Big in Japan: The importance of riparian corridors for Orthoptera

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Abstract

There are few studies on the Orthoptera of the floodplains, paddy fields, and levee embankments of Japan's riparian corridors. The research which has been undertaken indicates a relatively rich fauna (33% of Japan's grasshopper species recorded) with endangered species (e.g. *Eusphingonotus japonicus*) found on gravel floodplains, although diversity is restricted by forest cover and unfavorable land uses (e.g. agriculture). Management should focus on the alteration of levee mowing regimes to benefit orthopterans, and the control of invasive plant species and successional processes along river corridors, which appears to be important for grasshoppers of gravel substrates. Integrated Green Grey Infrastructure (IGGI) measures (levee terraces of Asteraceae plants) may enhance populations of Orthoptera and conserve declining plants such as *Aster tripolium* in Tokyo. More research is required throughout Japan to accurately determine the orthopteran fauna and appropriate conservation measures, particularly along super levees and in paddy fields.

Key words

conservation, ecosystem services, flood defense, floodplain, levee, paddy field, river

Introduction

A recent paper on the ecological niches of Korean Orthoptera in a meadow (Jung et al. 2018) highlights the dearth of research on conservation management techniques in temperate Asia. Linear corridors, such as riparian floodplains and associated levees, are of high importance for Orthoptera in Europe (Gardiner et al. 2015, Fargeaud and Gardiner 2018), but no assessment exists in Japan where an extensive network of flood defense levees are present in urban areas such as Tokyo (157 km of riparian levees; Tian 2014). The value of urban habitats with green corridors is illustrated by the banks and gardens of the Tokyo Imperial Palace where 45 species of Orthoptera (11% of Japan's estimated 390 species; Tojo et al. 2017) have been recorded (Biology Study Group 2001). Studies in the Tokyo area found a relationship between the distribution of green coverage and Orthoptera (Fukada 2002), with distance from existing habitats a key factor for determining species occurrence (Itagawa et al. 2012). Fifty species were collected in the Satoyama landscape (buffer zone between foothills and arable land) in Kanazawa (ElEla et al. 2012), while along the Nakatsu River the locally endangered grasshopper *Eusphingonotus japonicus* has been found on gravel habitats (Takeuchi and Fujita 1998).

Natural flood barriers such as sand dune forests and pine-covered islands (e.g. in Matsushima Bay; Fig. 1) can complement concrete and earthen levee embankments during storm surges and tsunamis (Tanaka 2012, Renaud and Murti 2013). These natural features function as vital secondary defenses when embankments overtop, or waves break during tsunamis, providing important ecosystem services (Renaud and Murti 2013). Movement of butterflies between the Urato Islands in Matsushima Bay (up to 6 km) is frequent, with wetlands, paddy fields, and linear levees contributing to host plant abundance (Yamamoto et al. 2007). However, green corridors, particularly in urban areas, may not be managed for the optimization of wildlife populations due to their human usage (Matsuba et al. 2016).

There are significant opportunities when rebuilding, repairing, and managing artificial and natural flood defenses to increase the abundance and diversity of wildlife (Cousins et al. 2017, Naylor et al. 2017, 2018). Mowing regimes can be altered to enhance populations of pollinators (Gardiner and Fargeaud 2018) such as endangered butterflies (Zhang and Miyashita 2017, Ohwaki et al. 2018), but could also be used to benefit orthopteran assemblages (Fargeaud and Gardiner 2018). Integrated Green Grey Infrastructure (IGGI) measures have been developed to provide engineers with a suite of options when it comes to the management of riparian embankments and floodplains (Naylor et al. 2017, 2018). Manipulation of floodplain vegetation to encourage Orthoptera (Yoshioka et al. 2010a) could benefit plant species such as the endangered *Aster kantoensis* (Takenaka et al. 1996, Kuramoto et al. 2005).

It is the aim of this review to highlight the current state of knowledge about the Orthoptera of riparian corridors in Japan and to ascertain which conservation management measures may be appropriate for further research and implementation.

