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FORUM

Drosophila suzukii in Southern Neotropical Region: Current Status and Future Perspectives

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Abstract

Non-native insect pests are often responsible for important damage to native and agricultural plant hosts. Since *Drosophila suzukii* Matsumura (Diptera: Drosophilidae) has become an important pest in North America and Europe (i.e., in 2008), the global production of soft thin-skinned fruits has faced severe production losses. In the southern Neotropical region, however, the first record of *D. suzukii* occurred in 2013 in the south of Brazil. It has also been recorded in Uruguay, Argentina, and Chile. Despite its recent occurrence in the southern Neotropical region, the fast dispersion of *D. suzukii* has inspired local research efforts in an attempt to mitigate the consequences of this insect pest invasion. In this forum, we explore the current status of *D. suzukii* in southern Neotropical regions, discussing its future perspectives. Additionally, we attempt to draft activities and a research agenda that may help to mitigate the losses caused by *D. suzukii* in native and commercial soft-skinned fruits produced in this region. Currently, *D. suzukii* appears to be well established in the south of Brazil, but considering the entire southern Neotropical region, the invasion panorama is still underinvestigated. The lack of studies and regulatory actions against *D. suzukii* has contributed to the invasion success of this species in this region. Considering several peculiarities of both the pest biology and the environmental of this region, the authors advocate for the need of intensive and integrative studies toward the development and implementation of area-wide integrated pest management programs against *D. suzukii* in the southern Neotropical region.

Introduction

Historically, alien pest invasions usually result in severe production losses due to economic, social, and health damage (Jackson & Lee 1985, Benedict *et al* 2007, Desneux *et al* 2011, Asplen *et al* 2015, Kriticos *et al* 2015, Singer 2017). The final scenario for pest establishment as well as the number of necessary efforts to mitigate the environmental disturbances caused by the pest has been a persistent question (Perrings *et al* 2002, Desneux *et al* 2011, Asplen *et al* 2015). However, early studies predicting all possible aspects of local interactions of the alien species with known or other potential hosts, pest competitiveness with the native species and susceptibility to endemic natural enemies can greatly aid the organization and development of the most adequate management plans (Cini *et al* 2012, Asplen *et al* 2015, Kriticos *et al* 2015). It is, however, worth noting that the use of current knowledge obtained in areas previously invaded by the alien pest will also help to organize and plan such efforts.

Although *Zaprionus indianus* Gupta (Diptera: Drosophilidae) has been well established as an important insect pest of the fig, *Ficus carica* L. (Moraceae), in Brazil (Raga *et al* 2003), *Drosophila suzukii* Matsumura (Diptera: Drosophilidae), also termed the spotted wing drosophila (SWD) or the cherry fly, has achieved the status of one the most important newly emerged insect pests of small soft-skinned fruits (Walsh *et al* 2011, Asplen *et al* 2015). *Drosophila suzukii* is a devastating, highly polyphagous fly that is native to Southeast Asia (Asplen *et al* 2015); it was described in 1931 by Matsumura, but this insect was first reported as a pest in 1939 by Kanzawa in Japan (Hauser 2011). The damage caused by these insects, however, only gained global attention after almost simultaneous reports of their damage to soft and thin-skinned fruit crops in the USA (Hauser 2011) and Europe (many countries) (Grassi *et al* 2009, Calabria *et al* 2012). Since then, many features of the bioecological roles of *D. suzukii* as well as its interactions with the production system have being intensively studied in an attempt to mitigate the economic loses in cultivated crops in North America and Europe [see Asplen *et al* (2015) for a more complete review].

In contrast to most drosophilid species (Drosophilidae), *D. suzukii* females have a serrated and strongly sclerotized oviscapt valves that allows them to penetrate the fruit epidermis and lay their eggs inside healthy undamaged fruits (Dreves *et al* 2009, Walsh *et al* 2011, Santos 2014, Lee *et al* 2015, Nava *et al* 2015). After the female lays its eggs, over a very short period from 1 to 2 days, the eggs hatch and the larvae start to feed on the fruit tissue (Walsh *et al* 2011). After three molts, the larvae become pupae, from which the adults emerge. At an average temperature of 22°C, this development takes approximately 11 days, followed by 1 to 2 additional days for the adult flies to become sexually mature, copulate, and start laying eggs (Emiljanowicz *et al* 2014, Tochen *et al* 2014, Asplen *et al* 2015). Hence, in approximately 13–14 days, a new fly generation is laying eggs. The adults can live, on average, up to 70 days, and they show a high reproductive output (Emiljanowicz *et al* 2014).

Thus, due to the high damage potential of *D. suzukii* in addition to the lack of registered pesticides and other regulatory means for controlling the dispersion of these flies in the southern Neotropical region, it is quite interesting to report the seminal efforts already applied to recognize the current status and future perspectives involving this pest in the southern Neotropical region, which herein refers to Uruguay, Argentina, Chile, and the South, Southeast, and Central regions of Brazil. Here, we will present current and future potential damage caused by *D. suzukii* in both native and commercial thin-skinned fruits cultivated in the southern Neotropical region. Finally, we will also propose future studies and potential programs to better manage this insect pest in this region.

Current Pest Status in the Southern Neotropical Region

Invasion history and current distribution

In Central and South America, which comprise the majority of the Neotropical region, the first record of *D. suzukii* was a personal communication (of P. M. O'Grady to M. Ashburner and to J. Máca) of specimens collected in Costa Rica and Ecuador in 1997 and 1998, respectively (Ashburner *et al* 2005, Calabria *et al* 2012). However, up to the year of 2010, such specimens were not found in any insect collection, and this species had not been recorded again in those countries. Thus, it is difficult to estimate when these flies arrived in the Neotropical regions (Hauser 2011). In addition to the inconclusive report described above, it is reasonable to consider the current distribution of *D. suzukii* in the southern of the Neotropical region (see Fig 1) to have started with invasive infestations that occurred via two possibilities. First, one potential route used to enter the southern Neotropical region refers to the southern region of Brazil, which had the

