

RE-NEW OPINION ARTICLE

Too salty to farm: rethinking coastal land use in response to soil salinization

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Soil salinization poses a growing threat to agriculture in coastal plains, exacerbated by climate change and sea-level rise. As salinization worsens, conventional soil regenerative practices become less effective, particularly in low-lying areas where saltwater intrusion and land subsidence intensify the issue. This position paper advocates for a shift from conventional agriculture toward nature-based approaches, such as the restoration of intertidal ecosystems, as a more sustainable alternative. These nature-based approaches harness natural processes to provide key ecosystem services, including enhanced biodiversity, carbon sequestration, flood protection, and improved water quality, often surpassing the benefits of maintaining degraded farmland. Despite challenges like societal resistance, case studies such as Plan Tureluur demonstrate the potential for successful adaptation. We call for a balanced discussion on prioritizing ecosystem health and coastal resilience over conventional agriculture in salinized regions, underscoring the need to rethink land use strategies to achieve sustainability in coastal areas.

Key words: agriculture, ecological indicators, functions, land abandonment, land use change, Plan Tureluur

Implications for Practice

- We suggest prioritizing restoration of intertidal habitats when considering land use transitions from agriculture on salinized soils.
- Including all stakeholders in an open discussion about transitioning from agriculture to intertidal habitats, is essential to prevent conflict and achieve a sustainable solution to the salinization crisis.

Salinization Crisis

Soil salinization is a major threat to agricultural land (Bless et al. 2018). It affects food production through decreased crop yield and quality as well as, causes soil degradation making arable areas unproductive in the long run (Feinerman et al. 1982; Li et al. 2012; Kirwan et al. 2024). See Supplement S1 for more extended information on salinization process and adaptation measures. While the adaptation measures provide options for farmers facing soil salinization challenges, climate change scenarios including relative sea level rise (SLR) predictions paint a dire picture for farmers with agricultural land on coastal areas due to saltwater intrusion (Mazhar et al. 2022).

Coastal agricultural areas are particularly vulnerable to SLR as they need to cope with more frequent changes in ground water salinity, occasional sea inundations, water stress and waterlogging (Awal 2014). In addition to SLR, climate change can significantly impact coastal areas by increasing the temperature and altering the frequency and intensity of flooding and drought, resulting in more pronounced extremes of wet and dry conditions (Gopalakrishnan et al. 2019). The deterioration of soil

fertility due to salt accumulation in the soil is a growing concern in coastal areas (Mazhar et al. 2022). Salinity reduces soil quality, limits crop growth, constrains agricultural productivity and in severe cases, leads to the abandonment of agricultural lands (Diome & Tine 2015; Sambou et al. 2016). Agricultural land abandonment is a major driver of rural landscape changes (Fayet et al. 2022). Many cases of abandonment of agricultural lands due to salinization are documented in Africa (Diome & Tine 2015; Sambou et al. 2016) and Asia (Chen & Mueller 2018; Gopalakrishnan et al. 2019). However, salinization also affects up to 3 Mha of land in Europe (Mazhar et al. 2022), with salinization-based losses estimated at \$0.54 billion (€0.5 billion) yearly (Ruto et al. 2022).

Within Europe, The Netherlands is particularly susceptible to salinization, as nearly one third of its land area lies below mean sea level (Fig. 1), and current land surface is still subsiding up to

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1 m per century (Oude Essink et al. 2010). A significant amount of the land surface (600,000 ha) in the Netherlands consists of polders, that is, pieces of land that have been reclaimed from a body of water through dykes and drainage canals (Huisman 1998). In areas that fall below the mean sea level, saline water can reach the surface by upward groundwater flow (Oude Essink et al. 2010). Dutch coastal regions such as the Wadden islands, coastal areas of Friesland, Groningen, South and North Holland, and Zeeland are especially vulnerable to salt intrusion (Fig. 1; van den Burg et al. 2024). With arable land in several regions of the Netherlands becoming increasingly salinized, and in cases where crop production is severely affected to the point that agriculture is no longer profitable, it is crucial that we explore other land use functions. In this paper, we argue that a transition toward intertidal ecosystems is a promising adaptation measure to cope with increasing salinization and provides—a plethora of long-term ecological and societal benefits. This position paper advocates for a balanced and informed discussion on the benefits of intertidal restoration, emphasizing the necessity of prioritizing ecosystem health and resilience amidst ongoing environmental pressures.

