The response of Orthoptera to grazing on flood defense embankments in Europe

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Abstract

European flood defense embankments form an excellent habitat for Orthoptera. To be effective against storms, these vegetated earth embankments have to be managed by grazing or mowing. However, grazing can impact invertebrates such as grasshoppers and crickets (Orthoptera). This management can lead to dispersal toward undisturbed grassland and reductions in the quality of habitat, food resources and oviposition sites. In most cases, orthopteran insects require heterogeneous vegetation patches with swards of varying height. The impact of grazing depends on the type of livestock; it is very important to choose appropriate animals, timing and intensity. Sheep grazing in late summer (September-October) at a moderate intensity seems to be favorable for Orthoptera. If grazing is carefully monitored, it can promote Orthoptera conservation while maintaining flood defense integrity.

Key words

biodiversity, bush-cricket, coast, conservation, dike, engineering, fluvial, grasshopper, sea wall

Introduction

In Europe, coastlands are protected from tidal flooding by vegetated earth embankments known as 'dikes' or 'dykes' (Verheij et al. 1997, Sprangers 1999). In the UK, they are referred to as 'sea walls' (Gardiner et al. 2015). There are 259 km of dikes on the Dutch coast (van Loon-Steensma 2015), 970 km in Germany (Rohde 1988), and 900 km in Denmark (Danish Coastal Authority 2015). In the UK, there are approximately 2100 km of sea wall (450 km in the county of Essex alone; Gardiner et al. 2015), which matches the total of the aforementioned three countries combined. A fluvial flood defense can also be required in flood-prone areas; alongside Hungarian rivers for example. In Hungary, 4000 km of dikes protect land from fluvial flooding (IUCN 1995). In England and Wales, there are 35000 km of tidal and fluvial embankments (Dyer 2004).

Significant changes have occurred in the way many vegetated sea walls around the coasts and estuaries of England are managed, not least through increasing efforts to meet common standards with respect to flood prevention (Environment Agency 2012). The main changes relate to increased removal of woody vegetation, changes in the frequency of mowing, and a reduction in grazing of sea walls. The growth of woody vegetation can undermine the structural integrity of sea walls and promote the activity of burrowing mammals such as badgers *Meles meles* L., 1758 (Carnivora: Mustelidae; Gardiner 2014). Woody vegetation and tall, unmown grassland make it difficult for engineers to inspect the condition of sea walls as a defense against tidal flooding, which is their main function (Environment Agency 2012). In the event of overtopping, water pouring over the crest and down the landward face could rip grass tussocks and trees out of the earth, leaving holes in the surface and damaging the sea wall (Gardiner et al. 2015).

A sea wall, or dike, is typically composed of several distinct habitats (Fig. 1). Sea walls have a complex mosaic of microhabitats which Orthoptera utilize (Gardiner et al. 2015) along with adjacent grazing marshes (Gardiner et al. 2017). When combined, these habitats represent a corridor for the dispersal of orthopteroid insects such as bush-crickets (Tettigoniidae), crickets (Gryllidae) and grasshoppers (Acrididae). Orthoptera are key species in many trophic levels but can be influenced by environmental stresses such as grazing (Gardiner et al. 2015). To be fully effective, embankments need to be managed; grazing by livestock is one of the solutions to maintain a healthy ecosystem and flood defense (Davis et al. 2014). Grazing can also occur naturally, for example where rabbits *Oryctolagus cuniculus* L., 1758 (Lagomorpha: Leporidae) and hares *Lepus europaeus* Pallas, 1778 (Lagomorpha: Leporidae) occur (Gardiner et al. 2015). According to Gardiner (2018), '*grazing prevents succession of open grasslands to scrub and forest, creates heterogeneity in sward height, and provides patches of bare earth through the action of livestock hooves breaking the vegetative cover.*'

In European semi-natural grasslands, livestock grazing is a common practice which maintains a high floristic species richness (van Klink et al. 2016). However, grazing can alter habitat quality and negatively affect invertebrates (Ma et al. 2017) by reducing food abundance and influencing microclimate and oviposition sites (O'Neill et al. 2003). Development of vegetation in grassland varies in response to habitat factors and management (Sprangers 1999). It is therefore very important to choose the appropriate

Fig. 1. The typical composition of a sea wall (Brightlingsea, Essex); credit K. Fargeaud.

kind of livestock for grazing dikes and sea walls (Gardiner et al. 2015). In this paper, we investigate how flood defense management (dikes and sea walls) and Orthoptera conservation can be balanced in Europe by collating the available literature and assessing its implications.

