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Distribution range and extinction risk of tree snail subgenus *Amphidromus* (Pulmonata: Camaenidae) in Thailand

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Abstract. *Amphidromus* species are attractive pulmonate tree snails that may be threatened by future climate change and human impact. Currently, distributional, ecological, and biological information about *Amphidromus* (*Amphidromus*) in Thailand is inadequate and urgently required to address conservation concerns. Our study focused on modellling potential species distributions using MaxEnt and predicting the species distribution under the current and future climates (A1B Scenario). The species distribution models were predicted in relation to eight climate variables. The results suggest that the distributions of five out of six studied *Amphidromus* are negatively affected by a warming climate. By 2050, four *Amphidromus* subspecies may lose over 40% of their distribution range compared to the climate conditions of the year 2000. Decreases in species distribution ranges may increase the extinction risk of *Amphidromus* species, whose survival is also threatened by habitat loss and the commercial shell trade. To achieve successful conservation of *Amphidromus* species, assessments of their conservation statuses should be prioritised, with legal protection accorded if necessary, and their natural habitats preserved.

Key words. *Amphidromus*, Thailand, species distribution model, climate warming, extinction risk, MaxEnt

INTRODUCTION

Tree snails of the genus *Amphidromus* Albers, 1850, are beautiful and attractive pulmonate snails. Most species are highly restricted in distribution and endemic to small localised regions within Southeast Asia (Solem, 1965; Sutcharit & Panha, 2006), and northern Australia (Solem, 1983). Biological and ecological data of *Amphidromus* remains inadequate, and little is known about *Amphidromus* snail microhabitats, and their life history (Laidlaw & Solem, 1961). There is possibly considerable risk of extinction to *Amphidromus* species because of their limited dispersion ability (Schilthuizen et al., 2005b), and their high dependence on specific types of natural forest habitats (Tumpeesuwan, 2007). *Amphidromus* may also be threatened by overexploitation as the shells are attractive with immense diversity in color and pattern (Laidlaw & Solem, 1961). Thus, there is considerable demand for *Amphidromus* shells as ornamental objects. Moreover, the extinction risk of *Amphidromus* may be increased due to habitat loss from deforestation and climate warming.

Species distribution studies of *Amphidromus* are especially important for their conservation and useful for extinction risk assessments as well as for identification of potential areas for protection. Species distribution modelling is a powerful tool and an effective method for analysing and predicting suitable habitats for targeted species in a wide geographic space. The models are also able to project the change in distribution range in the future and suitable areas for conserving *Amphidromus*. Thus, species distribution modelling for *Amphidromus* spp. in Thailand was chosen for this study.

Many terrestrial species across taxa and regions have shifted their distribution ranges upwards into higher altitudes and poleward into higher latitudes due to the effects of climate warming (Chen et al., 2011). In this study, we modelled the species distribution of *Amphidromus* (*Amphidromus*) spp. in relation to climate variables using MaxEnt. MaxEnt is a software modelling program for species geographic distributions using presence-only records (Phillips et al., 2006; Elith et al., 2011). This study focused only on the subgenus *Amphidromus* as it has a clearer taxonomic status. This genus has three subgenera, i.e., *Amphidromus*, *Syndromus*, and *Goniodromus* (Laidlaw & Solem, 1961), and 87 species in total (Chan & Tan, 2010; Sutcharit et al., 2007). The subgenus *Amphidromus* comprises four species and six subspecies in Thailand (Sutcharit & Panha, 2006) (Fig. 1). Species distributions are estimated by determining the probability distribution of maximum entropy (the species distribute closest to uniform), subject to a set of constraints that represent our incomplete information about the target distribution (Phillips et al., 2006). MaxEnt has an advantage as it uses presence-only data, as presence-absence data are