Examining Land Use Transition Options Through a Sustainability Lens

Anthropogenic activities have been estimated to directly modified at least 70 MKm² or >50% of Earth's ice-free land area (Hooke et al. 2012). Agriculture has expanded into forests, savannas, and steppes in all parts of the world to meet global demand for food, feed and biomass (Lambin et al. 2003), covering nearly 40% of the terrestrial surface of the earth (Power 2010). Agricultural ecosystems, however, provide humans with food, bioenergy, and nutraceuticals (Power 2010). In addition to their provisioning services, agroecosystems can also provide regulating and cultural services (Power 2010). So, when cessation of agricultural activities is necessary due to soil salinization, the ecosystem services provided by agriculture come to a halt, prompting the question of which other functions can be carried out on highly salinized lands? What ecosystem services do these functions provide? And what are the ecological and societal benefits of these functions?

Here, we argue that restoration of intertidal ecosystems from salinized agricultural lands provides several additional ecological benefits, providing an array of ecosystem services (Table 1) that respect our planetary boundaries. The concept of planetary boundaries defines the safe environmental limits within which humanity can continue to thrive (Rockström et al. 2009). This means that as we explore new activities, especially on land areas unsuitable for agriculture, we must prioritize regenerative practices that not only reduce or reverse negative environmental impact but also enhance the buffering functions of ecosystems such as carbon sequestration, water purification, and biodiversity conservation. Moreover, these intertidal ecosystems also have economic benefits (Johnston et al. 2002; Beaumont et al. 2008; Boerema et al. 2016), and the inclusion of these type of activities help to minimize soil degradation costs that occur under saline conditions (Qadir et al. 2014). By

fostering activities with an environmental footprint where the positive impacts outweigh the negative, we can contribute to sustainability in a manner that respects the natural limits of our planet, supports human well-being, and promotes long-term economic resilience.

Restoration of Intertidal Ecosystems

Converting salinized agricultural land to intertidal ecosystems offers substantial benefits. Intertidal habitats provide essential ecosystem services to coastal communities such as carbon sequestration, coastal protection, trophic enrichment of coastal waters, nursery areas for fish species, habitat for aquatic invertebrates, and resting areas for migratory birds (Barbier et al. 2011) (Table 1). Furthermore, intertidal habitats play an essential role in mitigating salinization by trapping sediments, which can limit salt intrusion into adjacent farmlands (Tarolli et al. 2024). However, this land use change is most feasible for salinization-prone agricultural areas in close proximity to tidal and estuarine environments (Fig. 1, overlapping orange and blue hatching). These areas can be reconnected by removing or modifying parts of seawalls, allowing tidal influence to return and supporting the transition to intertidal habitats. Restored intertidal ecosystems are considered especially valuable “blue carbon” ecosystems, because they can store carbon at efficient rates for centuries, playing a crucial role in climate regulation (Burden et al. 2019; Byun et al. 2019; Bulmer et al. 2020). Intertidal habitats also contribute to water quality by regulating nutrient cycling (Boerema et al. 2016; Rios-Yunes et al. 2023). Additionally, silt soils present in this type of landscapes provide flood protection benefits, reducing the need for costly dyke maintenance and enhancing flood safety (Gedan et al. 2011; Möller et al. 2014; Vuik et al. 2019). When considering the broader spectrum of ecosystem services, including these alternative benefits, the economic value of intertidal areas often exceeds that of agricultural land, as demonstrated by Boerema et al. (2016) in the case of the Hedwige-Prosperpolder. Thus, recognizing intertidal nature as a multifunctional environmental and economic asset offers a more sustainable and valuable nature-based approach to land management, particularly in the context of increasing salinization.

While we advocate transitioning salinized agricultural land to intertidal ecosystems, it is important to acknowledge the potential for ecosystem disservices—negative impact to society that can arise from ecosystem processes (Saunders 2020; Wu et al. 2021). In this context, the disservices may include loss of traditional agricultural practices deeply tied to regional identity and culture as well as, substantial investment costs associated with restoring intertidal habitats (Boerema et al. 2016), among others. Nevertheless, given the inevitable decline of agricultural productivity due to land subsidence and salinization, reverting these areas back to their original intertidal environment is not only the best option but an unavoidable one. In coastal plains like those in the Netherlands, land use changes through the reclamation of intertidal and estuarine ecosystems have triggered a slow boom-and-bust cycle in agriculture, rendering long-term farming unsustainable (Fig. 2, see Supplement S2 for extended explanation on agriculture on reclaimed intertidal wetlands).