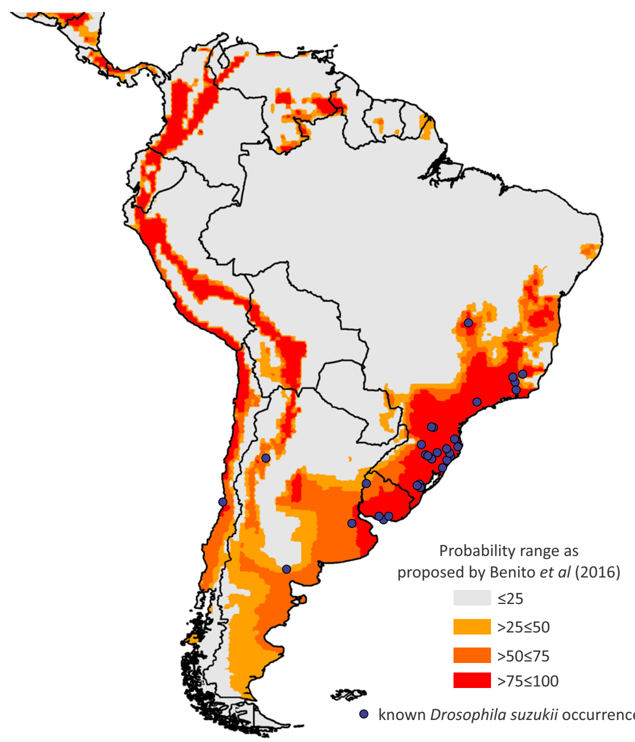

Fig 1 Graphical representation of part of the Neotropical region with the known *Drosophila suzukii* occurrence map overlapping the distribution probability range for this species, as proposed by Benito *et al* (2016). All plotted dots are based on references listed in Table 1, or on the author's personal observations/unpublished data.

first documented report of this pest in South America (Deprá *et al* 2014). The second possibility, however, points to the Pacific coast of Chile, where the species were collected around Valparaíso port, which imports a variety of fresh fruits from Asia (Medina-Muñoz *et al* 2015). To clarify whether these two not mutually exclusive possibilities (or even others) could precisely define the real origin of *D. suzukii* in the southern Neotropical region, it is necessary to conduct genetic and philogeographical analyses. Table 1 summarizes all the published records of *D. suzukii* in the southern Neotropical region. Because one the most relevant goals of this forum is to report all existing information about the occurrence of *D. suzukii* and early researches with this pest in the southern Neotropical region, we could not avoid the citation of reports that have only been published in congresses or symposium abstract form.

In Brazil, during the first year of the occurrence of *D. suzukii* (i.e., 2013), the individuals were only collected in traps located in natural reserves (Souza *et al* 2013, Deprá *et al* 2014, Paula *et al* 2014). The *D. suzukii* individuals were collected in a drosophilid survey using banana-baited traps at a natural reserve in the state of Santa Catarina (SC). Two months later, the same survey program revealed *D. suzukii* in the northeast region of the state of Rio Grande do Sul (RS) (Deprá *et al* 2014). Later, during that year, *D. suzukii* was collected in apple cider vinegar traps placed in a natural forest area in the southern region of RS state (Souza *et al* 2013). In 2013, one *D. suzukii* male was captured in a banana-baited trap in the central region of Brazil in a natural Cerrado (savannah-like vegetation) reserve at the Brazilian Federal (DF) district (Paula *et al* 2014). Subsequently, in 2014, *D. suzukii* was reported in agricultural ecosystems, either collected in McPhail traps (Nunes *et al* 2014) or infesting native cultivated fruits (Müller & Nava 2014, Nunes *et al* 2014) in the southern region of RS state. Following these first reports, strawberry, *Fragaria x ananassa* Duchesne (Rosaceae), producers from the northeast of RS state started to experience fruit losses of up to 30% due to infestations by this fly (Santos 2014). The presence of *D. suzukii* in the state of Paraná was also reported by Geisler *et al* (2015). Collectively, these findings allow us to state that *D. suzukii* is currently distributed and well established throughout the entire southern region of Brazil (Fig 1).

Outside the southern region of Brazil, *D. suzukii* was reported in 2014 in the São Paulo municipality, São Paulo state (SP), developing in marketed blueberry fruits that were produced in the municipality of São Joaquin, SC state (Vilela & Mori 2014). Furthermore, *D. suzukii* was also collected in traps placed in a native Atlantic Rainforest in the state of Rio de Janeiro (RJ) (Bitner-Mathé *et al* 2014) and from strawberry fields in the state of Minas Gerais (MG) (Andreazza *et al* 2016a).

In Uruguay and Argentina, *D. suzukii* was found infesting blueberries, *Vaccinium ashei* Reade (Ericaceae), and raspberries, *Rubus idaeus* L. (Rosaceae) (Cichón *et al* 2015, González *et al* 2015, Santadino *et al* 2015), but in Uruguay it was also found in traps in the urban area of Montevideo city (González *et al* 2015). In Chile, there has only been one report of this species, which was collected from traps near the Valparaiso Port (Medina-Muñoz *et al* 2015).

Damage ability and cultivated hosts in the Southern Neotropical Region

Currently, the main cultivated host that is susceptible to severe economic losses in the southern Neotropical region is strawberries, which have been shown to achieve production losses up to 30% (Santos 2014). However, other common non-native cultivated soft and thin-skinned fruits, such as blueberries, as well as native fruits such as the Surinam cherry, *Eugenia uniflora* L. (Myrtaceae), and Cattley guava, *Psidium cattleyanum* Sabine (Myrtaceae) (Fig 2), have been reported under high levels of natural infestations (Müller & Nava 2014, Santadino *et al* 2015).

The southern Neotropical region exhibits a high overlap of environmental conditions with the northern hemisphere, where *D. suzukii* is well established (Kenis *et al* 2016). Hence, many of the crops cultivated in the southern Neotropical region are known as hosts of *D. suzukii*. This is the case for blackberries [*Rubus* sp. (Rosaceae)], blueberries, cherries [*Prunus cerasus* L. (Rosaceae)], grapes [*Vitis vinifera* L. (Vitaceae)], peaches [*Prunus persica* (L.) Batsch (Rosaceae)], plums [*Prunus domestica* L. (Rosaceae)], raspberries, and strawberries. In addition to the similarity of the cultivated hosts, the southern region of Brazil, as well as Uruguay and part of Argentina, has a highly favorable Climex (a common model used to predict the potential geographic distribution of alien pest species), which increases the economic damage potential of this pest (Benito *et al.* 2016). These authors observed percentages of overlap between potential host cultivation and the highly favorable Climex area they defined for *D. suzukii,* which ranged from 45.5 to 98.3% for six potential cultivated hosts. The same authors estimated monetary economic loses of US$ 21.4 million for peaches and US$ 7.8 million for figs, but they could not estimate losses for the other hosts due to the lack of data.

