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Worldwide invasion of vector mosquitoes: present European distribution and challenges for Spain

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Abstract

An Asiatic mosquito species, *Aedes albopictus*, began to spread worldwide in the 1970s thanks to marine transport of tires and other goods, leading to colonization of many areas of the world. This species is a vector of major human diseases such as Dengue, Yellow Fever and the West Nile virus. In Europe, it was established in Albania and Italy and has been detected in other countries such as France; no records exist for Spain as yet. Colonization by *Aedes albopictus* is a major public health concern considering that the West Nile virus and several other viruses are known to circulate sporadically in the Mediterranean. Additionally, the parent species *Aedes aegypti* was the vector causing severe outbreaks of Dengue and Yellow Fever two centuries ago. Although *Ae. aegypti* was also introduced, it was eradicated from Spain. Both mosquitoes shared habitat types, diseases transmitted and many bionomic data. This article contains a review of the present *Ae. albopictus* distribution range worldwide and discusses the likelihood of an establishment in Spain in view of climatological and geographical data.

Introduction

Globalizing the economy leads to an increase of the worldwide transport of goods, which raises the chances of accidental transport of foreign species. This has been the case of many agricultural pests unknowingly embarked within plant shipments, leading occasionally to establishment in destination countries and challenging local economies as well as natural systems.

Other groups of species play an important role in public health. Mosquitoes are vectors of many relevant human diseases, from Malaria to filariasis as well as viral pathogens such as Dengue, Yellow Fever and the West Nile virus. Therefore, foreign mosquito species entering new countries may not only produce ecological stress but they are also considered a potential threat to public health. The most notorious case in the past was the ship-mediated introduction in the Mediterranean area of *Aedes aegypti*, causing Yellow Fever and Dengue outbreaks during the 18th and 19th centuries.

Most of the present concern on the invasion of temperate areas by tropical vectors is focused on accidental transport of infected insects from tropical countries on aircraft (Isaäcson 1989). However, commercial worldwide transport of used tires, for example, is an efficient carrier for some mosquito species, so there is a need again to monitor marine transport as a potential threat to human health.

The present article deals with the unprecedented, rapid worldwide spread of the vector mosquito *Aedes (Stegomyia) albopictus* (Skuse 1894) (Diptera: Culicidae), from its original areas in Asia to the rest of the world through colonization of shipments of used tires. There are a number of excellent reviews on *Ae. albopictus*, commonly referred to as the 'Asian Tiger Mosquito' (see e.g. Hawley 1988; Mitchell 1995), so we will mostly focus on reviewing the present European situation and its implications for Spain.

Bionomics

Aedes albopictus is a treehole mosquito, and so its breeding places in nature are small, restricted, shaded bodies of water surrounded by vegetation. However, its ecological flexibility allows it to colonize many types of man-made sites such as cemetery flower pots, bird baths, soda cans, abandonded recipients and especially used tires. As these are often stored outdoors, they collect rainfall and retain rain water for a long time. The addition of decaying leaves from the neighboring trees produces chemical conditions similar to tree holes, thus providing an excellent substitute breeding place. It has been pointed however that *Ae. albopictus* can also establish and survive throughout non-urbanized areas lacking any artificial containers, raising additional public health concerns if mosquitoes are likely to come into contact with enzootic arbovirus cycles (Moore 1999). The adult flight range is quite short, as expected for a scrub-habitat mosquito. Therefore, most medium and long range colonization is the result of passive transportation.

Aedes albopictus is an aggressive, outdoor daytime biter that attacks humans, livestock, amphibians, reptiles and birds. The females lay desiccation-resistant eggs above the surface of the water in treeholes or tires. The eggs from strains colonizing temperate regions resist lower temperatures than those from tropical areas (Hanson and Craig 1995). Additionally, in these strains, the combination of short photoperiods and low temperatures can induce the females to lay diapausing eggs which can hibernate (Hanson and Craig 1995). Overwintering is necessary north of the +10 °C January isotherm (Mitchell 1995; Knudsen et al. 1996). The combination of these adaptations accounts for the success in colonizing temperate regions.

Recent spreading and present distribution

A fraction of the present Asiatic distribution range of *Ae. albopictus* is the result of invasions prior to the 20th century, as in Hawaii before 1902 (Sprenger and Wuithiranyagool 1986).

The first modern establishment outside this original range occurred in 1979 in Albania (Adhami and Reiter 1998) although not much concern was raised due to the political isolation of the country. The species is believed to have already been there for some years when discovered, and was probably imported in tire shipments from China (Adhami and Reiter 1998).

