Impact of climate change on the distribution of tropical pines in Southeast Asia

M. van Zonneveld, J. Koskela, B. Vinceti and A. Jarvis

Climate envelope modelling is used to predict possible shifts in the distribution of Pinus kesiya *and* P. merkusii*, which could have implications for the conservation and use of their genetic resources.*

The natural pine forests of Southeast Asia consist of two widespread economically important species, *Pinus kesiya* and *P. merkusii*, and two rare endemic species, *P. dalatensis* and *P. krempfii*. During the past decades deforestation has decreased their area (FAO, 2007), despite several conservation projects (e.g. Danida Forest Seed Centre, 2000; Razal *et al.*, 2005). Unsustainable resin-tapping and fuelwood collection is degrading many of the remaining pine stands. Climate change is likely to create additional threats and affect the regeneration, growth and distribution of these pine forests.

With deforestation, the genetic resources of the pine species have been eroded. However, the remaining pine forests still include genetic resources that could be useful for rehabilitation of the degraded natural pine forests, tree improvement and establishment of tree plantations.

This article describes the use of climate envelope modelling (CEM) to estimate the potential occurrence of *P. kesiya* and *P. merkusii* in Southeast Asia under the present climate and to analyse how it may shift as a result of climate change. It also discusses the implications of the results for conservation and use of the genetic resources of these two pine species in Southeast Asia.

PINES IN SOUTHEAST ASIA

Pinus kesiya grows in the highlands (800 to 1 200 m) from the Assam Hills in India across Myanmar, Thailand, the Lao People's Democratic Republic, Viet Nam and Cambodia to southern China and the Philippines (Turnbull, Armitage

Pinus kesiya ***grows in the highlands in Southeast Asia: a natural stand on a ridge (left slope) at 1 200 to 1 300 m altitude, Chiang Mai Province, northern Thailand***

Maarten van Zonneveld is associate expert of the Americas office of Bioversity International in Cali, Colombia.
Jarkko Koskela and **Barbara Vinceti** are with the Europe office of Bioversity International in Maccarese (Rome), Italy.
Andy Jarvis is with Bioversity International and the International Centre of Tropical Agriculture (CIAT) in Cali, Colombia.

Pinus merkusii ***grows at lower elevations: a natural stand at 600 m altitude, Chiang Mai Province, northern Thailand***

and Burley, 1980). *P. merkusii* is found at lower elevations in the same countries, excluding China and India (Cooling, 1968), as well as in Indonesia (Sumatra), thus being the only pine species growing naturally in the Southern Hemisphere. *P. dalatensis* and *P. krempfii* are limited to the highlands of southern Viet Nam (Richardson and Rundel, 1998).

P. kesiya is planted both within and outside its natural range; it has become an important tree species for plantation forestry in several African countries in particular. *P. merkusii* is of less interest for plantation forestry because in mainland Southeast Asia the initial height growth of seedlings is delayed for several years (as the species has a so-called "grass stage" when needles take the form of clumps of grass while a robust taproot develops – considered to be a selective advantage for natural regeneration in areas where forest fires are frequent). *P. merkusii* has been used for plantations only in Indonesia as its insular populations do not have the grass stage.

P. kesiya and *P. merkusii* grow on poor, well-drained soils, often forming mixed stands with broadleaves (e.g. *Dipterocarpus*, *Quercus* and *Shorea* species). The two pine species are rather well adapted to forest fires, but frequent anthropogenic fires often prevent successful regeneration and lead to formation of open, savannah-like pine stands. However, fires may help pines occupy sites where they would otherwise be outcompeted by broadleaves (Turakka, Luukkanen and Bhumibhamon, 1982).

PREDICTING PRESENT AND FUTURE DISTRIBUTION AREAS

Climate envelope modelling is a useful tool for rapid assessment of the potential impact of climate change on the distribution of species and ecosystems. This type of modelling uses the documented geographic distribution of a species as a basis for predicting its climatic niche, i.e. the potential occurrence of the species. Future shifts of the climate niche are then estimated based on the climate projections of global circulation models.