Orthoptera on flood defense embankments

The English coastline can be rich in grasshoppers, bush-crickets and groundhoppers (Gardiner et al. 2015). In the county of Essex, as in the Wadden Sea (Netherlands and Germany) and Tisza Basin (Hungary), flood defense embankments provide an important habitat for a range of common and scarce Orthoptera (Table 1). The species richness of the tidal Essex (n = 13) and Wadden Sea (n = 12) flood defense embankments was low in comparison to the fluvial walls of the Tisza Basin (n = 31). The species assemblages of the embankments were markedly different, with only four species common to all three areas: lesser marsh grasshopper *Chorthippus albomarginatus* De Geer, 1773 (Orthoptera: Acrididae), field grasshopper *Chorthippus brunneus* Thunberg, 1815 (Orthoptera: Acrididae), short-winged conehead *Conocephalus dorsalis* Latreille, 1804 (Orthoptera: Tettigoniidae) and *Tetrix subulata* L., 1761 (Orthoptera: Tetrigidae). For the Essex sea walls, two species were locally scarce: grey bush-cricket *Platycleis albopunctata* Goeze, 1778 (Orthoptera: Tettigoniidae) and great green bush-cricket *Tettigonia viridissima* L. 1758 (Orthoptera: Tettigoniidae), compared to four scarce species on the Tisza Basin embankment: crested grasshopper *Acrida ungarica* Herbst, 1786 (Orthoptera: Acrididae), heath bush-cricket *Gampsocleis glabra* Herbst, 1786 (Orthoptera: Tettigoniidae), *Tesselana veyseli* Kocak, 1984 (Orthoptera: Tettigoniidae) and large conehead *Ruspolia nitidula* Scopol, 1786 (Orthoptera: Tettigoniidae), and four scarce species on the Wadden Sea embankment: bow-winged grasshopper *Chorthippus biguttulus* L. 1758 (Orthoptera: Acrididae), lesser grasshopper *Chorthippus mollis* Charpentier, 1825 (Orthoptera: Acrididae), Cepero's groundhopper *Tetrix ceperoi* Bolivar, 1887 (Orthoptera: Tetrigidae) and *T. subulata* (Sprangers 1999, Verheij et al. 1997). The only embankment species on the IUCN Red Data List for Europe was *G. glabra* which is Near Threatened (Hochkirch et al. 2016) and found on the Tisza Basin embankment.

From 1980 to 2009 in the UK, major changes occurred in climate and land use. Beckmann et al. (2015) studied the changes in distribution of some grasshoppers and crickets. They concluded that habitat generalism, southerly distribution and oviposition above ground in vegetation positively influenced range changes. Two species commonly found on sea walls significantly increased: *C. fuscus* and Roesel's bush-cricket *Metrioptera roeselii* Hagenbach, 1822 (Orthoptera: Tettigoniidae) made use of these flood defense corridors during their range expansions. A study in Hun-

Table 1. Species of Orthoptera recorded from earth embankments in three areas of Europe.