Aedes albopictus was next detected in the United States in 1985. Although scattered individuals had already been sporadically collected in the country (Hawley 1988; Reiter 1998), the cluster detected in Harris County, Texas, was the first established population (Sprenger and Wuithiranyagool 1986). Adaptation to cold suggested that the strain probably came from a non-tropical area of Asia, as confirmed by specimen detection in tires coming from Japan (Reiter 1998). In the US, the eastward dispersion of the mosquito was very rapid while the spread to the north and the west was slower, probably due to increasing dryness and cold, respectively (Moore 1999); in 2003, 866 counties from 26 states were infested (CDC, unpublished data).

In 1986 *Ae. albopictus* was detected in Brazil, and Mexico became the next positive country in 1988. Between that year and 1995, the species was detected in most of Central America (Honduras, Costa Rica, Guatemala, El Salvador, Panama), part of the Caribbean islands after 1993 (firstly Dominican Republic, then Cayman Islands and Cuba). More recently, *Ae. albopictus* has also been reported from Guatemala and Bolivia (1995), Colombia (1997), Argentina (1998) and Nicaragua (2003).

In the Pacific area, *Ae. albopictus* was detected in Salomon, Australia (1988), Fidji (1988), New Zealand (1994), and La Réunion (1994). Some African countries such as South Africa (1990) have detected the species, with establishment in Nigeria in 1991. It was recently found to be well established in southern Cameroon (Fontenille and Toto 2001). No other African country has reported *Ae. albopictus,* but the scarcity of surveys might mask a broader presence in the continent.

European concern rose when the species was detected in Italy, firstly in September 1990 as a few adults of unknown origin in Genoa (Sabatini et al. 1990). An established population was found 1 year later near Padua (Dalla Pozza and Majori 1992). Research disclosed that the infestation originated in a tire depot that received egg-infested shipments of aircraft tires from Atlanta, US. Further genetic analysis showed affinities between Italian, US and Japanese *Ae. albopictus* (Urbanelli et al. 2000). The Tiger Mosquito rapidly spread across the northern and central regions of Italy and Sardinia by means of domestic tire trading, and reached Rome in 1997; although some local eradications have been achieved, the species is now present in nine regions and 190 municipalities (Romi 2001).

Ae. albopictus was first found in two tire dumps in France in 1999 during a specific survey (Schaffner and Karch 2000; Schaffner et al. 2001). There was evidence that the species was established from at least the previous year. Chemical control actions undertaken in 2001 by health authorities apparently eradicated the mosquito from these points (Schaffner 2002). However, the presence of *Ae. albopictus* was detected the same year in a new continental location and in Corsica as well by 2002 (F. Schaffner, pers. comm.).

Investigating the French findings and tracing back the route of infested shipments led to the discovery of *Ae. albopictus* in the year 2000 in one location in Belgium, which became the fourth European positive country (Schaffner 2002). Recently, the species has been formally reported from Montenegro (D. Petric, pers. comm.) and from discarded tires in the vicinity of an airport in Israel (Pener et al. 2003). There are references on the possible presence of *Ae. albopictus* in Hungary (Schaffner 2002), but no direct reports.

It is worth noting that many detection reports of *Ae. albopictus* have not been followed by establishment. Quarantine and inspection measures in Australia allowed detection of 17 larval introductions between 1997 and 2001 and five more interceptions in seaports since 2001. As immediate control measures have been applied, *Ae. albopictus* has not yet become established in the continent (R. Russell, pers. comm.). In the Mediterranean, only the introductions in Albania, Italy and probably Israel led to establishment. The other cases are very local, too recent or have been subject to eradication actions yet to be evaluated.

New transport types and other mosquitoes

During the summer of 2001, containerized shipments from China of the plant known as Lucky Bamboo (*Dracaena* spp.) were found to contain *Aedes albopictus* on inspection by quarantine officers on arrival at Los Angeles, USA (Linthicum 2001). Several live adult mosquitoes escaped while opening as *Ae. albopictus* larvae had been transported within *Dracaena* plants shipped in standing water. Destination wholesale nurseries in California were also found to be infested (Madon et al. 2002).

The trade in Lucky Bamboo is increasing because it has cultural relevance within the Asiatic communities in the US and elsewhere, and it has also gained worldwide attention as a popular gift. Large nurseries are located in the Guangdong province of China, where the climate is suitable for *Ae. albopictus* (Madon et al. 2002).

Although the problem appeared recently, the importation of Lucky Bamboo plants is not recent. However, until ca. 1999, the plants were dry packaged and airfreighted; the increase in demand and cost cutting led to the use of container ships. The plants are usually transported in standing water, thus providing the conditions for the breeding of the *Ae. albopictus* larvae. Therefore, the US authorities dictated an embargo on this type of shipment favoring dry airfreight. However, this overlooked the possibility of mosquito eggs being transported on the plant stems.