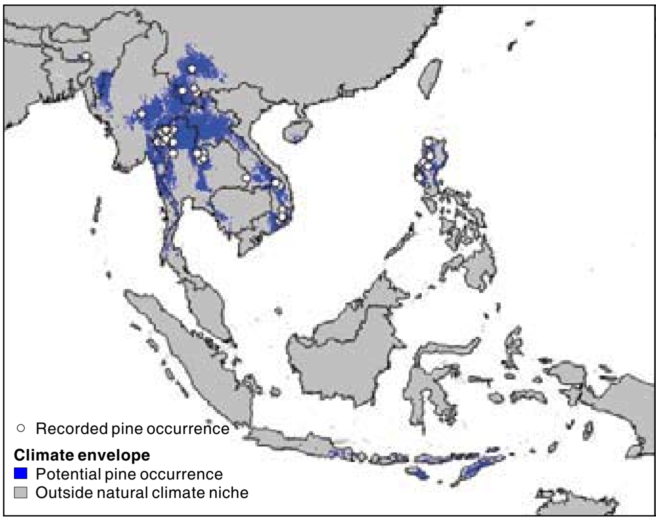
The analysis for *Pinus* species in Southeast Asia used location data for natural pine populations identified as provenances for seed collection programmes (FAO, 1970; Danish/FAO Forest Tree Seed Centre, 1973; Barnes and Keiding, 1989) and forest stands prioritized for *in situ* conservation programmes (Danida Forest Seed Centre, 2000; Razal *et al.*, 2005), as well as herbarium data that are freely accessible through the Global Biodiversity Information Facility (see www.gbif.org). The data included the locations of 46 natural *P. kesiya* populations and 50 natural *P. merkusii* populations.

The present climate of the natural pine populations was described using the 19 climate variables of Bioclim (Busby, 1991), derived from the global climate layers of the WORLDCLIM database (Hijmans *et al.*, 2005a). This database also provided information on the species' present altitudinal range. Climate projections were made for the year 2050 using the average of the predictions of two widely used global circulation models (HADCM3 and CCCMA) under a "business as usual" CO_2 emission scenario.

The CEM modelling program Maxent (Phillips, Anderson and Schapire, 2006) was used to elaborate the present and future climatic envelope for the natural occurrence of the two pine species. The climate envelopes were then mapped and changes or shifts in the distribution ranges were observed.

CURRENT AND POTENTIAL PINE DISTRIBUTION UNDER PRESENT CLIMATIC CONDITIONS

The climate envelope developed for *P. kesiya* (Figure 1) shows that in addition to the areas where natural populations have been recorded, the species



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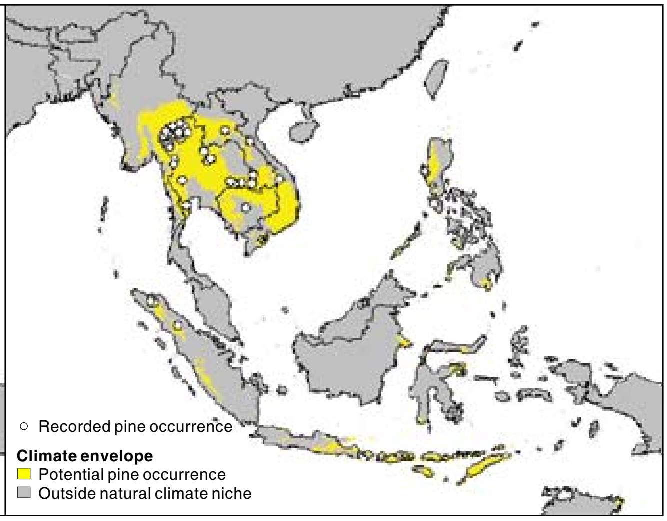
***Recorded and potential occurrence of* Pinus kesiya**