Species	Essex Coast (EC)	Wadden Sea (WS)	Tisza Basin (TB)
Acrida ungarica[3]			X
Adreppus nutans			X
Aiolopus thalassinus			X
Calliptamus italicus			X
Chorthippus albomarginatus	X	X	X
Chorthippus biguttulus[2]		X	
Chorthippus brunneus	X	X	X
Chorthippus dichrous			X
Chorthippus dorsatus			X
Chorthippus mollis[2]		X	
Chorthippus oschei			X
Chorthippus parallelus	X		X
Conocephalus dorsalis	X	X	X
Conocephalus fuscus	X		X
Dociostaurus brevicollis			X
Euchorthippus declivus			X
Gampsocleis glabra[3]			X
Gryllus campestris			X
Leptophyes albovittata			X
Leptophyes boscii			X
Leptophyes punctatissima	X	X	
Meconema meridionale		X	
Meconema thalassinum	X	X	
Mecostethus parapleurus			X
Metrioptera bicolor			X
Metrioptera roeselii	X		X
Oecanthus pellucens			X
Omocestus haemorrhoidalis			X
Omocestus rufipes			X
Pezotettix giornae			X
Phaneroptera falcata		X	
Phaneroptera nana			X
Pholidoptera griseoaptera	X		
Platycleis affinis			X
Platycleis albopunctata[1]	X		
Ruspolia nitidula[3]			X
Stenobothrus stigmaticus			X
Tesselana veyseli[3]			X
Tetrix ceperoi[2]		X	
Tetrix subulata[2]	X	X	X
Tetrix undulata	X		
Tettigonia viridissima[1]	X	X	
Number of species	13	12	31

X indicates presence.
[1]Essex Red Data List species (Gardiner and Harvey 2004).
[2]Wadden Sea Red Data Book species (Holst et al. 1996).
[3]Endangered or protected species in Tisza Basin (Torma and Bozsó 2016).

gary showed that insect groups respond differently to habitat and landscape characteristics and Orthoptera are generally influenced by landscape more than habitat features (Torma and Bozsó 2016). Krausz et al. (1995) found that the distance between habitats was correlated with a difference in orthopteran assemblages. They also highlighted the lack of knowledge in the role of population isolation and of habitat corridors such as sea walls and dikes in structuring Orthoptera assemblages. A small-scale study in Essex suggested that the absence of intensive agriculture and livestock grazing on an island with sea wall flood defenses created important refuges for Orthoptera (Gardiner and Ringwood 2010).

Therefore, flood defense embankments seem to be an important corridor habitat for Orthoptera across Europe and grazing management should seek to enhance their value without compromising flood risk.

Fig. 2. Sheep grazed sea wall with a homogeneous, short sward; credit T. Gardiner.

General grazing effects

Timing.—Year-round grazing can be a useful tool for maintaining the insect assemblages of large grassland areas (Fleischer and Hölzel 2013). This management can maintain the characteristic biodiversity of semi-natural heathlands and grasslands (WallisDeVries et al. 2016). In lowland heathland in the Netherlands, grazing seems more beneficial to early successional species than late successional species which are negatively affected (WallisDeVries et al. 2016). In grasslands in southwest Montana (USA), Davis et al. (2014) showed that herbivory affected many plants and arthropod characteristics in a similar manner: early grazing (June) can negatively affect species which need forage in the early growing season. Davis et al. (2014) suggest that the timing of grazing can have big effects on the biodiversity of multiple trophic levels and effects can depend on the grassland habitat type. However, they found that Orthoptera were unaffected by grazing and that plant height was greater with early grazing (late June) than late grazing (July and August). In the Netherlands, a continuous pasturing lasts for the entire grass growing season (mid-April to mid-October) with a low density of livestock (Muijs 1999). In Essex, sea walls are often grazed with sheep through September and October (Gardiner et al. 2015). Indeed, sheep grazing can be the best method if it includes rest periods in areas where plants need to germinate. The grassland should be mown twice a year to reduce the nutrient content of the soil; if not, once a year in mid-July may be sufficient (Sprangers 1999).