The spread of *Ae. albopictus* might well be only the first step in mosquitofauna globalization. Similar mechanisms that allowed invasion by *Ae. albopictus* have also transported other mosquito species. The North American mosquito *Ochlerotatus atropalpus* (Coquillett 1902) was also introduced in Italy through the tire trade from the USA as detected in the Veneto region (Romi et al. 1997). As the infestation was local, rapid control measures greatly reduced the population density in 1997, with no positive reports in 1998 (Romi et al. 1999).

Monitoring *Ae. albopictus* in France led to the discovery of another exotic treehole species: in this case, *Ochlerotatus* (Finlaya) *japonicus japonicus* (Theobald 1901) was found in French territory in 2001 (Schaffner et al. 2003). This mosquito probably came together wth *Ae. albopictus* in tires from the USA, where it is present in several Eastern states following introduction from Japan in 1998 (CDC, unpublished data). Both *Ochlerotatus japonicus* and *Ae. atropalpus* are efficient vectors of the West Nile virus (Turell et al. 2001); and *Oc. japonicus* is also believed to be a vector of Japanese Encephalitis (CDC, unpublished data).

Starting in 1992, several countries in South America (to our knowledge, Venezuela, Chile, Bermuda, Costa Rica, Argentina and Brazil) have dictated embargoes on used tire importations, in an attempt to not only prevent mosquito introduction but also to protect local industries as well as prevent Dengue if *Ae. aegypti* is already present. Although this is an efficient strategy, it also has an economic impact; additionally, in the European Union, it would be a less-efficient measure as due to free internal commerce, the country of origin may remain unknown (Reiter 1998). Several countries have passed regulations for the inspection, certification and quarantine of used tires (Reiter 1998), but these are difficult to enforce thoroughly. Local laws have been passed in Italy, but no tire legislation exists at the national level (Romi et al. 1999).

Competition with other mosquito species

Little, if any, attention has been paid to the impact of the presence of *Ae. albopictus* on autochthonous tree-hole breeding mosquitoes. In Spain, interspecific competition might affect *Aedes (Finlaya) geniculatus* (Olivier 1791), *Ochlerotatus (Ochlerotatus) berlandi* Séguy 1921, *Anopheles (Anopheles) plumbeus* Stephens 1828 and the less frequent *Orthopodomyia (Orthopodomyia) pulcripalpis* (Rondani 1872), among others.

Competition has been studied, however, between imported vectors. Distribution ranges of *Ae. albopictus* and *Ae. aegypti* partially overlap, although they occupy different biotopes. The former inhabits densely vegetated rural environments, whereas *Ae. aegypti* prefers less humid, urban breeding places (Mitchell 1995). In some parts of Asia, a general replacement of *Ae. albopictus* by *Ae.aegypti* has been noted. This may be attributable to the urbanization of rural areas (Hawley 1988). However, *Ae. albopictus* will also readily colonize urban habitats if *Ae. aegypti* is not present. Therefore, it has been suggested that larval competition resolved in favor to *Ae. aegypti* could also play a role in some habitats (Hawley 1988).

Interestingly, the opposite replacement is recorded in certain locations in the USA after the introduction of *Ae. albopictus*, apparently inducing the decline or even disappearance of *Ae. aegypti* (Hobbs et al. 1991). It has been hypothesized that the better adaptations to colder climates by *Ae. albopictus* are a reason for this exclusion. In reviewing the literature, Christophers (1960) concluded that the dominant factor on *Ae. aegypti* distribution was a short summer season rather than low winter temperatures. In the laboratory, tropical *Ae. aegypti* eggs can survive for months at 4 °C (P. Reiter, pers. comm.) However, in regions with a January isotherm close to 0 °C, the air temperature is below freezing for many days in the winter months. Clearly, *Ae. aegypti* eggs can only survive in such conditions if sheltered, but these circumstances are not uncommon: in Memphis, Tennessee, the species was abundant in late spring after a winter in which temperatures had dropped to −18 °C (P. Reiter, pers. comm.). Thus, factors other than temperature have induced these changes of range.

Due to this replacement of species, the arrival of *Ae. albopictus* has sometimes been hailed as good public health news because *Ae. aegypti* is considered to be more efficient as a Dengue vector. Unfortunately, *Ae. albopictus* was more receptive to artificial laboratory infection with the West Nile virus than *Ae. aegypti* (Turell et al. 2001).

Aedes aegypti-related diseases in Spain

The Mediterranean Yellow Fever and Dengue outbreaks during the 19th century were transmitted by the parent species *Ae. aegypti,* present as a result of previous invasions. Both species share much of habitat types, bionomics and vector diseases; thus, information from the past distribution of *Ae. aegypti* is worth considering here.