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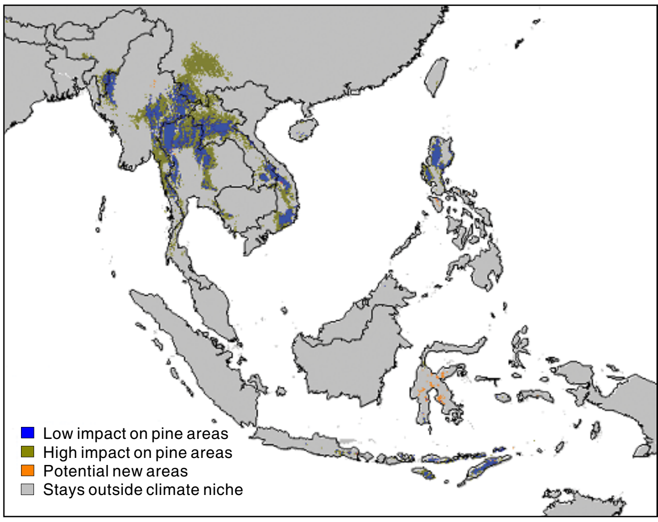
***Recorded and potential occurrence of* Pinus merkusii**



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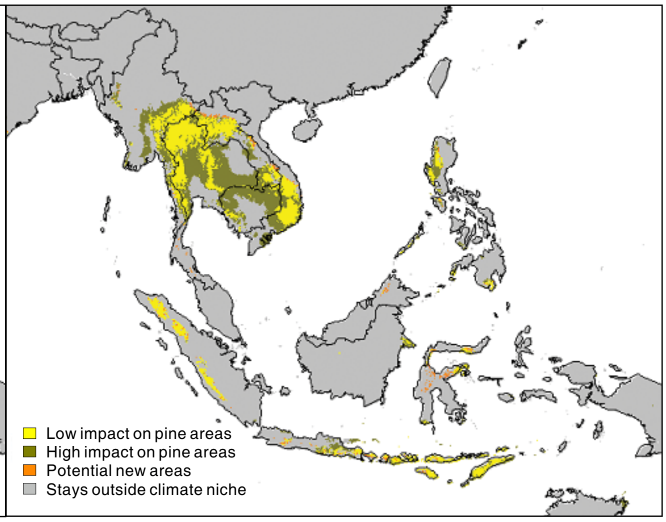
Climate change impact prediction for natural* Pinus kesiya *occurrence



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Climate change impact prediction for natural* Pinus merkusii *occurrence

could potentially occur in several other locations in Myanmar, northeastern and southern Thailand, the Lao People's Democratic Republic and southwestern Cambodia. Although only one population was recorded in Myanmar, *P. kesiya* is likely to occur more abundantly in that country than available information implies. The Indonesian provinces of Java and Nusa Tenggara are outside the recorded natural distribution range of *P. kesiya* but appear to have a suitable climate for the species.

The climate envelope developed for *P. merkusii* (Figure 2) coincides with the observed distribution of the species in mainland Southeast Asia and in Sumatra. The results from CEM suggest that the climate is suitable for *P. merkusii* outside its natural geographic range in several parts of the Malay Archipelago and in northern Australia.

POTENTIAL CLIMATE CHANGE IMPACTS ON PINE DISTRIBUTION

In general few new areas in mainland Southeast Asia are expected to become suitable for the two pine species as a result of climate change (Figures 3 and 4). Lowland *P. merkusii* stands in Cambodia and Thailand are expected to be most threatened by climate alterations (Figure 4). On the other hand, the climate is predicted to become more suitable for plantations of *P. merkusii* and to lesser extent of *P. kesiya* in several parts of the Malay Archipelago.

Most of the recorded *P. kesiya* populations occur at higher altitudes, on average 1 022 m above sea level. Climate change is not expected to affect these populations significantly. *P. kesiya* populations that occur in areas characterized by high temperature seasonality are expected to become most threatened (Table 1), especially those in southern China (Figure 3). However, the impact of climate change on these populations may not be as dramatic as predicted by CEM. Provenances of *P. kesiya* from China established in trials outside the species' natural climate range in southeastern Africa and Viet Nam have performed moderately well (Costa e Silva, 2007), which suggests that these provenances are able to adapt to new climatic conditions.