It is important to note that, at least for some peach cultivars, *D. suzukii* displays very low oviposition on undamaged fruits but can use damaged fruits as a reservoir host (Andreazza *et al* 2017a). The same pattern has been observed during infestation of the apple, *Malus domestica* L. (Rosaceae), in which prior damage is necessary for *D. suzukii* oviposition to occur (Oliveira *et al* 2015).

Table 1 Summary of the published reports of *Drosophila suzukii* collected from traps or infested fruits in the southern Neotropical region.

Baited with/host	*N*	Location	Date	Reference
Traps				
Banana	1	Nova Veneza-SC, Brazil	Feb 2013	Deprá *et al* (2014)
Banana	40	Erechim-RS, Brazil	Mar 2013	Deprá *et al* (2014)
Banana	45	Botuverá-SC, Brazil	Apr 2013	Deprá *et al* (2014)
Banana	2	Vila Maria-RS, Brazil	May 2013	Deprá *et al* (2014)
Banana	68	Osório-RS, Brazil	May 2013	Deprá *et al* (2014)
Banana	1	Brasilia-DF, Brazil	Dec 2013	Paula *et al* (2014)
Banana	461	Torres-RS, Brazil	May-Oct 2013	Alexandre (2016)
Banana	Unknown	SC, Brazil	2013–2014	Ramírez *et al* (2015)
Banana	25	Montevideo, Uruguay	Feb 2014	González *et al* (2015)
Banana	1	Brasilia-DF, Brazil	April 2014	Paula *et al* (2014)
Banana	3	Petrópolis-RJ, Brazil	Nov 2014	Bitner-Mathé *et al* (2014)
Apple cider vinegar	21	Capão do Leão-RS, Brazil	Sep 2013	Souza *et al* (2013)
Apple cider vinegar	21	Vacaria-RS, Brazil	Mar 2015	Oliveira *et al* (2015)
Apple cider vinegar	Unknown	Farroupilha-RS, Brazil	2015	Borba *et al* (2016a)
Plum	67	Valparaiso, Chile	2015	Medina-Muñoz *et al* (2015)
McPhail trap	Unknown	Morro Redondo-RS, Brazil	Nov 2013-Feb 2014	Nunes *et al* (2014)
McPhail trap	Unknown	Southern Uruguay	Mar 2014	pers. comm. *in* González *et al* (2015)
Yellow pan trap	17	La Rioja, Argentina	Mar 2015	Lue *et al* (2017)
Miscellaneous	13 per trap	São Joaquim-SC, Brazil	Jan 2016	Padilha *et al* (2016)
Collected from fruits				
Butia sp.	2	Torres-RS, Brazil	2013–2014	Alexandre (2016)
Eriobotrya japonica (Thunb.)	300	Pelotas-RS, Brazil	Sep 2014	Andreazza *et al* (2016b)
Eriobotrya japonica (Thunb.)	15	União da Vitória-PR, Brazil	2014	Geisler *et al* (2015)
Eugenia involucrata DC.	26	Porto Vitória-PR, Brazil	2014	Geisler *et al* (2015)
Eugenia uniflora L.	116	Pelotas-RS, Brazil	unknown	Müller & Nava (2014)
Eugenia uniflora L.	67	Pelotas-RS, Brazil	2014/15 crop	Andreazza *et al* (2015)
Fragaria x *ananassa*	Unknown	Vacaria-RS, Brazil	Jan 2014	Santos (2014)
Fragaria x *ananassa*	35	Ervália-MG, Brazil	Mar 2016	Andreazza *et al* (2016a)
Fragaria x *ananassa*	1489	Pelotas-RS, Brazil	2015/16 crop	Wollmann *et al* (2016)
Prunus persica L.	3	União da Vitória-PR, Brazil	2014	Geisler *et al* (2015)
Prunus persica L.	Unknown	Farroupilha-RS, Brazil	2015	Borba *et al* (2016b)
Psidium cattleianum Sabine	161	Capão do Leão-RS, Brazil	unknown	Müller & Nava (2014)
Psidium cattleianum Sabine	101	Cerrito-RS, Brazil	unknown	Müller & Nava (2014)
Psidium cattleianum Sabine	36	Pelotas-RS, Brazil	unknown	Müller & Nava (2014)
Psidium cattleianum Sabine	23	Pelotas-RS, Brazil	2014/15 crop	Andreazza *et al* (2015)
Psidium guajava L.	Unknown	Morro Redondo-RS, Brazil	Nov 2013, Feb 2014	Nunes *et al* (2014)
Psidium guajava L.	388	Pelotas-RS, Brazil	2014/15 crop	Andreazza *et al* (2015)
Psidium guajava L.	3	Ervália-MG, Brazil	Mar 2016	Andreazza *et al* (2016a)
Rubus idaeus L.	Unknown	Rio Negro, Argentina	2014	Cichón *et al* (2015)

Table 1 (continued).

Baited with/host	*N*	Location	Date	Reference
Rubus idaeus L.	4	Torres-RS, Brazil	2013–2014	Alexandre (2016)
Rubus sp.	8630	Pelotas-RS, Brazil	2015/16 crop	Wollmann *et al* (2016)
Vaccinium ashei Reade	44	Canelones, Uruguay	Jan. 2014	González *et al* (2015)
Vaccinium spp.	100	Buenos Aires, Argentina	Dec. 2014	Santadino *et al* (2015)
Vaccinium spp.	12	Intercepted at São Paulo-SP, Brazil	Feb 2014	Vilela & Mori (2014)
Miscellaneous	Unknown	Salto, Uruguay	May-Mar 2014	González *et al* (2014)
Miscellaneous	Unknown	San José, Uruguay	May-Mar 2014	González *et al* (2014)
Miscellaneous	Unknown	Canelones, Uruguay	May-Mar 2014	González *et al* (2014)
Miscellaneous	Unknown	Montevideo, Uruguay	May-Mar 2014	González *et al* (2014)

Among other factors that might increase or suppress the pest potential of this species in South America is the ability to interact with fruits that have been damaged by other pest species, as is the case for the introduced and well-established African fig fly, *Z. indianus* (Commar *et al* 2012), and the native South American fruit fly, *Anastrepha fraterculus* (Wiedemann) (Diptera: Tephritidae) (Malavasi & Zucchi 2000). In strawberry fields, drosophilid-like larval damage appears to result in increased effects of *Z. indianus* compared with *D. suzukii* (Nava *et al* 2015, Andreazza *et al* 2016a).