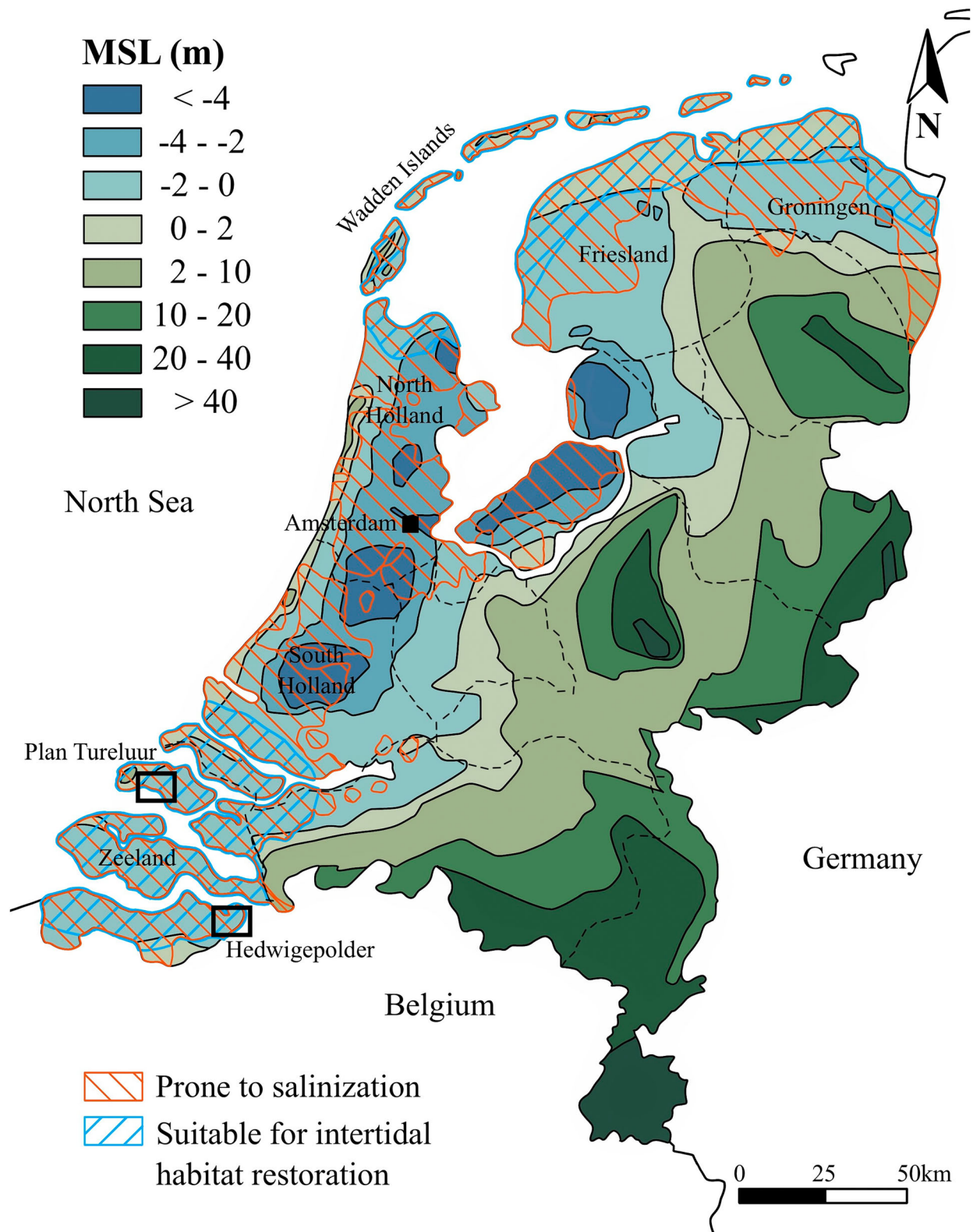


Figure 1. Map of the Netherlands showing land area in relation to mean sea level (MSL) and indicating areas vulnerable to soil salinization, and areas suitable for intertidal habitat restoration (≤ -2 m NAP) (adapted from Oude-Essink 2001).

Table 1. Categorization of ecosystem services provided by intertidal habitats (Adams et al. 2021; Pascual et al. 2023; Hagger et al. 2024).