Earlier outbreaks of Yellow Fever in Spain occurred from 1701 onwards. The disease especially affected the southernmost region of the country, where it remained endemic for more than a century (Pittaluga 1928). Both the vector and the disease were imported by sailboats, so outbreaks originated in coastal cities reaching further inland locations, sometimes as far as Madrid (Pittaluga 1928). A single concatenation of Yellow Fever outbreaks in 1800–1803 took >60,000 lives in Cádiz, Sevilla and Jerez de la Frontera (Nájera 1943; Angolotti 1980). According to Pittaluga (1928), another episode in Barcelona (1822–1824) affected 80,000 inhabitants, 20,000 of whom died. There are total estimates of more than 300,000 casualties from Yellow Fever during the first half of the 19th century; a detailed epidemiologic review can be found in Rico-Avelló (1953). The last Yellow Fever episodes in Spain occurred between 1870 and 1880 (Nájera 1943).

The name 'Dengue' is derived from the Spanish word 'derrengue', which applies to a condition of extreme exhaustion (Angolotti 1980); the word is still used in parts of southwestern Spain as an adjective for lazy people (T. Romero, pers. comm.). Dengue epidemics were not as well documented as Yellow Fever, but can be traced to southern and eastern Spain; the first probable outbreak is recorded in Cádiz in 1778. The mortality was so low that the disease was popularly called 'La Piadosa' ('the compassionate') (Angolotti 1980). Although physicians were aware of the different nature of the two diseases, Dengue was less noticed than Yellow Fever because it caused much lower mortality. An outbreak from 1927 reported by Pittaluga (1928) killed less than 5% of infected people, simultaneously to the huge outbreak in Greece that caused one million cases in 2 years, of which more than 1000 died (Adhami and Reiter 1998).

The last documented sample of *Ae. aegypti* was collected in downtown Barcelona in 1939 (Margalef 1943), and the species was described as 'very common'. In his review on the Aedines of Spain, Clavero (1946) also quoted *Ae. aegypti* as being common, but remarked that the present distribution should be better documented. Rico-Avelló (1953) again considered the species as being 'very common' in Spain (see his map in Figure 1) but failed to list his references. García Calder-Smith (1965) did not find *Ae. aegypti* in the Barcelona province, despite multi-year sampling from 1958 to 1965. More recent reviews by Torres Cañamares (1979) and Encinas Grandes (1982) both stated again that *Ae. aegypti* was present in Spain, again on a bibliographic basis only. Thus, due to a lack of field reports, the position was adopted in the latest checklist on the Spanish mosquitoes (Eritja et al. 2000) to formally consider that *Ae. aegypti* had been eradicated, although the reasons for this remain unknown.

Besides sanitation measures, the repetitive introductions by ships were highlighted as a factor of maintenance of the vector. Sailors were aware that old sailboats were healthier than newly built ships: they leaked so much that