Fig 1. Grassland buffering the shoreline on Fukuura Island in Matsushima Bay, acting as a natural flood defense. Grasshoppers (*Oxya* spp.) were numerous in this coastal corridor. Photo by T. Gardiner.

The overlooked Orthoptera

Japan is a global biodiversity hotspot with approximately 390 species of Orthoptera (Tojo et al. 2017). The native orthopteran fauna of the mainland (Honshu: 175 species) is species-poor compared to the islands (Bonin Islands: 0.07 spp./km^2, Honshu: 0.0008 spp./km^2; data from Yamanaka et al. 2015 and Cigliano et al. 2018), which in part reflects the extensive mainland development which has dramatically altered ecosystems (Nakamura et al. 2006). Suitable habitats for Orthoptera are becoming rarer; 61% of Japanese wetlands (current area 850 km^2; Natuhara 2013) have been lost in the last 100 years (Fujioka et al. 2010), concomitant with a steep decline in paddy field area since 1970 (Ichinose 2007, Katayama et al. 2015) to the current level of approximately 25,000 km^2 (6.6% of Japan's land area; Natuhara 2013). Riparian forest cover has been reduced due to the development of pasture (Table 1), which has led to riverbanks covered by native and alien plant species (Nakamura and Yamada 2005). The forest cover that remains is unlikely to be a favorable habitat for Orthoptera of open ground, restricting endemic species such as *E. japonicus* to pockets of gravel floodplain not encroached upon by trees. Unmanaged succession of riparian habitats to forest cover may be a critical threat to the persistence of this species (Takeuchi and Fujita 1998).

Where riparian wetlands have been converted to paddy fields (Table 1), they form a vital role in maintaining landscape heterogeneity through their network of levee banks (Fukamachi et al. 2005, Katayama et al. 2015, Normile 2016) and are an effective substitute for natural ecosystems (Natuhara 2013). Many paddy fields have been abandoned (Ichinose 2007, Yamada et al. 2013, Normile 2016) or converted to dry arable land, and those that remain are typically smaller than 1 ha (Fujioka et al. 2010) and intensively managed with chemical pesticides (Ichihara et al. 2014b, Katayama et al. 2015). The usage of pesticides has been linked to a decline in the abundance of harvestable grasshoppers for consumption (*Oxya* spp.) since the 1980s (Payne 2014). The proportion of modern riparian paddy fields with undeveloped land (e.g. levee banks 1–3 m high) has been reduced due to agricultural intensification and rationalization of the field network (Natuhara 2013). Where levees exist, natural vegetation cover has often been replaced with concrete to reduce mowing labor and improve slope stability (Fukamachi et al. 2005); this, however, removes suitable habitats for Orthoptera.

What is clear is that Orthoptera form an important part of grassland ecosystems (Gardiner 2018), consuming between 0.3–8% of net primary production (Köhler et al. 1987), although they are particularly wasteful feeders (e.g. *Chorthippus parallelus* consumes 2% of net primary production, but wastes 8%; Ingrisch and Köhler 1998). Orthoptera are also a vital constituent of food chains (Latchininsky et al. 2011). In a Japanese forest-stream ecosystem (Sato et al. 2011), orthopterans infected by nematomorph parasites (*Gordonius* spp.) were 20 times more likely to enter the watercourse, where they were a significant source of food (60% of their annual energy intake) for endangered Japanese trout (*Salvelinus leucomaenis japonicus*). In paddy fields and other riparian habitats in suburban areas (Kaneko et al. 2009), orthopterans were recorded in high abundance, consequently forming an important component (21.5% of food items) in the diet of the Japanese weasel *Mustela itatsi*. On open riverside plains, waterbirds feed on grasshoppers before and after the harvest in rice field wetlands (Fujioka et al. 2010), while on Sado Island, paddy field Orthoptera are essential in the diet of the endangered crested ibis *Nipponia nippon* (Yoshio et al. 2009; Table 2).