P. merkusii forests already occurring in high-temperature conditions are predicted to be those most vulnerable to climate change (Table 2). The lowland provenances in eastern Thailand and northern Cambodia in particular are expected to suffer from further temperature increment (Figure 4). It can be expected that in several of these forest stands temperatures will increase beyond the tolerance range of the species, with maximum temperatures in the warmest month in 2050 predicted to be above 36°C (Table 2), a maximum temperature that will kill adult trees of this species according to FAO's Ecocrop database (see Hijmans *et al.*, 2005b). In these areas local provenances of *P. merkusii* can be expected to become degraded and eventually extinct.

IMPLICATIONS

The large potential distribution ranges of the two pine species does not necessarily mean that the pine forests can easily survive. In fact, the current distribution consists of a small number of remaining pine forests because of felling and exploitation for fuelwood. As a result, *P. merkusii* already has a vulnerable conservation status according to the criteria of the International Union for Conservation of Nature (IUCN, 2008). Climate change is an additional threat making the natural populations of this species even more susceptible to degradation and extinction.

As mentioned above, *P. merkusii* lowland provenances are predicted to be most affected by climate change. The degradation and extinction of these provenances may result in a loss of important genetic resources for plantation forestry and for reforestation activities using this species. Many *P. merkusii* lowland forest stands are isolated, and this is likely to restrict migration of lowland provenances upward to climatically better suited areas. Therefore transplantation of lowland provenances of *P. merkusii* to climatically more suitable areas might be the only alternative to conserve their genetic resources *in situ*. Similar measures have been recommended to conserve lowland provenances of *P. oocarpa* in Michoacán, Mexico (Sáenz-Romero, Guzmán-Reyna and Rehfeldt, 2006).

CEM climate change impact predictions take into account the climatic range in which a species occurs naturally at present. Since the species may be adapted to a wider range than this, these models may overestimate climate

TABLE 1. Average predicted changes of five key climate variables for *Pinus kesiya* populations in areas of low and high impact

Climate variables	Populations in areas of low impact			Populations in areas of high impact		
	Present	2050	Change	Present	2050	Change
Annual mean temperature (˚C)	21.7	23.3	1.6	22.9	24.3	1.3
Maximum temperature in warmest month (˚C)	30.4	32.7	2.3	32.0	33.9	1.9
Temperature seasonality (standard deviation of annual mean temperature x 100)	197.0	188.9	-8.1	271.3	259.3	-12.0
Annual precipitation (mm)	1754.1	1974.3	220.2	1511.0	1687.7	176.7
Precipitation in driest quarter (mm)	53.6	48.3	-5.3	60.4	56.5	-3.9

TABLE 2. Average predicted changes of five key climate variables for *Pinus merkusii* populations in areas of low and high impact

Climate variables	Populations in areas of low impact			Populations in areas of high impact		
	Present	2050	Change	Present	2050	Change
Annual mean temperature (˚C˚)	22.9	24.3	1.3	26.7	28.4	1.7
Maximum temperature in warmest month (˚C)	32.0	33.9	1.9	34.3	36.7	2.5
Temperature seasonality (standard deviation of annual mean temperature x 100)	271.3	259.3	-12.0	161.2	170.8	9.6
Annual precipitation (mm)	1511.0	1687.7	176.7	1721.7	1862.7	141.0
Precipitation in driest quarter (mm)	60.4	56.5	-3.9	35.6	32.1	-3.5

change impacts. Furthermore, several subtropical and tropical pines, including *P. kesiya*, have a high degree of genetic variation and tolerate a wide range of climates. Performance in multi-site provenance trials shows that they are adapted well to a wide range of climates Thus they may also be able to adapt to new climatic conditions in their natural habitat, even if these conditions are predicted to be unsuitable in CEM studies (van Zonneveld *et al.*, 2009).