Patch formation.—Orthoptera are influenced by the formation of grass patches in grazed habitats (Gardiner and Hill 2004). Heavy grazing can create a homogeneous sward of consistently short vegetation with little cover from avian predation or inclement weather (Fig. 2). In Germany, the interaction between fodder quality and grazing intensity can lead to cattle adjusting their grazing pattern according to the vegetation biomass, which leads to the establishment of heterogeneous patches (Fleischer and Hölzel 2013). On the Wadden Sea coastline, the choice of livestock type has smaller effects on trophic levels than stocking intensity (van Klink et al. 2016). Invertebrates, such as *C. brunneus*, sometimes opt for patches of short turf and bare ground as habitat because it provides ideal oviposition and basking sites (Gardiner et al. 2015).

Soil disturbance.—Orthoptera may also be affected by the soil disturbance associated with grazing. Grasshoppers, such as the mottled grasshopper *Myrmeleotettix maculatus* Thunberg, 1815 (Orthoptera: Acrididae), require exposed soil and sparse grassland (good egg-laying and basking conditions) which can be created by associated cattle trampling of the vegetation. However, cattle grazing can lead to a sward with uniformly short grass with reduced grasshopper suitability overall (Gardiner 2012).

Applying livestock

Sea wall and dike vegetation is often maintained by grazing animals. Herbivores grazing on grasslands stimulate grass productivity (Nolte et al. 2014). A study in the Netherlands found that canopy height is affected by two variables: livestock species and livestock density (Nolte et al. 2014). The livestock species (including wild herbivores like rabbits) can also affect plant abundance and assemblage diversity, which are correlated with Orthoptera conservation and pest management (Gardiner 2018). Herbivore species and densities should therefore be chosen depending on their impacts.

Moderate intensity sheep grazing (c. 10 sheep/ha) in Essex can create a high sward heterogeneity which is generally favorable for Orthoptera (Figs 3, 4). Like rabbits, sheep can easily reach inaccessible areas, which can be desirable or undesirable depending on the flood defense management objectives (Gardiner et al. 2015).

Less selective grazers such as cattle can create a relatively uniform sward height by removing long and coarse grass where many invertebrates like *M. roeselii* or *C. albomarginatus* occur (Gardiner et al. 2015). However, intense cattle grazing can damage the soil surface (Fig. 5) and the flood defense requiring costly repairs. For this reason, these grazers are not generally recommended for grazing dikes or sea walls (Gardiner et al. 2015).

Horses can also be used to graze dikes and sea walls. If their stocking intensity is heavy, a very homogeneous, short sward will be created (Fig. 6). Nevertheless, low stocking densities of equines in large areas can provide a varied mosaic with shortly grazed lawns and taller undisturbed vegetation. Ungrazed latrines (dunging areas) form an excellent tall-grass habitat for many species of Orthoptera such as the bush-crickets *C. fuscus* and *M. roeselii* (Gardiner et al. 2015).

To create heterogeneous, small-scale vegetation mosaics, Nolte et al. (2014) recommended cattle rather than horses, but at a

Fig. 3. Light sheep grazing on a sea wall creating a heterogeneous, patchy sward favorable for Orthoptera (Little Oakley, Essex, UK); credit T. Gardiner.

Fig. 5. Post-grazing cattle damage; credit T. Gardiner.

Fig. 4. Sheep grazing on a sea wall folding creating a heterogeneous, patchy sward favorable for Orthoptera (Brightlingsea, Essex, UK); credit T. Gardiner.

Fig. 6. Horse grazed area (left) vs. ungrazed area (right); credit T. Gardiner.

low intensity. However, cattle and horses contribute to very poor erosion-resistant revetments (Muijs 1999).

Of the Dutch dikes, 85% are grazed, and 15% have species-poor grassland used for haymaking (Sprangers 1999). Sprangers (1999) adds that the 'Frysian system' is very efficient. The principle of the system is that grazing a small dike parcel with a large number of livestock during a short period is better than grazing a large parcel with few livestock continuously. This results in periodical heavy grazing of small areas with 35 to 40 ewes and lambs per hectare, corresponding to 15 sheep per hectare per year. These livestock numbers reflect the 60% of sea dikes which were traditionally heavily grazed and fertilized. Moreover, Sprangers (1999) affirms that around 85% of the aforementioned heavily grazed dikes are managed using sheep. This is exactly the opposite in Essex where 86% of sea walls are mown and only 14% are grazed or unmown (Gardiner et al. 2016). This results in a taller vegetation on the Essex sea walls due to the late summer mowing in August and September (Fig. 7).