Despite their obvious role in sustaining food chains, studies on the Orthoptera of Japan in relation to riparian corridors are sparse. Yoshioka et al. (2010a) document species abundance on floodplain gravel and grassland along the Kinu River to the north of Tokyo (Table 2). The species list for gravel floodplain and buffer lands (Kinu grasslands) consisted of 12 recorded species, while 13 species were recorded in the Kitadan Valley wetland and surrounding habitats (ElEla et al. 2012). Three species were reported from the riverbed of the Nakatsu River (Takeuchi and Fujita 1998). In the coastal buffer lands of Tokyo, 10 species were recorded (Itagawa et al. 2012), although this may be a slight underestimate due to translation difficulties with the paper. A study of crickets on paddy field levees near Mount Fuji recorded seven species occurring on a levee and up to 15 m into the rice crop (Fig. 2).

The composition of the assemblages was markedly different between the six studies (due in part to three studies only focusing on one infraorder), with only two species each found in four studies (*Oxya yezoensis* and *Teleogryllus emma*) and one species found in three studies (*Atractomorpha lata*). Species such as *E. japonicus* are considered to be endemic to floodplain habitats and regionally rare (Takeuchi and Fujita 1998).

An interesting geographical influence can be noted from the comparison of two studies. The west coast study (Kitadan Valley) had the highest number of unique species (85% of 13 species), a difference reflected in the east coast samples (Tokyo) in which 70% of species were unique (Table 2). The east and west coast studies shared only two species in common (*O. yezoensis* and *T. emma*), which may in part be due to the artificial nature of the reclaimed coastal sites in Tokyo and the more natural wetland habi-

Table 1. Area of land use and vegetation types in Japanese riparian areas (after Miyawaki and Washitani 2004).

Land use	Estimated area (ha)	%	Value for Orthoptera
Native vegetation	71091	46	High
Pastures	18545	12	Medium*
Agricultural fields (incl. paddy fields)	17000	11	Medium*
Alien vegetation	12364	8	Low
Forestry	3091	2	Low
Others (urban etc.)	32455	21	–
Total	154545	100	

*value depends on the intensity of management (e.g. whether pesticides are used).

Table 2. Species of Orthoptera recorded in riparian corridors in Japan (X = recorded). Some studies only recorded one infraorder (Kinu, Nakatsu, and Fuji). The number of prefecture Red Data Lists a species is included in is also noted, and Japanese endemic species are in bold.

Infraorder, species	Kinu River[1]	Nakatsu River[2]	Fuji Paddy[3]	Sado Paddy[4]	Kitadan Valley[5]	Tokyo Coastal[6]	Prefect. Red List
Honshu location	Central	North	East coast	Sea of Japan	West coast	East coast	
Acrididea (grasshoppers)							
Acrida cinerea	X						
Atractomorpha lata	X			X		X	
Chorthippus biguttulus						X	
Eusphingonotus japonicus	**X**	**X**					**28**
Gastrimargus marmoratus	X						5
Glyptobothrus maritimus	X						2
Gonista bicolor	X						14
Locusta migratoria	X	X					1
Mongolotettix japonicus	X						2
Oedaleus infernalis	X	X					
Oxya yezoensis	**X**			**X**	**X**	**X**	
Parapodisma mikado					**X**		
Patanga japonica	X					X	
Shirakiacris shirakii	X						17
Stethophyma magister					X		4
Tetrix japonica					X		
Tettigoniidea (bush-crickets)							
Chizuella bonneti					X		1
Conocephalus maculatus				X		X	
Eobiana engelhardti subtropica					X		
Eobiana gladiella					**X**		
Euconocephalus varius						X	2
Gampsocleis buergeri					**X**		**3**
Mecopoda niponensis					X		18
Phaneroptera falcata						X	
Ruspolia lineosa				X		X	
Gryllidea (crickets)							
Dianemobius fasciatus			X				
Loxoblemmus arietuius			X				1
Mitius minor			X				5
Ornebius kanetataki						X	
Polionemobius taprobanensis			X				
Pteronemobius ohmachii			X				1
Teleogryllus emma			X	X	X	X	
Teleogryllus occipitalis					X		
Velarifictorus aspersus					X		
Velarifictorus micado			X		X		
No. species	12	3	7	5	13	10	15