Category	Service
Provisioning	- Food, feed, and biomass, e.g., salt-tolerant plant species and halophytes - Nursery for fish species—permanent or transient, including important habitat for commercial and recreational fisheries
Regulating	- Habitat for aquatic invertebrates - Water quality regulation—including minimizing pollution and disease outbreak - Nutrient cycling - Coastal defense—flood reduction - Wave attenuation—coastal erosion protection - Carbon storage and sequestration—buffers/mitigates climate change
Cultural	- Recreation, education, and ecotourism—amenity, aesthetic values, education, valuing nature - Cultural importance—cultural heritage value - Waterbird habitat—bird watching
Supporting services	- Carbon storage and sequestration - Trophic enrichment of coastal waters—high biodiversity and productivity - Resting areas for migratory birds and habitat for birds—including breeding and feeding grounds

Though irrigation and ditch flushing can temporarily alleviate salinization, continued subsidence and rising salt levels eventually make farming economically unviable. The increasing costs of managing salinity often fall on water management authorities. Conversely, restoring farmland to intertidal ecosystems can enhance water safety, reduce soil salinization, and protect neighboring farmlands by slowing saltwater intrusion.

Case Study: Plan Tureluur

Plan Tureluur, a Dutch initiative aimed at ecological restoration developed in Schouwen-Duiveland is a particular example of a successful land use transition from agriculture to nature restoration (Beijersbergen & Reest 2004). The results from this transition from agricultural fields to brackish wetlands already showed significant ecological, societal and economic benefits with ecosystem services including, climate change mitigation, water quality regulation, aesthetic value, and ecotourism among others (Beijersbergen & Reest 2004).

Transforming agricultural land into natural ecosystems however, often faces resistance due to societal conflicts, economic interests, and deeply held beliefs about valuing traditional land use for food production above all other functions. The attachment to traditional agricultural practices can make these transitions contentious and emotionally charged. Despite the challenges, cases like Plan Tureluur illustrate that when salinity levels become too high and land productivity declines, farmers become willing to sell their land for nature restoration projects.