In addition to climate, soil conditions, plant competition and other factors also influence species occurrence and are likely to be additional constraints for the present species distribution and future distribution shifts. However, as climate is considered the primary driver of future distribution changes, the CEM climate change predictions did not take these other factors into account. Furthermore, global circulation models vary considerably in their projections, and as a result CEM climate change predictions contain some uncertainty. Nevertheless, despite its limitations, CEM can be considered a useful tool for obtaining a first approximation of the potential impact of climate change on species occurrence (Pearson and Dawson, 2003).

This approach can also be used for other species and in other regions. For example, similar methods have been used to predict the effect of climate change on pine and oak (*Quercus*) species in Mexico (Gómez-Mendoza and Arriaga, 2007) and numerous tree species in the United States (Iverson *et al.*, 2008).

CONCLUSIONS

Climate envelope modelling has helped to predict which pine forests are most likely to be affected by climate change, enabling forest conservation and management programmes not only to anticipate impacts, but also to identify opportunities. Climate change is expected to favour pine plantation forestry in the Malay Archipelago, as new areas become climatically suited for *P. merkusii* establishment and to a lesser extent for *P. kesiya.*

Although these species may be able to adapt to the new climatic conditions in ways not predicted by the model, the situation for the lowland provenances of *P. merkusii* on mainland Southeast Asia seems critical as temperatures are expected to exceed the species' tolerance. If proper conservation measures are not taken, in the next decades these provenances are likely to become degraded and eventually extinct at the locations where they currently occur naturally. ◆

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Effect of global climate change on rare trees and shrubs

M.S. Devall

Pondberry,* Lindera melissifolia *– a rare species for which climate change poses a threat

C.T. BRYSON
USDA AGRICULTURAL RESEARCH SERVICE/BUGWOOD.ORG

Margaret Devall is an ecologist with the United States Forest Service Center for Bottomland Hardwoods Research, Southern Research Station, Stoneville, Mississippi, United States.

In the past, climate has fluctuated with periods of cooler, warmer, drier or wetter weather than at present. Plants have been able to adapt, but widespread, rapid warming could be disastrous for rare trees and shrubs – i.e. those native species that are among an area's most infrequent and most in need of conservation efforts. Rare plants and rare plant communities often exist as relicts of times past, and have survived locally owing to very particular combinations of environmental conditions.

Rare forest trees and shrubs face particular conservation challenges. A drier climate could be stressful for rare plants, but a wetter climate could cause flooding. Wetlands, especially if degraded, will be vulnerable to drying out in a warmer atmosphere. Rare trees and shrubs will likely be more vulnerable to extinction as a result of warmer climate. Many rare species have characteristics that place them at risk, such as small populations, habitat specialization or limited geographic range. In the southern United States, for example, a number of rare tree and shrub species are confined to areas spanning 100 km or less in latitude, and very few have continuous distributions of more than 100 km with no disjunctions. Plants occurring in mountainous regions may find refuge by ascending in elevation, where possible. Plant communities at lower elevation are vulnerable to rising sea levels. In many areas, land development has restricted the options for rare plant species to adapt. With climate change, rare plants may also become increasingly vulnerable to invasive plant and animal species. In the absence of human intervention, many rare trees and shrubs will probably become extinct.

An example of a rare species that will likely be threatened by global climate change is pondberry (*Lindera melissifolia*) in the southeastern United States. Pondberry is a shrub up to 2 m tall that occurs in seasonally flooded wetlands and on the wet edges of sinks, ponds and depressions. The species is dioecious, and female clones are usually smaller than male clones or sometimes absent from stands. As in many clonal species, seedlings are rarely observed. The distribution and abundance of pondberry have already been affected by habitat destruction and alteration, especially timber cutting, clearing of land and local drainage or flooding of wetlands. The species was listed as endangered by the United States Fish and Wildlife Service in 1986. Many of the existing pondberry colonies are small and occupy only a portion of the apparently suitable habitat. The Lower Mississippi Alluvial Valley, in which two-thirds of the present ponderry populations occur, is one of the most endangered ecosystems in the United States. Much of the habitat suitable for pondberry dispersal is fragmented today; thus populations that die out usually will not be replaced.