 2009). Impacts also depend on whether the landscape is characterised by annual or perennial cropping systems. Habitat heterogeneity at a range of spatial scales has been positively associated with the maintenance of farmland biodiversity (Benton et al., 2003). The introduction of biomass crops in farmed landscapes could improve habitat heterogeneity, thereby preserving biodiversity and simultaneously diversifying the income mix of landowners (Cook & Beyea, 2000). This could sustain farming in marginal high nature value farmlands (EEA, 2004) or help restore degraded land (UNEP, 2009).

At a landscape-scale, SRC fields of different age classes and a variety of crop species or clones would support a more diverse community of species (Baum et al., 2009). Furthermore, cultivating a variety of biomass crops could increase habitat diversity in agricultural landscapes and enhance arthropod-mediated ecosystem services (Landis et al., 2008).

Questions for policy consideration:

- How can strategic landscape design and positioning of plantations be implemented judiciously, especially in homogeneous annual crop dominated landscapes?
- How should biomass development be incorporated into regional Strategic Environmental Assessment (SEA) procedure?
- Can biomass crops be used to build ecological and ecosystem service values (other than provisioning services) into the existing land-use systems?

3.4 Regional scale impacts of energy crops

The anticipated large increase in energy crop production will require large land areas (UNEP, 2009). As high quality land for agricultural production is limited, or at least unevenly distributed, biomass crops will most likely compete with food and feed production, urban development, forestry and nature conservation or high nature value farming (Sala et al., 2009). Regardless of the total land area required for energy crops, the actual pattern of spatial distribution and habitat configuration of biomass crop plantations will determine their impact. When utilizing biomass feedstock for co-firing, locations of existing power plants and distances to markets or heat generating facilities influence the economic benefit of the crop and the net reductions of GHG emissions. This can create economic pressures for processing or combustion plants to be surrounded by large areas of biomass feedstock (RCEP, 2004). This could result in a spatial aggregation of biomass plantations in regions with appropriate infrastructure. Decentralised production of biomass for domestic market, or small scale combined heat and power stations, will result in a more dispersed distribution of plantations and will consequently have different implications for biodiversity (Hellmann & Verburg, 2010).

Centralized energy crop cultivation could result in large scale monocultures in the most suitable locations and a segregation of landscapes for energy production from landscapes for food production and for nature conservation. If this were the case, it would be futile to use energy crops in an attempt to increase structural diversity, introduce ecotones or buffer zones to improve landscape quality for wildlife. This would represent a worst case scenario for the conservation of biodiversity and its associated ecosystem services. There is room for a rational and efficient use of biomass at the rural level. Taking regional differences into account, risk assessment would have to include coarse scale ecological patterns and processes. This should be facilitated by interdisciplinary research and integrated modelling of environmental and socio-economic issues, necessary to formulate standards that help support long-term economic and ecological sustainability of bioenergy production.

Questions for policy consideration:

- Should feedstock with high conversion efficiencies be selected to minimize land area needed to produce biofuels?
- Can sustainability principles be applied so that novel farming activities are compliant with the overall conservation vision for a respective region?
- Does grant aid for bioenergy crop take economic collection distances of biomass crops into account?
- Can assessments of realistic landscape capacities of bioenergy feedstock production be undertaken to avoid over-optimistic projections regarding the potential contribution of bioenergy to the energy portfolio?
- How can cross-disciplinary research into the development of the bioenergy markets and the context of energy production and the impacts on environment, biodiversity and society be stimulated to evaluate sustainability and economic and environmental tradeoffs?
- How can the above be implemented without posing significant challenges to the farming community? How can capacity building for farmers, a close co-operation between specialist (Teagasc) advisors and farmers, and financial incentives be implemented to mitigatate actions in farming practice?

3.5 Issues that need further exploration or research

Given the scale of biomass production anticipated within Europe, the number of studies on potential effects on biodiversity is very small. In many countries, including Ireland, only a few commercially planted fields of biomass crops exist. In consequence, studies are often conducted on experimental SRC or perennial grass plots. Inferences for extensive commercial production of these crops are thus constrained, as different ecological patterns might emerge for full-commercial, long-term SRC production (Anderson et al., 2004). Addressing ecological questions is further constrained by the limited spectrum of plantation ages (only a limited number of mature energy crop field exist), the small size of most available plantations, poor establishment of some younger plantations, the lack of statistical independence between age and plantation size (most large plantations are young), and by a limited replication of landscape contexts (Rowe et al., 2009). Caution is advised for extrapolating conclusions about habitat or biodiversity value of biomass plantations from one landscape to another particularly as there is a tendency for different responses in forested as opposed to agricultural regions (Christian et al., 1997). Contradictory results may also arise from comparisons of biomass plantations located in different biogeographical regions. There is a need to match climatic conditions for sufficient yield with land availability in the respective regions.

An assessment of the impacts on biodiversity is also constrained by the fact that it is currently not clear which types of land use and habitats would be replaced by full scale commercial production of energy crops. Other socio-economic and policy implementation questions need to be addressed before a full assessment of the potential impacts of biomass cultivation can be undertaken in Ireland (for example, see Table 1).

Table 1: Questions to be addressed and answered satisfactorily to make a nationwide assessment of the biodiversity impacts of biomass crops possible. The current development of a GIS-based bioenergy information system by SEAI might provide a clearer picture at least with respect to the first seven of the questions asked

1. What are the prospects for biomass crop production in Ireland in terms of land-use change and land cover?
2. Which kinds of biomass feedstock are/will be produced?
3. In which counties or regions are/will they be produced and what is the present/expected allocation of land to those crops?
4. Who are the end-users of biomass feedstock, where are they located and how will their distribution affect the location and aggregation of biomass plantations?
5. Which types of land use are/will be available or freed-up for biomass production?
6. What area of biomass crops will be needed for achieving Irish bioenergy targets?
7. Which proportion will biomass crops account for in the Irish bioenergy portfolio and which other feedstock would have to be taken into account?
8. Would planting of energy crops in the form of buffer strips along streams, along forest edges, around protected areas or as “bioenergy hedges” to integrate them into existing agricultural landscapes make economical and environmental sense in an Irish context in the absence of financial incentives?
9. Does the take-up of biomass production by Irish farmers match the projections for energy crop production?
10. In which intensity will commercial biomass plantations be managed and is waste disposal (e.g. waste water disposal) an option for SRC and rhizomatous grass production in Ireland?

Currently only very limited data exist on the biodiversity value of biomass crops in comparison to managed grasslands or uncultivated and semi-natural habitats. Altogether, the limited amount of research makes it difficult to predict the possible effects of large-scale energy crop production on farmland biodiversity (e.g. Rowe et al., 2009). As any change of land use will affect some species positively, and others negatively, it is important to identify the priorities for biodiversity conservation with respect to expected landscape change (Firbank, 2008). Further research should investigate production methods that may enhance biodiversity and ecosystem services such as biocontrol over time. Also the effects of waste disposal in biomass crops and the bioaccumulation of heavy metals, organic toxins, polycyclic aromatic hydrocarbons in animal tissues and increased exposure risk to pathogens are of important concern and should receive more attention by future research (Britt, 2002).

In addition, newly established biomass plantations should be subject to monitoring for effects on biodiversity. The current knowledge base is weak and needs to be built up as experience is gained.

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