In a recent survey (2016–2017) in three municipalities of MG state, larger numbers of *Z. indianus* compared with *D. suzukii* (12.9 vs 0.2; 4.8 vs 0.0 and 0.2 vs 0.04, flies per fruit) were harvested from strawberry fruits with very low visual damage (author's unpublished data). The potential interactions between these two species have also been established elsewhere (Renkema *et al* 2013, Fartyal *et al.* 2014, Joshi *et al* 2014, Lasa & Tadeo 2015), highlighting the hypothesis that the co-occurrence of these pest species can increase the damage and economic losses in strawberry production and potentially other fruit crops. For example, although *Z. indianus* is known to be incapable of laying eggs inside healthy undamaged fruits, (Raga *et al* 2003), a recent investigation has revealed not only the ability of *Z. indianus* to infest undamaged strawberry fruits but also the increased infestation ability when the fruits were previously infested by *D. suzukii* (Bernardi *et al* 2017).

In contrast, the presence of *A. fraterculus* might reduce the damage potential of *D. suzukii* infestations, or it may not influence the *D. suzukii* attack capacity. In a susceptibility screening study using grape cultivars, the presence of oviposition punctures or of the development of *A. fraterculus* larvae did not induce *D. suzukii* oviposition (Andreazza *et al* 2016c). Additionally, *A. fraterculus* intrinsically infests fruits before they reach an advanced ripening stage (Bisognin *et al* 2015), which seems to be the preferable stages for *D. suzukii* infestations (Burrack *et al* 2013). Thus, depending on the market fruit destination and the *A. fraterculus* infestation intensity, it would be sufficient to cause the major economic loses, reducing the importance of *D. suzukii* infestation.

The abilities of *D. suzukii* to infest damaged fruits can turn less preferred hosts (e.g., peaches) into highly infested sites (Bellamy *et al* 2013, Andreazza *et al* 2017a), which might result in more severe infestations in preferred hosts that are cultivated nearby. Consequently, the role of previously damaged or less preferred hosts, as well as the native fruit species, must never be disregarded when considering the management of this pest.

Potential native hosts

As previously reported in Europe and North America (Poyet *et al* 2014, Lee *et al* 2015), *D. suzukii* can infest many native non-cropping hosts. Countries with continental proportions,

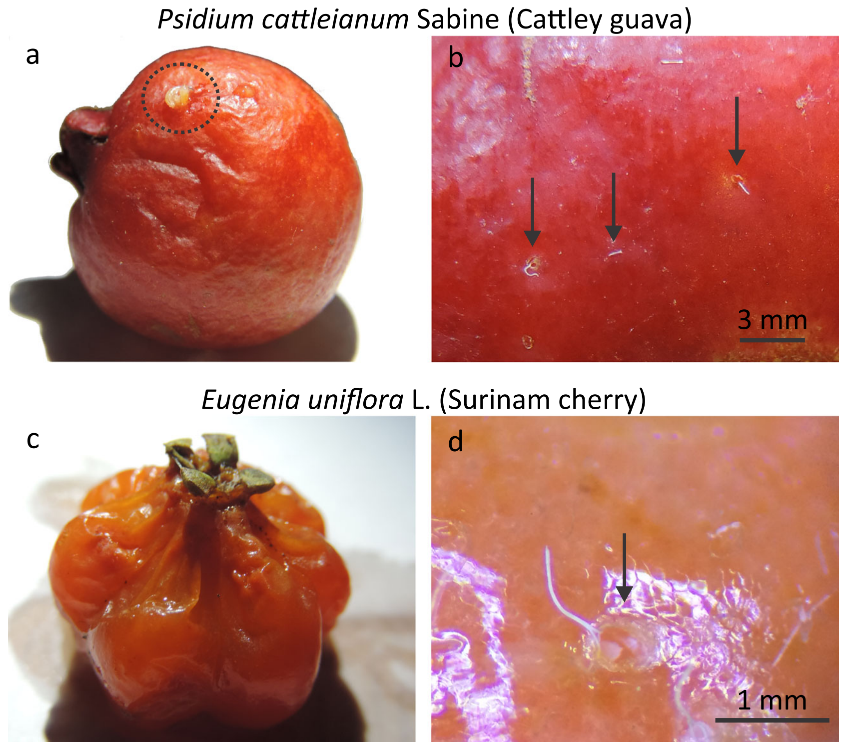

Fig 2 *Drosophila suzukii* damage in two Neotropical native hosts. **a**–**b** Fruit of Cattley guava, *Psidium cattleianum*. **c**–**d** Fruit of Surinam Cherry, *Eugenia uniflora*. In (**a**), it is possible to see a *D. suzukii* larva on the fruit surface (dotted circle). **b**, **d** White egg filaments emerging from the oviposition punctures made by *D. suzukii* (black arrows).

such as Brazil, offer the most varied climate types and plant hosts for *D. suzukii* infestations. Several native (and also exotic) fruits can offer conditions for the development and establishment of *D. suzukii*, which raise serious concerns about how and when mitigate the losses caused by this pest (Schlesener *et al* 2014, Schlesener *et al* 2015). Although it is not a native plant of the southern region of Brazil, the Loquat, *Eriobotrya japonica* (Thumb.) Lindley (Rosaceae), another *D. suzukii* host (Kenis *et al* 2016) is well established and naturally found among the native vegetation in the south of Brazil. As described in Table 1, several recent investigations have demonstrated the ability of *D. suzukii* to attack fruit species native to the southern Neotropical region (Müller & Nava 2014, Nunes *et al* 2014, Andreazza *et al* 2015, Geisler *et al* 2015, Souza *et al* 2017).

Thus, additional studies attempting to investigate the susceptibility of native plant species to the oviposition of *D. suzukii* (Table 2) are sorely needed. This study will provide a better understanding of *D. suzukii* establishment in the southern Neotropical region and help to predict geographic isolation due to lack of suitable hosts. Furthermore, knowledge of possible alternative hosts can help to create an annual host calendar (as shown in Fig 3), which will facilitate temporal predictions of how *D. suzukii* migrates from and returns to the surrounding natural or agricultural habitats to the fields.