Livestock effects on Orthoptera

Grazing by livestock affects vegetation, and therefore Orthoptera. Kruess and Tscharntke (2002) suggested that insect diversity increases in the following order: '*intensively grazed* (5.5 cattle/ha) > *extensively grazed* (1.4 cattle/ha) > *short-term ungrazed (ungrazed for 3 years)* > *long-term ungrazed (ungrazed for more than 5 years)*'. In Montana (USA), grazing and trampling encroach upon grasshoppers' food and influence the physical structure of vegetation and the soil surface which, in turn, impacts the thermal environment and oviposition sites (O'Neill et al. 2003). O'Neill et al. (2003) conclude that most grasshoppers are negatively influenced by these stresses. Herbivores frequently disturb Orthoptera, leading to dispersal of species such as the meadow grasshopper *Chorthippus parallelus* Zetterstedt, 1821 (Orthoptera: Acrididae) to undisturbed grasslands (Gardiner et al. 2015). In the long-term, reducing sward height and increasing disturbance through heavy grazing can lead to dispersal through undisturbed and infrequently cut

Fig. 7. Uncut grassland and scrub on a sea wall folding (Brightlingsea, Essex, UK); credit T. Gardiner.

Fig. 8. Sheep-grazed area (left) vs. undisturbed area (right); credit T. Gardiner.

areas (Fig. 8) (Gardiner et al. 2015). Moreover, the linear nature of grassland dikes promotes migration (Krausz et al. 1995).

The response of Orthoptera to a physical disturbance is to jump (Ben-Ari and Inbar 2013). However, this escape mechanism leads to an important energy expense. In Israel, Ben-Ari and Inbar (2013) studied the dropping mechanism of insects in response to mammalian breath. They found a direct influence of mammalian herbivores on plant-dwelling insects.

In the grasslands of the Eastern Eurasian steppe, Ma et al. (2017) recommended avoiding continuous years of intense sheep grazing. They found a significant cumulative effect; an increase in sheep grazing intensity caused decreases in insect abundance, diversity and species richness. Regarding cattle, their presence on sea walls can create very short, homogeneous grassland swards (uniformly <10 cm height) which reduces suitability for Orthoptera (Gardiner et al. 2015). Eventually, modifying grassland ecosystems with domestic livestock grazing can lead to a significant loss of biodiversity (Evans et al. 2015). On Essex sea walls in Eastern England, Orthoptera were recorded from 2 x 2 m quadrats (5 quadrats per plot) in cattle, sheep and rabbit grazed grassland plots and compared to mown plots using a one-way analysis of variance (ANOVA) after square-root transformation of count data to normalize it. A post-hoc Tukey test was performed to determine the differences between the plot means in the four differently-managed grassland types.

The statistical analysis revealed that significantly higher densities of Orthoptera were recorded in sheep and rabbit grazed grassland compared to mown swards (Table 2). Densities of Orthoptera could exceed 3 adults/m^2 on some grazed sea walls. The greater heterogeneity in sward height on the sheep and rabbit grazed sea walls was particularly favorable for grasshoppers such as *C. albomarginatus*. The mosaic of grass heights provided patches of short vegetation for basking and oviposition, and tall vegetation for shelter from avian predation and excessively hot microclimatic temperatures (Gardiner and Hassall 2009). Species richness did not differ between the sea walls (Table 2).