[1] Yoshioka et al. (2010a); [2] Takeuchi and Fujita (1998); [3] Ichihara et al. (2014b); [4] Yoshio et al. (2009); [5] ElEla et al. (2012); [6] translated from Itagawa et al. (2012).

tats of the Kitadan Valley, but also because of differing sampling methods/biases (Gardiner et al. 2005) and differences in climate (the Sea of Japan coast is wetter than the Pacific coast) and isolation by mountainous terrain (Tojo et al. 2017).

When prescribing management techniques for different geographical regions of the Japanese archipelago, careful consideration should be given to their diverse orthopteran assemblages. Five studies in Table 2 are from Honshu Island (Japanese mainland), with much variation in the Orthoptera of Japan's 6852 islands which extend over 3000 km along the Pacific 'Ring of Fire' (Tojo et al. 2017). Genetic diversity is hugely varied throughout the archipelago for *Locusta migratoria* (Tokuda et al. 2010), *Podisma sapporensis* (Kowalczyk et al. 2008), and Tetrigidae (Ichikawa 1994). The life cycle of widely distributed species such as *L. migratoria* is markedly different across the islands, diapause being influenced by latitude (Tanaka 1994).

Further targeted research into the species present from a range of islands and latitudes will yield a longer list of Orthoptera in riparian areas. Only 35 species are listed in Table 2, a relatively small proportion of the Japanese Orthoptera (c. 390 species). Five (14%) of these are endemic to Japan (*Eobiana gladiella*, *E. japonicus*, *Gampsocleis buergeri*, *O. yezoensis*, and *Parapodisma mikado*). Fifteen species (43%) (including two of the endemics) are included in regional prefecture Red Data Lists (NPO Wildlife Research Association 2007) while the remaining 17 species are widespread (Cigliano et al. 2018). This indicates that riparian habitats may not be especially vital to the conservation of endemic species, which may be present in other ecosystems, but could be regionally important due to the high percentage of species listed in prefectural Red Data Lists. In floodplain habitats, seven regional Red Data List species have been recorded, compared to just three in riparian paddy fields (Table 2). This hints at the possible importance of semi-natural riverine environments for locally rare Orthoptera against those more intensively managed for rice production, which is a potential avenue for future research.

The absence of a national red data list of Japanese Orthoptera makes it harder still to form any definitive view on the value of riverine areas for endangered species. It's difficult to assess the importance of riparian environments without a much broader understanding of the species present. To fill this huge research deficit,

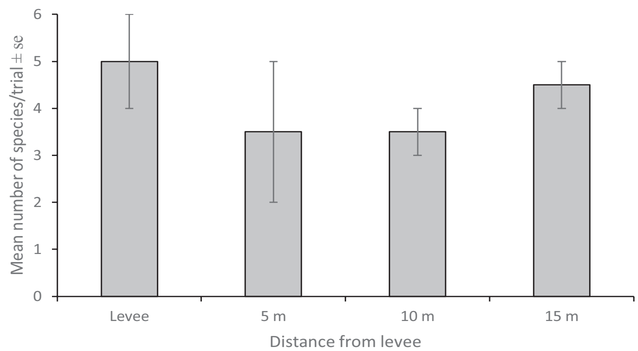

Fig. 2. The number of identified cricket (Gryllidae) species in a riparian paddy field near Mount Fuji at differing distances from a levee (after Ichihara et al. 2014b).

studies would need to focus on a wide geographical range, not just the main island of Honshu.