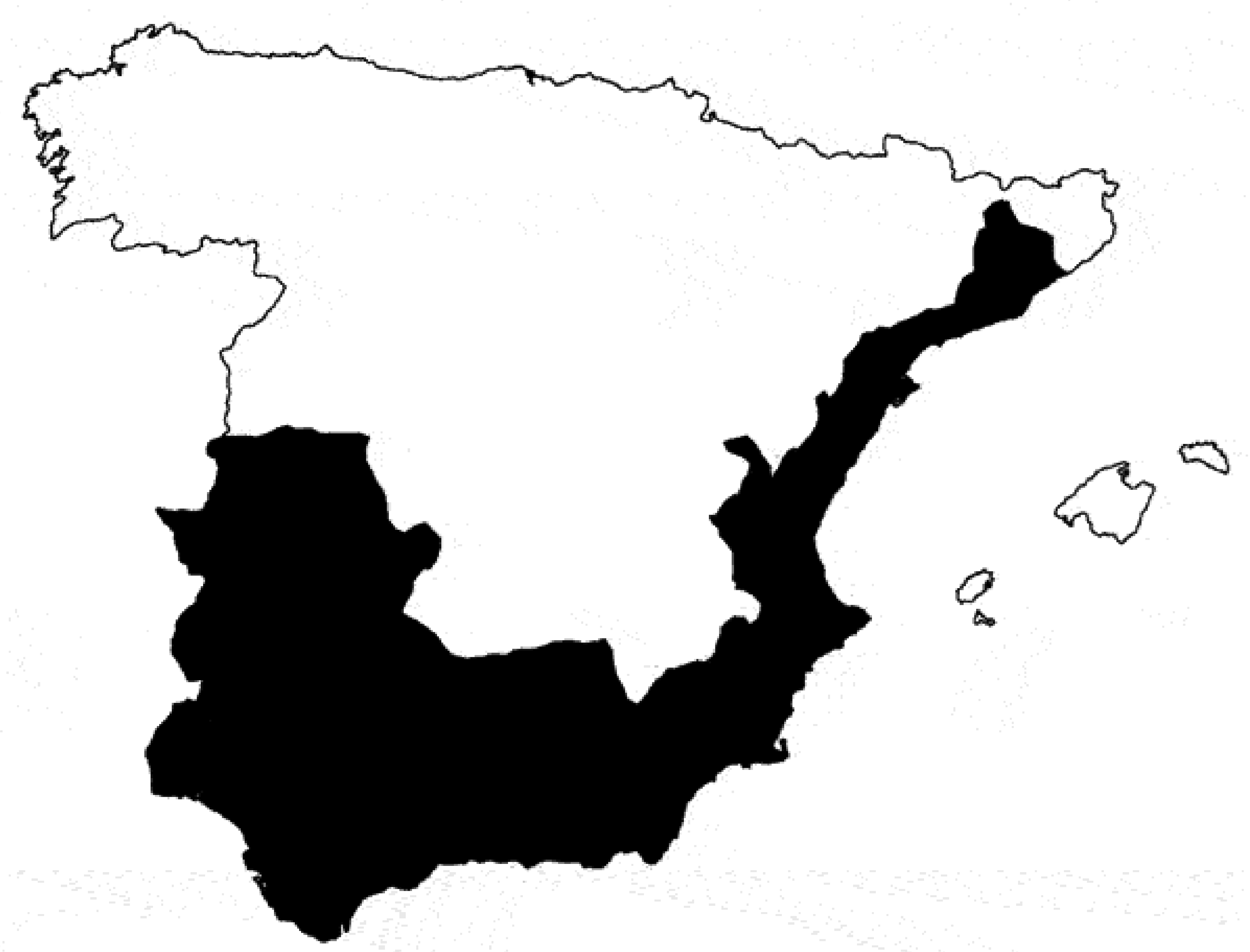

Figure 1. Past distribution of *Aedes aegypti* in Spain (redrawn from Rico-Avelló 1953).

pumping had to be continuous, thus suppressing breeding places onboard (Angolotti 1980). Thus, steamers may have been a major change because they allowed better water management and also shortened the journey across the ocean (Nájera 1943), preventing the development of multiple mosquito generations during the trip, which resulted in the infection of the whole crew.

Additional impacts on this species from the Malaria eradication programs during the first half of the 20th century have been suggested (Samanidou-Voyadjoglou and Darsie 1993; Reiter 2001). Unfortunately, as most of these programs remain undocumented in Spain, the impact of campaigns focused on ricefield Anopheline species on an urban, indoor mosquito cannot be discussed.

Public health risks from *Aedes albopictus*

Public health implications are not trivial as *Ae. albopictus* is only second to *Ae. aegypti* in transmission of Yellow Fever and Dengue. The Tiger Mosquito is believed to act as a secondary Dengue vector in rural environments where human population density is much lower than in cities, so that large outbreaks are not likely to occur; many episodes are not even recorded (Hawley 1988). In some cases, however, the absence of *Ae. aegypti* implicates *Ae. albopictus* in larger epidemics, such as the >100,000 case outbreak in Japan during WWII (Kobayashi et al. 2002). Transovarial transmission of Dengue has been demonstrated in the laboratory for *Ae. albopictus* (Rosen et al. 1983) and has also been verified in field-collected larvae (Moore and Mitchell 1997). European-established strains from Albania (Vazeille-Falcoz et al. 1999) and Genoa, Italy (Knudsen et al. 1996), are receptive to the virus.

The Tiger Mosquito is also an efficient vector for other Flaviviruses such as Japanese Encephalitis and West Nile virus. Several West Nile outbreaks have occurred in the Mediterranean, but the 1996 outbreak in Romania was remarkable, with 453 human cases (Hubálek and Halouzka 1999). Following the introduction of the virus in the USA in 1999, during the single year 2002 a total of 4161 human cases were reported, 277 of which died (CDC, unpublished data). *Aedes albopictus* may be a matter of concern as a bridge vector for the West Nile virus because it inhabits rural areas and has a wide host range including birds, so that it can readily pass enzootic cycles to humans. However, many autochthonous mosquito species (including the ubiquitous *Culex pipiens*) can play an exactly same role. Wild populations of *Ochlerotatus japonicus* have also been found infected by the West Nile virus in the USA (Turell et al. 2001) and experimentally infected with the EEE virus (Sardelis et al. 2002).