Management strategies

Since *D. suzukii* has a very short life cycle, a long adult lifespan and a high reproductive output (Emiljanowicz *et al* 2014, Tochen *et al* 2014), management strategies must target both immature and adult life stages of this pest. Most of the management programs established for *D. suzukii* worldwide, however, still rely heavily on applications of chemical insecticides (Haye *et al* 2016), especially in regions with zero tolerance for this pest, such as some states in the USA (Van Timmeren & Isaacs 2013). Thus, many research efforts have been conducted to evaluate the efficacy of several commercially available insecticides in North America and Europe, which has led to the identification of several chemical groups that provide satisfactory control levels (Beers *et al* 2011, Bruck *et al* 2011, Haviland & Beers 2012, Van Timmeren & Isaacs 2013, Cuthbertson *et al* 2014). However, despite recent investigations showing that some commercially available products in Brazil provide effective control against immature and adult life stages of *D. suzukii* (Andreazza *et al* 2017c), none of these products is officially registered by the Brazilian federal control agencies against *D. suzukii* (MAPA 2016). Similar situations are observed in Uruguay (MGAP-Servicios Agrícolas 2017) and Chile (SAG 2017). For Argentina, there is still, to our knowledge, no available information regarding the official registration of synthetic insecticides against *D. suzukii*.

The lack of registered products has not reduced the use of other management strategies. The use of good agricultural practices (i.e., field sanitization) is the major key for the success of *D. suzukii* management (Nava *et al* 2015, Haye *et al* 2016). Since the period from egg to adult is very short, harvesting fruits over shorter intervals and eliminating

Table 2 Confirmed and potential host plants for *Drosophila suzukii* in the southern Neotropical region.

Scientific name	Family name	Common name
Confirmed exotic cultivated hosts[a]		
Actinidia chinensis Planch.	Actinidiaceae	Kiwi
Diospyros kaki Thunberg	Ebenaceae	Kaki
Eriobotrya japonica (Thunb.) Lindl. ✓	Rosaceae	Loquat
Ficus carica L.	Moraceae	Figs
Fragaria x *ananassa* Duchesne ✓	Rosaceae	Strawberry
Malus domestica L.	Rosaceae	Apple
Morus spp.	Moraceae	Mulberry
Prunus armeniaca L.	Rosaceae	Apricot
Prunus avium L. ✓	Rosaceae	Sweet cherry
Prunus domestica L. ✓	Rosaceae	Common plum
Pyrus communis L.	Rosaceae	European pear
Pyrus pyrifolia (Burm.) Nak.	Rosaceae	Asian pear
Rubus fruticosus L. ✓	Rosaceae	Blackberry
Rubus idaeus L. ✓	Rosaceae	Raspberry
Vaccinium spp. ✓	Ericaceae	Blueberries
Vitis labrusca	Vitaceae	Fox grape
Vitis vinifera L.	Vitaceae	Grape vine
Confirmed native hosts[ab]		
Acca sellowiana (O.Berg) Burret	Myrtaceae	Feijoa
Butia spp.	Arecaceae	Butiá (a type of palm tree)
Eugenia involucrata DC.	Myrtaceae	Cherry of Rio Grande
Eugenia uniflora L. ✓	Myrtaceae	Surinam cherry
Prunus serotina Ehrhart	Rosaceae	Wild black cherry
Psidium cattleianum Sabine ✓	Myrtaceae	Cattley guava
Psidium guajava L.	Myrtaceae	Common guava
Potential native hosts[b]		
Allophylus edulis (A St.Hil.) Radlk.	Sapindaceae	Chal-chal
Campomanesia guazumifolia (Camb.) Berg.	Myrtaceae	Sete-Capotes
Campomanesia phaea (Berg) Landrum	Myrtaceae	Cambuci
Campomanesia pubescens (Aubl.) Griseb.	Myrtaceae	Guabiroba
Campomanesia xanthocarpa O. Berg	Myrtaceae	Guabiroba
Eugenia brasiliensis Lam.	Myrtaceae	Grumixama
Eugenia candolleana DC.	Myrtaceae	Cambuí
Eugenia guabiju O.Berg	Myrtaceae	Guabijú
Eugenia mattosii D.Legrand	Myrtaceae	Cereja anã
Eugenia subterminalis DC.	Myrtaceae	Cambuí-Pitanga
Eugenia uvalha Cambess.	Myrtaceae	Uvaia
Garcinia gardneriana Mart.	Clusiaceae	Bacupari
Myrciaria cuspidata Berg in Mart.	Myrtaceae	Cambuí
Myrciaria glazioviana Kiaersk	Myrtaceae	Jabuticaba-amarela
Odontocarya acuparata Miers	Menispermaceae	Capeba
Plinia aureana (Mattos)	Myrtaceae	Jabuticaba-branca
Plinia cauliflora (Mart.) Kausel	Myrtaceae	Jabuticaba
Plinia edulis (Vell.) Sobral	Myrtaceae	Cambucá

The host status was based on: Cini *et al* (2012), Bellamy *et al* (2013), Asplen *et al* (2015), Lee *et al* (2015), Kenis *et al* (2016), Souza et al (2017).

[a] ✓ = Preferred host.

[b] All hosts are native in south and/or southeast Brazil, and some are native also in Uruguay and Argentina. The authors did not include plant species from Chile in this suggested list.