The differences in site preferences may also be due to the differing niches of species, for example of *Acrida cinerea*, *A. lata*, and *Oedaleus infernalis* (grass, Asteraceae, and bare ground, respectively; Jung et al. 2018). Research should focus on the habitat requirements of Orthoptera in riparian corridors such as levees, buffer lands, and floodplains. No definite list of the species present on flood defense embankments yet exists, although *A. cinerea* and *T. emma* have been recorded on super levees (15 m high) along the Arakawa River in Tokyo since 2016 (T. Gardiner unpublished data).

Itagawa et al. (2012) discovered that in grasslands mown intensively, species with high mobility and good flying ability (e.g. *O. yezoensis*) were the most successful orthopterans. The fragmentation of ecosystems in Tokyo has an influence over the distribution of Orthoptera and the composition of species assemblages. This further highlights the need for research into the detailed autecological requirements of key invertebrates on flood defense levees that link parks together and may allow the dispersal of species between sites.

Paddy levees in riparian habitats (Ichihara et al. 2014a) allow several species of Orthoptera to disperse into fields after irrigation water has receded (Ichihara et al. 2014b; Fig. 2). Seed-eating crickets have a weed suppression role (of the non-native *Lolium multiflorum*) in Fuji paddy fields (Ichihara et al. 2014c). Some species which prefer dry habitats were found predominantly on paddy levees (*Loxoblemmus* spp.; levee 4.0–4.4 individuals/trap/day, field 0.3–0.7 individuals), whereas others, which are tolerant of both dry and wet conditions (e.g. *T. emma*), showed no preference for the embankment and were recorded up to 15 m into the field (Ichihara et al. 2014b).

If management enhances the abundance and diversity of invertebrates, landscape corridors along rivers could provide vital ecosystem services (supporting, provisioning, regulating, and cultural functions; Millennium Ecosystem Assessment 2005). Orthoptera, by their consumption of primary production, role in cycling nutrients up the food chain, weed suppression in paddy fields (particularly of *L. multiflorum*; Ichihara et al. 2014a), and even pollination (Negoro 2002, 2003, Micheneau et al. 2010), fulfil a supporting role in ecosystems (Gardiner 2018). They are also a traditional food source (Mitsuhashi 1997, Payne and Van Itterbeeck 2017). *O. yezoensis* is the most popular edible grasshopper, rich in proteins (Mitsuhashi 1997), and abundant throughout Japan (Table 2).

The ecological requirements of many species of Orthoptera in riparian corridors are poorly known. The habitat requirements of species from the genera *Conocephalus* and *Ruspolia*, which have been commonly found near water in Japan (Table 2), are not known. This makes it difficult to assess the important niches which they inhabit and how to undertake effective conservation management. Research on the ecology of Asian Orthoptera is only beginning to emerge (Jung et al. 2018). Therefore, targeted studies on the riparian habitats of species linked to water are needed to fully assess the value of corridors for Orthoptera.

Greening the grey – measures to enhance riparian corridors for Orthoptera

Habitat preferences of Orthoptera may relate to choice of oviposition site (Choudhuri 1958), food preferences (Bernays and Chapman 1970a, b), vegetation height and biomass (Gardiner et al. 2002), and grassland management regimes (Clarke 1948). Vegetation structure is an important factor for grassland fauna (Duffey et al. 1974, Morris 2000, Gardiner 2009). Clarke (1948) and Gardiner and Hassall (2009) noted that vegetation height and density are the most important habitat factors for grasshoppers, particularly in respect to their influence on microclimate. Unfortunately, management of landscape corridors can often be detrimental to the needs of species due to human pressures on land use (Matsuba et al. 2016). In Tokyo, measures are already being undertaken along the Arakawa River super levees to improve the mowing regimes for invertebrates (Fig. 3). Outside of unmown areas, recreational land uses pose a threat to Orthoptera, particularly the establishment of baseball and football fields with their required short grass turf (<10 cm height), which is generally unfavorable for grasshoppers (Gardiner et al. 2002).