A German study found a bottom-up effect in heavy cattle grazing impacting plant-insect interactions (Kruess and Tscharntke 2002). Increasing grazing intensity may affect trophic levels by negatively affecting both primary and secondary consumers (Ma et al. 2017). Removal of vegetation biomass by grazing negatively affects herbivorous arthropod abundance and consequently reduces predator numbers, especially of the field vole *Microtus agrestis* L., 1761 (Rodentia: Cricetidae; Evans et al. 2015). In a ten-year experiment, Evans et al. (2015) suggested that intense long-term ungulate grazing can have an important impact on trophic levels but not on plant diversity. Kruess and Tscharntke (2002) found that decreasing grazing intensity improved insect diversity but not plant diversity, which was low in intensively grazed pastures and high in abandoned areas. In intensively modified vegetation, even if the diversity is not impacted, Orthoptera and their predators are negatively impacted. Evans et al. (2015) also detected a strong positive effect of vegetation biomass on arthropod abundance.

The effect of grazing is usually species-specific because the response of species and assemblages differs in accordance with the region and the grassland type (Gardiner 2018). Both phytophagous and entomophagous insects are affected by grazing intensity (Kruess and Tscharntke 2002). However, not all groups are negatively impacted, such as some larvae and soil-dwelling insects (Evans et al. 2015). Kruess and Tscharntke (2002) consider that grazing or abandoning of grassland does not affect habitat specialist or generalist insects.

Table 2. Density and species richness of Orthoptera on Essex sea walls (UK) with differing management (Gardiner unpublished data, 2011).

Management (n)	Density/m^2	No. species/plot
Rabbits (4)	2.9 ± 0.4	2.0 ± 0.0
Sheep (4)	2.6 ± 0.8	2.5 ± 0.3
Cattle (4)	1.4 ± 0.1	3.3 ± 0.9
Mown (12)	0.7 ± 0.2	2.4 ± 0.4

One-way ANOVA:
Density: F = 9.05, d.f. 3, sheep vs. mown sig. P<0.05, rabbits vs. mown sig. P<0.01.
Species: F = 0.74, d.f. 3, P=0.54.

Mixed management

Grazing can alternate with other kinds of management such as mowing or occasional burning. Sometimes, mowing may be the only solution in areas hardly accessible to domestic livestock such as remote sea walls. A rotational management strategy produces complex effects on orthopteran assemblages and develops a diverse range of vegetation structures (Gardiner 2018). A combination of grazing and mowing is possible on dikes and sea walls. Alternate periods of grazing and mowing on a dike or sea wall can increase biodiversity while ensuring flood defense integrity is maintained (Gardiner et al. 2015). The use of rotational sheep grazing on English sea walls develops suitable conditions for large populations of grasshoppers, especially *C. albomarginatus* (1.7 adults/m^2; Gardiner and Charlton 2012). In the Netherlands, grassland needs to be managed by grazing and mowing to prevent irregular grass (Muijs 1999). In Germany, some dikes were frequently mown and grazed, so no impacts were found on already impoverished grasshopper populations (Batáry et al. 2009). In Hungary, grasshopper abundance was higher on extensive fields, and all arthropods (including grasshoppers) were impacted in their community structure (Batáry et al. 2009). The relatively high species richness on some Hungarian dike sides is probably due to the infrequent mowing disturbance (Krausz et al. 1995).

Benefits of unmanaged sites

The structure of grassland provides an excellent habitat for Orthoptera when it is uncut (ungrazed and unmown; Gardiner et al. 2015). In undisturbed patches on Essex sea walls (Fig. 9), locally scarce species such as *T. viridissima* can be abundant. Ungrazed pastures with tall grassland provide important refuges, like latrines, for Orthoptera (Gardiner 2018). Indeed, an experiment showed that *C. parallelus* nymphs and adults released in a heavily grazed area dispersed to tall grass (Gardiner and Hill 2004). Gardiner and Hill (2004) concluded that these directional movements reflected a preference for ungrazed grass as a more favorable breeding habitat.

Fig. 9. Undisturbed grassland on a sea wall folding; credit T. Gardiner.