Table 1 summarizes the known receptivity of *Ae. albopictus* to pathogenic viruses by experimental laboratory infection, as well as the list of viruses isolated from field-collected individuals. Included are the four quoted Flaviviruses, plus seven Alphaviruses and 10 Bunyaviruses. One additional Flavivirus and two Bunyavirus have neither been tested in the laboratory nor in the field but are known to circulate in the Mediterra-

Table 1. Known virus receptivity in the laboratory for *Aedes albopictus;* viruses isolated from wild mosquito populations, and human pathogenic viruses present in the Mediterranean (compiled from Mitchell 1995; Moore and Mitchell 1997; Gerhardt et al. 2001; Holick et al. 2002).

Virus	Laboratory infection	Field positives	Presence in the Mediterranean
Flavivirus			
Dengue (all 4 serotypes)	*	*	* (past)
West Nile	*	*	*
Yellow Fever	*		* (past)
Japanese Encephalitis	*	*	
Israel Turkey Encephalitis			*
Bunyavirus			
Jamestown Canyon	*	*	
Keystone	*	*	
LaCrosse	*	*	
Oropouche	*		
Potosi	*	*	
Rift Valley fever	*		*
San Angelo	*		
Trivittatus	*		
Cache Valley	*	*	
Tensaw	*	*	
Tahyna			*
Batai			*
Alphavirus			
WEE	*		
EEE	*	*	
VEE	*		
Chikungunya	*		*
Sindbis	*		*
Mayaro	*		
Ross River	*		

nean and to be pathogenic to humans (Mitchell 1995). *Ae. albopictus* is also a vector of filariasis caused by *Dirofilaria immitis* (Nayar and Knight 1999).

Tentative forecasts on spreading

The original distribution area in the North of Asia occasionally reaches the −5 °C isotherm, and may do so in North America (Mitchell 1995). Even assuming the more conservative 0 °C isotherm, this means that the species could become established in northern Europe as far as the southern coast of Sweden and Norway, with most countries at risk (Mitchell 1995). This contrasts with the +10 °C January isotherm that apparently delimits establishment areas of *Ae. aegypti* (Knudsen et al. 1996), as well as diapausing populations of *Ae. albopictus.*

Within this broad range, local establishment would depend on climatic conditions based on temperature, photoperiod, humidity and rainfall. It has been suggested (Mitchell 1995; Knudsen et al. 1996) that areas at risk in Europe would have mean winter temperatures higher than 0 °C, at least 500 mm rainfall and a warm-month mean temperature higher than 20 °C. Rainfall and temperature covary regionally, so higher temperatures are positive for the species as long as the breeding sites do not completely dry out (Alto and Juliano 2001). It is believed that less than 300 mm rainfall per year would make establishment extremely unlikely (Mitchell 1995). This is viewed as reasonable; inspection by the authors of tire depots located in Spanish areas with less than 250 mm, disclosed less than 5% of sampled tires contained water, however, in very small amounts (our own unpublished data from September 2002).

The active season in southwestern US and Japan is from late Spring to early fall (Alto and Juliano 2001). In Rome, larvae are found from March to November, but some females are active until December (Di Luca et al. 2001). This situation is likely to be reproduced in Spain. However, a wide array of scattered climatic areas are affected by mountain ranges as well as maritime and continental influences. For a tentative graphic evaluation of the most suitable regions for an *Ae. albopictus* establishment in Spain, series of climatic information have been plotted in Figures 2–6. All underlying data have been collected from reports of the Instituto Nacional de Meteorología (Font 1983) and the Spanish Ministry of Agriculture (unpublished GIS data). The January 0 °C isotherm in Spain is not relevant to this purpose because it only delimits a few high mountain areas; so that the entire country is primarily at risk under this criterion. The Canary islands have been excluded from the plotting because by geographic configuration the influence of microclimates exceeds general climatic influence at this study scale.

Figure 2 plots the mean annual rainfall rate. Following the literature, only areas receiving more than a yearly minimum of 500 mm have been greyed. However, in our climatic conditions, the rainfall can be heavy but occurs on a seasonal basis, failing to provide continuous breeding places for mosquitoes during the warm season. Thus, we have plotted in Figure 3 the areas with >60 rainy days per year (if >0.1 mm water is recorded). This is intended to correct for stormy-season regions and has been verified by checking against a plot of the >0.5 humidity class region, following UNESCO nomenclature.

Figure 4 deals with mean temperatures. The northern blank area is delimited by the 11 °C all-year isotherm, which Kobayashi et al. (2002) found to delimit *Ae. albopictus* distribution in northern Japan. In Spain, this line very closely matches another suggested climate conditioning factor, the 20 °C warm-month isotherm (not shown). This is an interesting coincidence as these two criteria have been proposed by different authors.