The Arakawa levee grasslands are cut at different heights for invertebrates, management which may be highly beneficial to orthopterans such as *A. cinerea* and *O. infernalis* which have differing ecological niches (Jung et al. 2018). The latter species prefers habitats with bare ground which are present on the trampled paths of levees, whereas *A. cinerea* has been most commonly recorded on grasses. Species such as *A. lata*, observed on the east and west coast (Table 2), have been found mainly on Asteraceae plants (Jung et al. 2018). In south-east Asia, six species of Orthoptera (including *Acrida* sp., *Atractomorpha* sp., and *Conocephalus maculatus*) have been observed visiting Asteraceae plants, feeding on the flowers (Tan et al. 2017a, b, Tan and Tan 2018a, b). Given the conservation measures being put in place for *Aster tripolium*, such as terraces on the riverside slope of flood defenses in Tokyo, it is likely that *A. lata* will have plenty of favorable habitat, although further experimental research is required to investigate the connection between grasshopper and plant. The creation of shorter grassland areas (but not uniformly <10 cm) through mowing should benefit *A. cinerea*, a species of Poaceae (Jung et al. 2018), and hotter swards (Gardiner and Hassall 2009).

The management of paddy field levees on floodplains could incorporate rotational mowing regimes (Fujioka et al. 2010) and a reduction in the frequency of cutting to conserve Orthoptera populations (Yoshio et al. 2009) and those of endangered butterflies (Ohwaki et al. 2018). Herbicide usage is the most damaging option for paddy levees; mowing and no management are better measures for conserving Orthoptera (Yoshio et al. 2009, Giuliano et al. 2018). In a study of paddy levee crickets at the foot of Mount Fuji, seed-eating crickets were in high abundance on plants such as *Phlox subulata* (Polemoniaceae), compared to weedy levees or those with *Zoysia japonica* (Poaceae), which were the least preferred (Ichihara et al. 2014a). It is suggested that the sowing of levee banks with plants favorable for crickets may assist them in their role of weed suppression (*L. multiflorum*) in paddy field ecosystems (Table 3).

Grazing can have benefits for Orthoptera (Gardiner and Haines 2008, Bazelet and Gardiner 2018) and might be ideal for conserving orthopterans on levees and floodplain grasslands. Grazing is an issue which needs careful consideration before the introduction of livestock so that populations of rare plants and grasshoppers are not endangered. Research should focus on the ecological requirements of key orthopteran species in riparian environments, relating abundance and assemblage diversity to sward height, microclimate, and botanical characteristics. The type of animal used for grazing could be a focus for future work in grazed riparian habitats. The maintenance of levees and floodplains in an early successional state by grazing livestock may be desirable for species such as *E. japonicus* and *O. infernalis* which are threatened by unmanaged development of woody vegetation.

In closed grassland swards, the creation and maintenance of bare earth is essential for the persistence of disturbance-dependent orthopterans (Gardiner et al. 2015) and may benefit early successional species such as *O. infernalis* in Japan. Trampling of levee vegetation may also occur due to grazing livestock and the action of walkers' feet on paths in Satoumi landscapes such as those in Matsushima Bay where *O. infernalis* is found on well-walked tracks (T. Gardiner unpublished data). The creation of scrapes on the flat berms of super levees in Tokyo could create suitable bare-ground niches for grasshoppers (Table 3). Trials on artificial soil disturbance in riparian grassland could run alongside studies on microclimate and vegetation cover. We advise against soil disturbance on the slopes of levee embankments due to the potential for destabilization and possible problems with soil erosion during breaching or overtopping in a flood. A summary of the most appropriate sward management techniques on flood defense and paddy levees is found in Table 3.