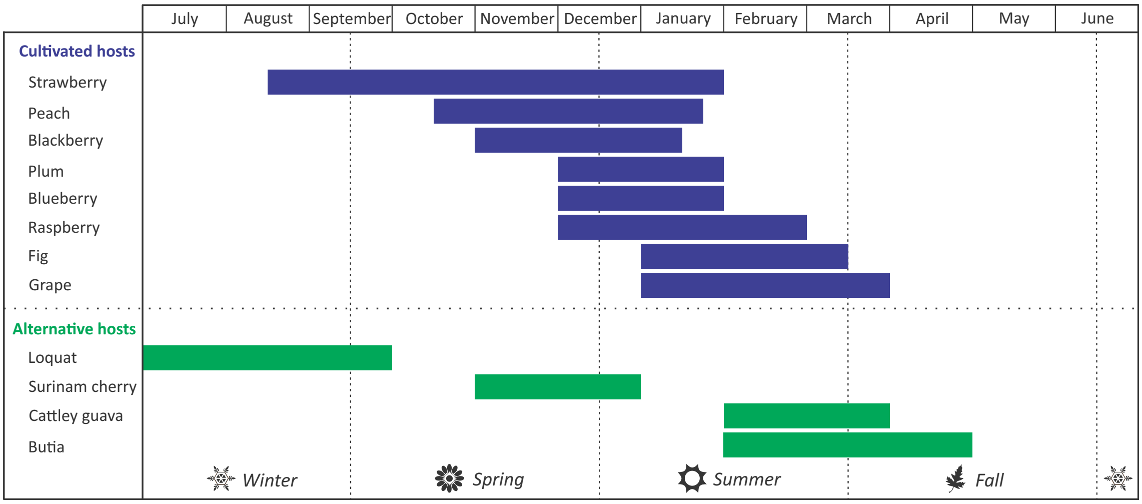

Fig 3 Proposed annual calendar showing the availability of *Drosophila suzukii* hosts in suitable stage (bars) (ripe fruits-near harvest) in the macro-region of Pelotas-RS, Brazil. The host phenology was based on: Bianchi *et al* (1998), Raseira *et al* (2004), Antunes *et al* (2008), Castro (2008), Madail & Raseira (2008), Azambuja (2009), Azevedo (2010), Cardoso *et al* (2012), Carvalho (2013), Bisognin *et al* (2015). See Table 2 for the host's scientific names.

(destroying) any damaged fruit can partially prevent the development of new adults in the field. Pruning fruit trees or removing dead leaves from strawberries (Nava *et al* 2015), as well as managing intercropping weeds, promote less favorable environments for this pest, which prefers a humid microhabitat and a mild temperature (Tochen *et al* 2014, Tochen *et al* 2016).

One effective, but costly, strategy is the use of netting to cover the plants, preventing the contact of flies with the fruits (Nava *et al* 2015). In some countries in Europe, the use of netting associated with mass trapping and chemical insecticides has been shown to be effective against *D. suzukii* (Ioriatti *et al* 2015). In Brazil, where there are currently no quarantine actions or legal tolerance levels to be followed, the growers can legally manage their fields with a low and acceptable population level of the pest.

Finally, the use of biological agents to suppress *D. suzukii* has also been intensively investigated (Asplen *et al* 2015). There are reports of several parasitoids species attacking *D. suzukii* (Chabert *et al* 2012, Gabarra *et al* 2015, Daane *et al* 2016, Guerrieri *et al* 2016), and the application of pathogens such as nematodes and fungi are part of on-going efforts in many countries (Haye *et al* 2016). One of the most prospective parasitoid species is *Trichopria drosophilae* Perkins (Hymenoptera: Diapriidae), which presents high levels of pupal parasitism (Wang *et al* 2016) and could control *D. suzukii* in strawberry cultivated in greenhouses in Italy (Trottin *et al* 2014). In the southern Neotropical region, a closely related species, *Trichopria anastrephae* Lima (Hymenoptera: Diapriidae), and *Leptopilina boulardi* (Barbotin, Carton & Kelner-Pillault) (Hymenoptera: Figitidae) were recently reported to attack *D. suzukii* pupae and larvae in strawberry and blackberry fields (Wollmann *et al* 2016). In the same region, *T. anastrephae* were also collected from strawberry fruits and mass reared in the laboratory on either pupae of *D. suzukii* or *Z. indianus* (Andreazza *et al* 2017b). These previous results are very important and provide a prospective for the development of both conservative and augmentative biological control in the southern Neotropical region.

Future Perspectives

Potential distribution range: observations of Its dispersion paths

The main factor that might limit future *D. suzukii* establishment in Brazil, as well as other parts of the southern Neotropical region, is the combination of adequate temperature and relative air humidity (Benito *et al* 2016). These factors were well discussed in their work, and their results are partially presented in Fig 1. Furthermore, the availability of potential *D. suzukii* host plants is a relevant factor capable of impacting the distribution of *D. suzukii* in the Neotropical region. As shown in Table 2, several plant species can serve as potential hosts for *D. suzukii*. However, knowing that this species is highly polyphagous (Kenis *et al* 2016), we should expect a lack of some other potential hosts that are not listed in this table that can also expand the limits of the distribution and establishment of *D. suzukii*.

The application of adequate laws to regulate the fresh fruit trade market, not only among the regions proposed by Benito *et al* (2016), might be the most effective way to delay the arrival and establishment of *D. suzukii* in new areas. Some important considerations concerning the invasion history in the southern Neotropical region, as described earlier in the text, are helpful to understand the rapid spread of *D. suzukii* in this region.

In the same year that *D. suzukii* was first recorded in the south of Brazil (Deprá *et al* 2014), the species was also reported in a natural reserve approximately 1400 km north of that locality (Paula *et al* 2014). Although further investigations are needed to evaluate whether the single specimen collected in this second location is or is not related to the first ones, these two consecutive reports suggest the rapid dispersion capacity of *D. suzukii*. The infestation in Uruguay and Argentina are likely a consequence of the natural spread of this species after its introduction in the southernmost region of Brazil, especially due to the geographical proximity and absence of physical barriers. However, the hypothesis that the introduction of *D. suzukii* to these countries (i.e., Argentina and Uruguay) occurred through the fresh fruit trade market, either from Brazil or from other infested regions such as North America, Europe, or Asia, cannot be overlooked. This last hypothesis is strongly applicable to the case in Chile, where the fly was found only in traps near Valparaíso Port in Valparaiso city, which imports large amounts of fresh fruits, such as plums, from Asia (Medina-Muñoz *et al* 2015). These authors also highlighted that *D. suzukii* specimens present in this region of Chile had a strong preference for plum-baited traps instead of banana-baited traps, supporting the close relationship with this host.

The dispersion path through the fresh fruit trade market was also reported in Brazil in 2014, when blueberries grown in SC state had *D. suzukii* infestations at a fruit market in São Paulo city (Vilela Mori 2014). Another host that certainly provided means for the dispersion of this pest is the grape. In January 2017, a large number of *D. suzukii* flies were observed and collected in grapes being transported to a winery on a truck approximately 90 km from its growing location in RS state, Brazil (author's personal observation). Independently if the flies were the primary or secondary organisms infesting these grapes, according to the driver, a delivery of grapes from the same field would be performed the next day in a winery in SC state, which is approximately 250 km from the growing field. Even the Brazilian Ministry of Livestock and Supply is monitoring the presence of the species in some production regions (not in all states) (authors' personal information), the lack of further information about the presence of the pest and mitigation of regulatory means clearly contribute to the actual scenario of *D. suzukii* invasion.