Figure 5 accumulates and presents the previous three climate figures graphically. The dark patches are the regions where all three conditions are simultaneously met; thus, they are also the most suitable areas for *Ae. albopictus.*

Climate-based forecasts are a charming entertainment but are of a very simplistic nature, even using good-quality data. Whereas microclimates cannot be considered at this study scale, they may play a major role. It is however indicated in Figure 5 that many inland territories behind the Spanish eastern coast, including the mid-Ebro valley and large areas of Andalusia, are unsuitable owing to dryness. In the latter, however, the presence of several mountain ranges may provide

Figure 2. Spanish areas receiving more than 500 mm mean rainfall per year.

Figure 4. Spanish areas with mean yearly temperatures higher than 11 °C.

Figure 3. Spanish areas having more than 60 rainy days (0.1 mm rainfall minimum each) per year.

Figure 5. Hypothesized suitable areas (darkened) for *Ae. albopictus* establishment, plotted by intersecting dark areas in Figures 2 and 3 and further suppressing from the result the cold (white) area in Figure 4.

suitable conditions within their slopes. Western parts of Extremadura and Leon would be at risk, as well as most of Catalonia, all these areas sharing a relatively dry, warm-summer climate.

On the other hand, it is worth noting that the entire northern Cantabric shore and corresponding inland areas (including also most of Galicia) could allow establishment of *Ae. albopictus*. These areas have more humid and rainy climates. Given that breeding water would not be limiting here, only low local mean temperatures could theoretically prevent establishment of *Ae. albopictus*.

All areas in Figure 5 are re-plotted in Figure 6 against the human population density if there are more than 20 inhabitants per square kilometer. Known tire dumps are also represented in this map by circles. Data on their locations were collected from chambers of Commerce, phone directories, referrals by collaborators and professional societies (unpublished data). This list is only a rough guide because many of the real (and probably more interesting) existing tire depots may not be officially identified as such.

Discussion

Stopping the invasion in the long term is usually considered to be extremely difficult, if not impos-