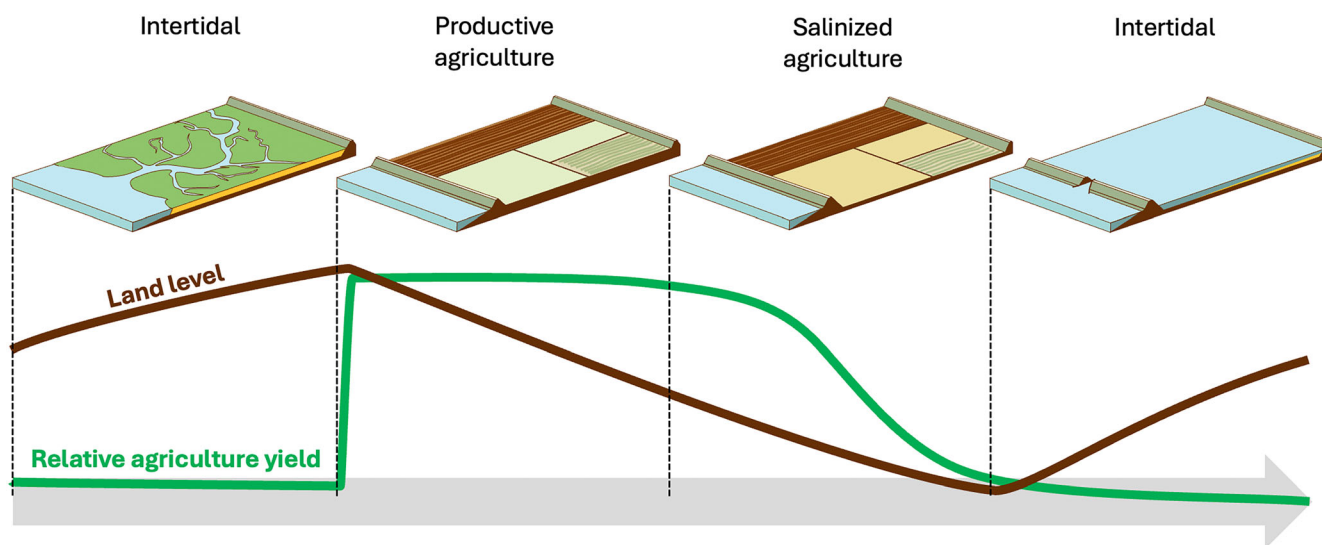


Figure 2. Conceptual model of land use and ecosystem services in coastal zones transitioning due to autonomous processes. The inevitable shift from natural intertidal wetlands to agricultural and degraded landscapes forces a reversion to intertidal zones over time. The x-axis represents land use types along a gradient, transitioning from vegetated intertidal wetlands to productive agriculture, salinized agriculture, and eventually unvegetated intertidal wetlands. The relative levels of ecosystem services (light green) and agricultural yield (dark green) change as land elevation declines and salinization increases. Agricultural productivity initially peaks in the productive agricultural phase but diminishes with rising salinity, resulting in both lower yields and reduced ecosystem services in degraded landscapes. This model illustrates the trade-offs between agricultural development and ecological resilience in coastal systems. The variety of ecosystem services is highest in natural intertidal wetlands but becomes more restricted to food production in agricultural lands, with further reductions due to salinization.

Their willingness highlights the potential for land use change when economic and ecological realities align.

With the construction of the Delta Works, including the Oosterschelde, Philipsdam, and the Eastern Scheldt Storm Surge Barrier, a significant amount of intertidal nature in the region was lost (Wolff 1992). Additionally, the Eastern Scheldt loses approximately 100 ha of intertidal habitat each year due to sand starvation, a process in which reduced intertidal energy disrupts natural sediment replenishment, leading to erosion of intertidal flats and salt marshes (De Ronde et al. 2013). This decline impacts vital habitats that serve as critical stopover points for many migratory bird species (Smaal & Nienhuis 1992).

To address this, Plan Tureluur focused on creating nature restoration solutions inland, where high-water refuges, saline marshlands, and wetlands could be developed to rehabilitate saline ecosystems. Although these restored areas do not fully replicate the original intertidal habitats, they offer valuable alternatives that can be integrated into the landscape given the current constraints.

Conclusion

The soil salinization crisis in the coastal areas of the Netherlands is intensifying, threatening the viability of agriculture and forcing a crucial question: *which land use function can replace agriculture in these increasingly salinized areas?* With SLR and climate change projections becoming more pressing, land use decisions will play a pivotal role in determining how well coastal regions around the globe can cope with the mounting challenges brought upon by climate change. Intertidal ecosystems as an alternative function to agriculture likely provide the robustness needed to better withstand those challenges. Projects like Plan Tureluur in Schouwen-Duiveland and the nature-based solutions explored in the Hedwige-Prosperpolder illustrate that nature restoration can enhance water security, mitigate salinization and provide a myriad of alternative economic opportunities. Recognizing the ecological and economic value of intertidal habitats is crucial to overcoming the biases that often prevent land use transitions before it is too late. To foster a sustainable future, we must continue to promote a balanced, and fair discussion about the broader societal benefits of intertidal ecosystems as an alternative to agriculture.

With a salinization crisis particularly pressing in coastal areas, and considering SLR and climate change scenarios, shifting toward a nature-based approach is likely our best chance to build resilient coastal areas that support both food production and healthy ecosystems. In regions where food security and the Zero Hunger Sustainable Development Goal (SDG2) are urgent priorities, however, tailored solutions are essential. Nature-based approaches, such as integrating salt-tolerant crops, as highlighted in recent studies (Tarolli et al. 2024; van den Burg et al. 2024) can help address the challenges of salinization in food-critical areas. The world-wide adaptability of such approaches not only addresses immediate agricultural challenges, but also contributes to ecological resilience, promoting biodiversity and ecosystem services essential for maintaining the functionality of our landscapes under shifting climatic conditions (Desplanque 1982). By leveraging the principles of nature-based solutions, we can identify and implement innovative

strategies tailored to the unique socio-ecological contexts of each coastal community. Finally, by enabling discussion and collaboration, local stakeholders are empowered and engaged as active stewards of their environments, fostering a sense of ownership and accountability for sustainable resource management. Ultimately, the promise of nature-based approaches lies in their capacity to integrate human activities with natural processes, thereby enhancing adaptive capacity and promoting ecosystem health. By doing so, we pave the way for a sustainable future in which resilience is not merely an aspiration but a measurable outcome, enabling communities to thrive in the face of environmental uncertainties.

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Supporting Information

The following information may be found in the online version of this article:

Data S1: Supplement S1: Salinization process and adaptation measures.
Supplement S2: Agriculture on reclaimed tidal wetlands.

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