Corroborating the predictions of Benito *et al* (2016), dos Santos *et al* (2017), based on climatic variables, mathematically predicted that the central region of southern Brazil, the southern half of Paraguay, all of Uruguay, and the east and south of Argentina are potential distribution areas for *D. suzukii*. On the Pacific coast, the entire coastline of Chile is indicated as a potential distribution area of this insect pest. The areas of greatest environmental suitability for *D. suzukii* are in southern Chile, Uruguay, on the south coast and in south Brazil, and along a small range on the northern coast of Argentina (dos Santos *et al* 2017).

What to do to mitigate the problem

According to current knowledge about *D. suzukii* bioecology in areas where this pest is already established (Asplen *et al* 2015), as well as the similarities of its interactions with hosts that have been damaged by some other well-known fruit fly pests (Diptera: Tephritidae), it is necessary to consider area-wide (AW) integrated pest management (IPM) programs. The AW approach has also recently been recommended by research conducted in the Northern Hemisphere (Cini *et al* 2012, Asplen *et al* 2015, Haye *et al* 2016, Kenis *et al* 2016). The best way to cope with this pest is a well-integrated composite of actions by regulatory agencies, researchers, extension services, and growers, which can be a great challenge in some parts of the southern Neotropical region due to the cultural characteristics and historical experience of growers in terms of managing other native fruit fly species.

Unfortunately, *D. suzukii* has never been included in any quarantine list in Brazil (the authors have no information about Uruguay, Argentina and Chile), which would have alerted customs barriers and extension services to readily establish monitoring programs in the most susceptible areas, near ports and in areas with potential host plants. Nevertheless, regulatory actions are still needed and are very useful, especially to avoid continued reintroductions (Cini *et al* 2014) that could increase, for example, the source of insecticide resistance genes. Controlling fresh fruit trade market is essential since it has been suggested to be the main dispersion means of this pest worldwide (Cini *et al* 2014) as well as in the southern Neotropical region (Vilela & Mori 2014, Medina-Muñoz *et al* 2015).

Another important action to be taken by the regulatory agencies and industries is the registration of insecticides and biological control agents for safe and legal use in the field. The lack of registered control agents can lead to an increase in the unregulated and illegal market of pesticides as well as its unsafe use in the field. In this respect, laboratory and field efficacy screening tests with products that have already been registered to manage other pests in *D. suzukii* cultivated hosts are sorely needed, which can reduce the amount of paperwork and time needed to obtain the product licenses. Some information regarding the synthetic insecticides used in Brazil is already available (Andreazza *et al* 2017c), but additional studies are still needed.

In addition to regulatory actions, the extension service must gather as much information as possible on the available *D. suzukii* management strategies [as in Nava *et al* (2015) and

Haye *et al* (2016)] and work with the growers to delay this pest establishment in production fields. As discussed above, one of the main bottlenecks for the implementation of an AW-IPM for *D. suzukii* in the southern Neotropical region is the knowledge about the host suitability of native or non-cultivated fruit plants, as reported by Diepenbrock *et al* (2016) and Kenis *et al* (2016). Finally, more field surveys for endemic parasitoid species, such as that conducted by Wollmann *et al* (2016), and the development of mass rearing techniques for these parasitoids (Andreazza *et al* 2017b) will support information to plan conservative and augmentative biological control programs in each macroregion of the southern Neotropical region.

In addition to the most common or traditional managements approaches, studies must also focus on products and strategies that cope with organic production regulations in each country or meet international market reduction of residue requirements, as described by Haviland & Beers (2012). Screening for non-synthetic insecticides (e.g., plant extracts, essential oils, or other products already used by local organic growers that may be effective against this species) will provide alternative options that could be integrated with the other management practices discussed earlier in the text.

Growers are a key piece for the sustainable management of this pest. All the management strategies discussed herein and in other studies [such as in Cini *et al* (2012), Asplen *et al* (2015), Nava *et al* (2015) and Haye *et al* (2016)] should be applied by growers with professional supervision, especially if an AW-IPM program should be ever applied. Some recommendations, such as the destruction or sanitization of any other fruit species around the production field, may experience barriers in farm borders when neighborhoods refuse to participate in AW management of this pest, or if native protected vegetation areas are located nearby. Thus, a regulatory disposition coordinating these actions is necessary.

Development of a large-scale (AW-IPM) management program for D. suzukii

The concept of the AW approach for pest management was introduced by Knipling and Rower (Kogan 1998). However, even before its conceptualization, the AW approach was already used against several invasive pests [e.g., the grafting of all European grapes with American phylloxera-resistant rootstocks; the eradication of the tsetse fly *Glossina palpalis* Robineau-Desvoiy (Diptera: Glossinidae) from Portugal in 1914; and the fruit fly management programs in the USA, as reported for *Ceratitis capitata* Wiedemann (Diptera: Tephritidae) in California] (Vreysen *et al* 2007). In theory, the AW approach must be applied over large geographical areas led by organizations rather than by individual farmers, with a focus on population suppression or, if viable, eradication of the pest (Kogan 1998). *Drosophila suzukii* possesses bioecological characteristics, such as its high polyphagia, that compromise any eradication programs for this species in regions with high host availability and climate adequacy for the species. Hence, population suppression should be the focus of a management programs in the southern Neotropical region (perhaps in Chile, geographical isolation might be considered), and an AW approach using IPM strategies is likely optimal. However, it is important to note the social concerns about the strategies employed, the willingness of the farmers to collaborate, and the lack of regulatory efforts to prevent consecutive re-invasion of the managed regions, represents high threats associated with any AW-IPM program (Vreysen *et al* 2007). These factors partially determine the success or failure of these programs (please see Klassen (2005) for a list of examples). Consequently, regulatory provisions from governmental agencies coordinating actions, such as the removal of alternative hosts from the proximities of the cropping fields, are essential (Vreysen *et al* 2007).

Below, we provide a draft proposal of step-by-step actions to be taken to develop an AW-IPM program to suppress the *D. suzukii* population not only farm-by-farm but in a wide area, following the proposal by Vreysen *et al* (2007).

Basic research. The core of any AW-IPM program is the development of new tools and technologies. According to Vreysen *et al* (2007), successful programs were achieved when an independent institution was responsible for planning and developing the new tools and methods for the program. Failure in this first step, although it is not noticed during this first program phase, will compromise the entire program.