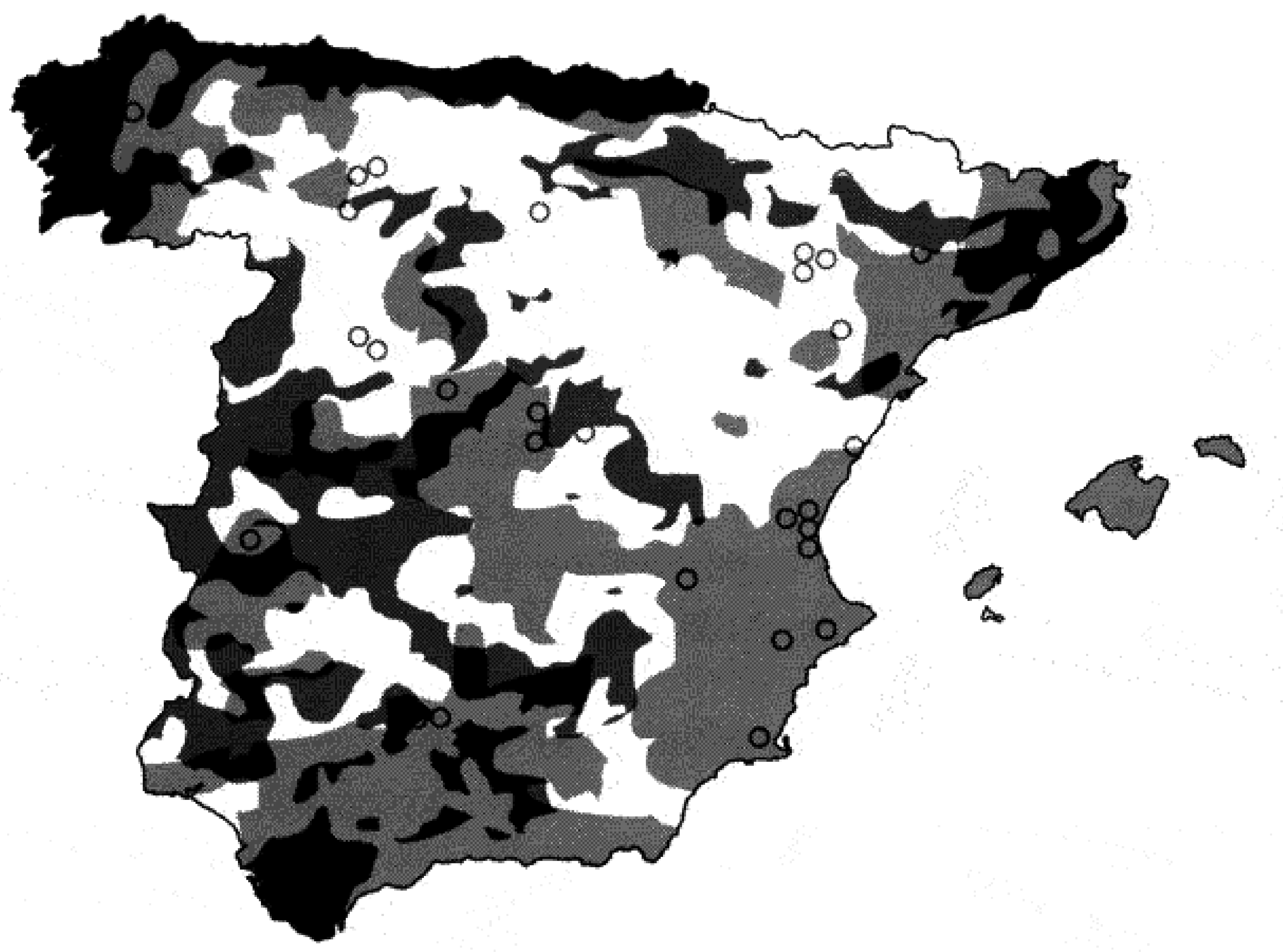

Figure 6. Suitable areas from Figure 5 together with human density population in Spain (grey area; 1991 census, >20 inhabitants per square kilometer). Circles represent the locations of known relevant tire dumps.

sible (Reiter 1998). The spreading of *Aedes albopictus* is quite slow *per se*: it has not yet spread along the Mediterranean coast from Italy to France, in spite of the relatively short distances. All infestations in Italy were tracked to tire depots (Knudsen et al. 1996; Romi et al. 1999), and it was also shown that the early infestations in the US were clustered along the interstate highways (Moore and Mitchell 1997). On the other hand, rapid invasion of some large areas (southern Cameroon, US) strongly suggested multiple simultaneous infestations.

Source reduction strategies such as larval or adult control within tire dumps have proven to be difficult and relatively inefficient due to the shape and abundance of the water surfaces. This was successful in Australia and France (Schaffner 2002) where it has been (and still is) applied on initial invasion stages; source reduction by tire management is more advisable for established situations.

Preliminary data for Spain indicated that used tire importations are a low-volume business, although existing data might underestimate this activity. Export figures collected from origin countries by Reiter (1998) included relevant amounts for Spain as a destination of tire exports from the US, Japan and South Korea between 1989 and 1994. On the other hand, the Lucky Bamboo plant is also being imported to Spain from China. Preliminary test inspections by the authors in February 2002 on *Dracaena* shipments arriving at a wholesale plant nursery disclosed the presence of more than 70 l of standing water in a single container. Plant stems did not have attached eggs, but the remains of one drowned, unidentifiable adult mosquito plus a damaged larva (*Culex* spp.) were filtered out from the water (unpublished data).

Awareness of the risks is absolutely necessary at all official levels even if it is impossible to stop the establishment of *Aedes albopictus* within its suitable geographical range. Such an introduction would be easier to deal with if *Ae. albopictus* could be kept in a rural range, as are the 24 present Aedine species in Spain, none of which occurs significantly within urban environments. In dealing with such aggressive species, the simple biting nuisance can also be a form of public health threat. Preventing the arrival of a new stock and suppressing already present populations would retard their arrival in cities, would limit the replenishment of gene pools and diminish the risk of pathogens introduced within transovarially infected mosquitoes.

The historic relationship between Spain and South and Central America implies many exchanges within these countries. This raises risks derived from the presence of Dengue-infected people that could theoretically initiate transmission in Spain if appropriate mosquitoes were present, as *Aedes aegypti* was two centuries ago. However, a comprehensive healthcare system, housing facilities and many other social factors as well as urban management, would reduce the epidemiological risks such as they may be at present. Monitoring for several viral disease agents would, however, be necessary with a strong emphasis on the West Nile virus as a major local risk. In Spain, no immediate vectorial risks are reasonably expected, and they have not occurred in Italy. However, severe local nuisance could be expected as the experience of Rome clearly demonstrates.

Pittaluga wrote in his documented article on Yellow Fever in Spain and the tropics (1928): 'The problem of the Yellow Fever is a European problem and we must be concerned about the possible danger, taking into account the historical epidemic cycles' [translated by the authors]. These warning words are still valid now that a new potential threat to public health is colonizing

Europe. The Mediterranean received the impact from *Ae. aegypti* and related diseases two centuries ago. At present, all countries are at risk from a parent species that will probably not transmit any significant disease; however, this one came to stay.

In Spain, a scientific network named EVITAR was built up early in 2003 to study and monitor viral arthropod- and rodent-borne diseases. Within this frame, the authors are in charge of the surveillance campaign for managing possible introductions of *Aedes albopictus* and other mosquitoes, as well as other exotic Arthropod species of medical relevance.

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