The selection of IGGI measures developed by Naylor et al. (2017) may provide benefits for Orthoptera. Options likely to be highly favorable for orthopterans include altered mowing regimes on levees and large-scale development incorporating enhanced habitat features, although it should be acknowledged that trials should be undertaken before any major changes are made to riparian habitats. Terraces of *A. tripolium* on the riverside slope of flood defenses in coastal areas may be of some value for grasshoppers, particularly *A. lata*, which could benefit from the increased provision of Asteraceae plants (Fig. 4), although a direct link between the two species would need to be determined before widespread implementation. The concrete levees of modern paddy fields offer very little habitat for Orthoptera (Fig. 5); greening of these structures could be investigated in future trials. Removal of concrete walls and replacement with grassy embankments might aid restoration of traditional paddy field systems.

Table 3. Sward management techniques for conserving populations of Orthoptera on flood defense and paddy levees in Japan (X indicates a suitable measure).

Technique	Flood levee	Paddy levee
Different cutting heights (10–20 cm)	X	X
Reduced number of cuts (<4 cuts)	X	X
Rotational mowing	X	X
Uncut refuges	X	X
Soil disturbance (scrapes, ruts etc.)*	X	
Reseeding with appropriate vegetation		X
Grazing livestock*	X	
Avoidance of herbicide application		X

*on flat berms only to avoid destabilizing embankment slopes.

The management of floodplains poses a different set of problems (Fig. 6). A detailed understanding of the geomorphology of the river system is essential (Washitani 2001, Nakamura et al. 2002). Japanese rivers are typically short and steep owing to the mountainous nature of the main island of Honshu (Yasuda et al. 2016). The seasonally high levels of rain and snow mean that rivers can flow rapidly, shifting sediments quickly (Nakamura et al.

Fig. 3. Arakawa super levee in Tokyo. Grassland is left uncut to produce a mosaic of habitats for Orthoptera. Photo by T. Gardiner.

Fig. 4. Flat terrace on the riverside slope of a flood defense embankment at Kasai Rinkai Park at the mouth of the Edogawa River in Tokyo Bay. The terrace is accumulating vegetation, including *Aster tripolium*, a rare and declining species in the Bay. Photo by T. Gardiner.

Fig. 5. Concrete paddy levee and field along the Tama River (Fussa) providing minimal habitat for Orthoptera. Photo by T. Gardiner.

2006). Such dynamic systems can be vulnerable to rapid changes in their geomorphology, increasing rainfall due to climate change and typhoons (Yasuda et al. 2016).

Invasive plants such as *Eragrostis curvula* present a threat to grasshopper populations on gravelly floodplains (Yoshioka et al. 2010a, b). Twelve species of grasshopper were negatively affected by the abundance of *E. curvula*; habitat specialists such as *E. japonicus* experienced significant declines in abundance with increasing *E. curvula* coverage (Yoshioka et al. 2010a). The reduction in open gravel habitat due to the spread of alien plants may also be a threat to other species such as the endemic *A. kantoensis* (Kuramoto et al. 1992, 2005).

Climate change will affect riverine ecosystems, making any habitat modifications susceptible to increasing pressures from, for example, typhoons (Hoshino et al. 2012, Yasuda et al. 2016). Riparian paddy fields fulfil a vital role in flood storage, preventing flooding downstream (Natuhara 2013). Riparian rehabilitation and natural flood management is well advanced in Japan, with over 23,000 river restoration schemes completed since 1991 (Nakamura et al. 2006). The combined threat from alien plants and climate change complicate the IGGI measures suitable for rivers and floodplains (Roca et al. 2017). River engineering measures could have potential benefits for Orthoptera in riparian ecosystems (Table 4), although this remains unproven due to the dearth of research throughout the world. Removing river levees may lead to a larger, more natural floodplain suitable for orthopterans such as *E. japonicus*. Alteration of riverbed levels creates a diversity of gravel substrates suitable for Orthoptera of early successional habitats (Nakamura et al. 2006), although modification of the geomorphology must be carefully undertaken in consultation with specialists (Nakamura et al. 2002).