As a very first point, it is important to understand the genetic "blue print" of the pest species, *D. suzukii*, within the regions the AW-IPM program to be applied. For this purpose, molecular tools are available (Hoy 2013) and make it possible to analyze the genetic diversity and prevent future control failures as a result of this diversity. In association, it is important to access the differential responses of local pest populations to xenobiotics such as insecticides, elucidating and preventing any possible resistance selection. Other techniques that might be developed for use in an AW-IPM program for *D. suzukii* involve the reduction of reproduction, either by using sterile insect techniques (Klassen 2005), as is currently being used for mosquito control in Piracicaba city, SP, Brazil (Waltz 2016), or by using *Wolbachia* strains that would cause cytoplasmic incompatibility, as is being developed for *Bemisia tabaci* Gennadius (Hemiptera: Aleyrodidae) (Zhou & Li 2016).

As advocated by the IPM component of the program, other components must be used in association to achieve a successful program (Kogan 1998). The study of the local biodiversity and development of mass rearing techniques for use in augmentative biological programs with endemic promising parasitoids species is fundamental (Wollmann *et al* 2016, Andreazza *et al* 2017b). Additionally, the conservation of this species in the field should be considered, leading to the need for selectivity studies of products that could be used against *D. suzukii*.

Modeling and developing new methods. Modeling tools can be used to understand population fluctuations in time and space and to predict the potential pest distribution and/or spreading capacity (Vreysen *et al* 2007). For example, Benito *et al* (2016) and dos Santos *et al* (2017) used the climatic index (Climex) and algorithms, respectively, to predict the potential spread of *D. suzukii* in the southern Neotropical region. In addition to modeling, the development of new simple tools, such as a year-round calendar of available hosts, strongly helps to coordinate the management efforts over time. This calendar also helps researchers or pest advisors to identify gaps or bottlenecks in host availability that may be used to develop new management strategies. Thus, we proposed an annual calendar (Fig 3) comprising the known *D. suzukii* main hosts cultivated in the southernmost region of Brazil. Due to the large area of the southern Neotropical region and different production models, the production calendar greatly varied from and should be adapted into each macro region and updated with information provided from future studies conducted in each location.

Feasibility studies and regulation. In addition to the development of new tools and technologies by basic research, collecting data for cost/benefit analyses will be fundamental for the success of the WA–IPM program (Vreysen *et al* 2007). Among these investigations, the continuous collection of data regarding *D. suzukii* fluctuations throughout the year in fields and natural habitats, as well as the estimation of all possible economic losses caused by these fly infestations, is noteworthy. With these data, feasibility studies can better plan and later monitor the efficiency of the program. Additionally, the development of a logistical design of cultivation and IPM component rotation based on both the crop phenology and the pest life-history traits (such as the early proposed crop calendar) is also essential, and a pilot study may be used (Vreysen *et al* 2007).

Well-conducted feasibility studies will help to convince all stakeholders about the program needs, requirements and fund raising. It will also identify logistical challenges such as the availability of resources and infrastructure for an operational program, enabling planning to mitigate all these challenges. Thus, political and regulatory efforts by governmental agencies are necessary (Hendrichs *et al* 2007).

The regulatory framework of products and technologies to be used in a potential *D. suzukii* AW-IPM program will aid not only the operability of the program but also the international trade market. Recently, the first patent deposit of flavoring esters for *D. suzukii* control in the Neotropical region represents an example of non-toxic environmentally friendly products being regulated in the southern Neotropical region (Garcia *et al* 2016). The development and regulation of postharvest treatments that guaranty pest-free products, such as ionizing radiation, which meets International Plant Protection Conventions provisions, will provide additional tools to prevent continuous re-infestations of *D. suzukii* in managed areas.

Pilot and operational AW-IPM programs. The pilot trials are very effective for identifying program failures and improvement needs for a completely operational AW-IPM program to be successfully implemented. Thus, in addition to testing technologies commonly used in field-by-field IPM, the testing of technologies more related to the AW approach will be required (e.g., pilot mass-rearing facilities of sterile flies, and/or parasitoids, pilot field release of such species, intensive training of staff to work in these facilities). An example is the program that is already being developed in the south of Brazil to rear and mass release sterile fruit fly species and parasitoids (Embrapa 2016).

After all the technologies have been tested and validated under field pilot conditions, the program can be implemented. Great attention must be used in this phase due to the use of a large-scale area and resources. The political, regulatory and commitment off all parts is essential to guarantee success. One remarkable recent example of an operational AW-IPM program that does not rely on mass rearing and release of insects (which can be the most challenging part of developing and implementing an AW-IPM program) is the eradication of the boll weevil in the USA. This program has been very successful and is based mostly on intensive monitoring and detection tools, integrated with a few other control tools (Hendrichs *et al* 2007), and it serves as an example that with the commitment of all parts (from research, government, growers, industries and market), a fully operational AW-IPM program for *D. suzukii* will be viable in the future.

Final Considerations

The current panorama of *D. suzukii* infestation in the southern Neotropical region is still underinvestigated. Most empirical studies (published studies, excluding notes of occurrence) were developed only in Brazil by a few research groups in an attempt to validate international information for local realities, demonstrating a delay in actions against this alien pest invasion. As discussed in this forum, intensive and integrative studies, such as i—monitoring the pest presence and field fluctuations, ii—identifying and classifying the host status of cultivated and non-cultivated fruit species, iii—identifying and improving any source of natural in-field biological control, and finally iv—discussing, testing, and developing new tools and management strategies to cope with this highly mobile pest species using an AW-IPM approach system are essential and needed. The integration of the research community with growers, especially the collaboration of the governmental regulating agencies for the establishment of a collaborative regulatory framework, and the full commitment of funding agencies in providing the necessary resources for the development of science related to this highly damaging invasive species will mitigate economic losses and generate positive profit for the national and international economies of the affected countries.

A large amount of very diverse information was discussed in this forum. The authors hope that their goal of raising the attention of all stakeholders regarding the urgent needs of a cooperative discussion about *D. suzukii* invasion has been accomplished. It is very important to search for answers about what can be done to mitigate this problem in an efficient, low-cost, environmentally friendly and sustainable way. Thus, we advocate that government and industry should focus more attention on collaborative efforts, such as the promotion of regional, national and international meetings involving the various interested parts.

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