Grassland undisturbed for many years provided an important habitat for large populations of Orthoptera, especially for *M. roeselii* (Gardiner et al. 2015). On a sea wall, the uncut and ungrazed folding next to the borrowdyke is the most important habitat in terms of Orthoptera distribution (Fig. 9, Table 3). Bush-crickets (*Conocephalus* spp. and *M. roeselii*) preferred tall vegetation patches on the uncut folding and the landward slope. Grasshoppers (especially *C. brunneus* and *C. parallelus*) preferred the track disturbed by vehicle wheels because of the frequent patches of bare earth probably used as basking and oviposition sites. Soil disturbance is a key consideration in the conservation of flood defense embankment Orthoptera, with trampling live-

Table 3. Orthoptera abundances recorded from five sections of a seawall (Brightlingsea, UK) using quadrat sampling (Gardiner et al. 2015).

Orthoptera species	Folding (uncut)	Folding (track)	Landward Slope	Crest	Seaward slope	TOTAL (%)
Conocephalus spp.	52	0	35	0	7	94 (13)
Pholidoptera griseoaptera	6	0	0	0	0	6 (1)
Chorthippus brunneus	1	31	12	9	10	63 (9)
Chorthippus parallelus	15	32	15	0	3	65 (9)
Chorthippus albomarginatus	5	4	35	6	41	91 (12)
Metrioptera roeselii	236	1	170	1	7	415 (57)
TOTAL	315	68	267	16	68	734 (100)

Table 4. Advantages and disadvantages of three different grazing animals for grassland Orthoptera conservation and maintaining flood defense integrity.

	Sheep	Cattle	Horses
Advantages	Heterogeneous sward height[1] Control scrub	Heterogeneous sward height[1] Poaching creates bare ground Control scrub	Heterogeneous sward height[1] Poaching creates bare ground Latrine areas Control scrub
Disadvantages	Homogeneous, short sward[2] Limited poaching	Homogeneous, short sward[2] Damage to flood defense from poaching	Homogeneous, short sward[2] Damage to flood defense from poaching

[1]At low-medium stocking intensity.
[2]At high stocking intensity.

stock hooves providing the necessary disturbance in the absence of vehicles (Table 4).

Dike habitats provide diverse resources, completely or incompletely fulfilling resource requirements depending on the species of Orthoptera (Gardiner et al. 2015). The main grazing animal on European sea walls is sheep, which can be favorable for Orthoptera when the stocking intensity is light-moderate establishing a heterogeneous sward (Table 4). However, Orthoptera may also be negatively impacted at high stocking intensities due to the creation of a uniformly short sward with few tall grass refuges (Table 4). It is advisable to alternate grazing with mowing and to prefer sheep over cattle and horses to minimize soil damage on the flood defense.

Conclusion

Flood defense embankments in Europe are commonly rich in Orthoptera. In some cases, grazing can promote plant species richness and favorable habitat for Orthoptera, including scarce species such as *G. glabra* and *T. ceperoi*. Where high flood risk exists, dikes and sea walls are sometimes over-managed by heavy grazing and/or mowing. Controlled management should aim to establish a heterogeneous sward with varying grass heights. The main criteria when deciding on the appropriate flood defense embankment management for Orthoptera are: grazing duration, stocking intensity (numbers of animals per hectare) and type of livestock (Table 5). Without compromising the effectiveness of the defense, a balance can be applied between management intensity and conservation of the Orthoptera. Further research is needed into the precise influence of sheep grazing on sea wall Orthoptera throughout Europe, but particularly where there is a high proportion of scarce and endangered species such as the Wadden Sea.

Table 5. Matrix to enable appropriate grazing and mowing regimes to be chosen in relation to Orthoptera abundance and maintaining flood defense integrity.

	Low flood risk (farmland)	High flood risk (properties)
Low Orthoptera abundance (<3/m²)	Rabbits* Sheep- Mowing-	Sheep+ Mowing+
High Orthoptera abundance (>3/m²)	Rabbits* Sheep-	Sheep+

Key: - low intensity grazing (≤10 sheep/ha) or mowing (1-2 cuts/yr)
+ high intensity grazing (>10 sheep/ha) or mowing (>2 cuts/yr)
* naturally occurring rabbits, not stocked

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