Fig. 6. Gravel floodplain along the Tama River, early successional habitat for the endangered *Eusphingonotus japonicus* grasshopper and *Aster kantoensis*. Photo by T. Gardiner.

Table 4. Integrated Green Grey Infrastructure (IGGI) measures and their potential benefits for Orthoptera along rivers in Japan.

Aim of IGGI measure	Potential benefit for Orthoptera habitat
River embankment (levee) removal	Creation of larger floodplain habitat
Lowering/removal of weirs/culverts	More natural floodplain
Meander restoration of channel	More natural floodplain
Changing bed level of channel	Variation in gravel substrates
Regrading of river embankments (levees)	Shallower bank habitat
Narrowing river channels	Creation of larger floodplain habitat

Recommendations for further research and management

It is clear from this review that despite the Japanese Orthoptera being described in detail (Ichikawa et al. 2006, Murai et al. 2011), there is a large research deficit when it comes to the conservation management of habitats, particularly those of riparian areas. Despite this, a hypothetical relationship can be inferred from existing research (Table 1, Fig. 7) and subjected to further studies of orthopteran species composition throughout Japan. The natural floodplains with native vegetation can have a high diversity of Orthoptera including endemic and regionally endangered species (Yoshioka et al. 2010a); whereas with greater anthropogenic modification of riparian areas (flood defense levees and arable/paddy fields), diversity can decrease (Itagawa et al. 2012). This is often due to intensive management regimes, such as regular mowing on levees and chemical pesticide usage in paddy fields, creating an unsuitable environment for the persistence of Orthoptera (Ichihara et al. 2014b, Payne 2014). The traditional Satoyama landscape of paddy fields and terraces can have value for grasshoppers (e.g. Sado Isand; Yoshio et al. 2009) and crickets (e.g. near Mount Fuji; Ichihara et al. 2014b) but increasing abandonment of this way of farming will probably lead to a decrease in the diversity of Orthoptera (Natuhara 2013).

In the modified riparian landscape of paddy fields and terraces, levees could form corridors which allow the dispersal of Orthoptera in a similar way to sea wall flood defenses in Europe (Fargeaud and Gardiner 2018). Climate change may be behind the expansion in range of species such as *Phaneroptera nana* which has been found on a sea wall along the River Thames (Gardiner and Couch 2019 in press). Phaneropterinae have been recorded in Tokyo (Itagawa et al. 2012) and may utilize flood defenses for dispersal in Japan. Further research should aim to determine the importance of levee embankments for the dispersal of Orthoptera through unfavorable landscapes (intensively managed paddy fields and urban areas) in relation to climate change.

Given the importance of flood defense in Japan due to climate change and typhoons (Hoshino et al. 2012), green measures can be implemented during the maintenance and rebuilding of levees to enhance populations of common and scarce Orthoptera species. Such measures include alteration of mowing regimes and the design of vegetated terraces on riverside flood defenses. The presence of orthopterans such as *A. cinerea*, *A. lata*, and *O. infernalis*, which are common across a range of habitats, is a good indication of the success of management techniques.

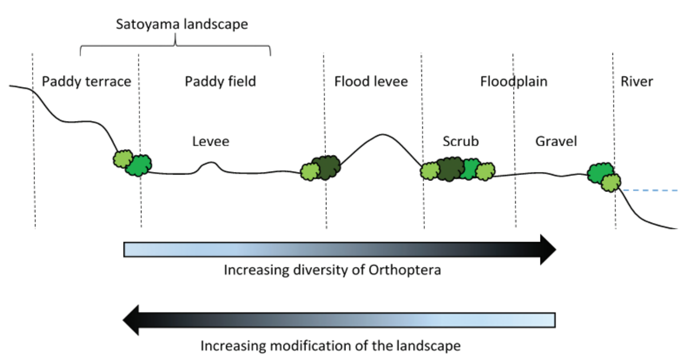

Fig. 7. Cross section of a floodplain ecosystem in relation to diversity of Orthoptera and anthropogenic modification of the landscape.

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