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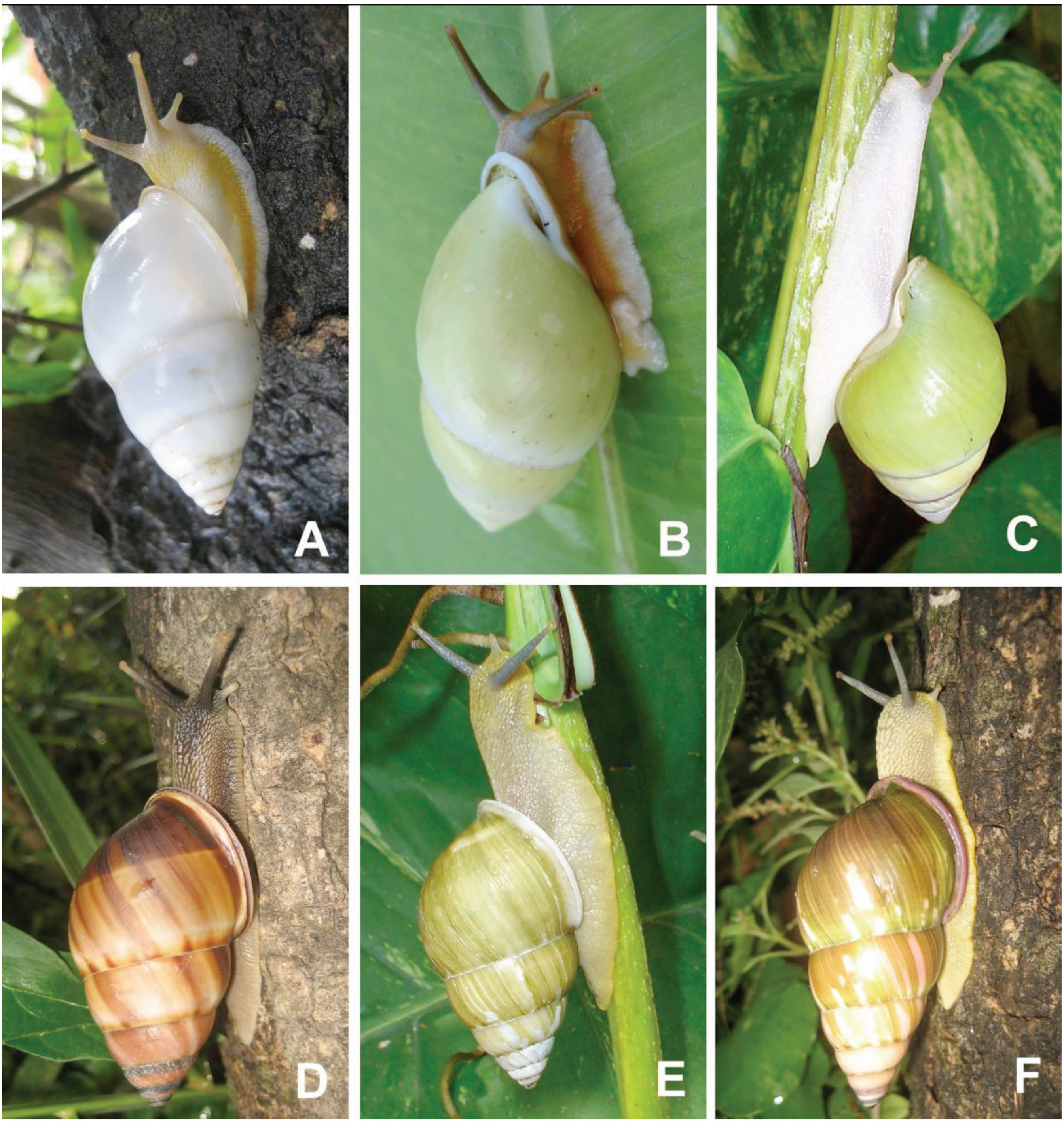

Fig. 1. Tree snails in subgenus *Amphidromus*. A, *Amphidromus* (*Amphidromus*) *atricallosus atricallosus*; B, *A.* (*A.*) *atricallosus leucoxanthus*; C, *A.* (*A.*) *givenchyi*; D, *A.* (*A.*) *inversus annamiticus*; E, *A.* (*A.*) *schomburgki dextrochlorus*; F, *A.* (*A.*) *schomburgki schomburgki*.

usually unavailable in tropical regions. MaxEnt has the highest predictive performance compared with other present-only data modelling methods (Elith et al., 2006; Kumar & Stohlgren, 2009). The predictions of MaxEnt also have high success rates for low species occurrence data: for as low as five records (Pearson et al., 2007; Jarnevich et al., 2015). The predicted changes to the species occurrence areas of *Amphidromus* tree snails in a warmer future climate will be useful for conservation purposes.

MATERIAL & METHODS

Species records. Species records of *Amphidromus* (*Amphidromus*) in Thailand were obtained from publications, such as research papers and theses. The data collected were scientific names (focused on subspecies level), locality information, geo-reference (co-ordinates), and geo-reference precision. Species records were selected for the time span from the years 2001 to 2010. Records with a geo-reference better than 5 km were used in the subsequent analysis.

Climate of Thailand. Climate models of Thailand for the years 2001–2010 were created using climate data from the Thai Meteorological Department. Climate variables from the Meteorological Department were maximum, minimum, and mean monthly temperatures and monthly precipitation from 2001 to 2010. The data was calculated to be a mean of a 10-year time period and then used in the climate model interpolation, using the Kriging method. The models were at a 30 Arc-second resolution (equivalent to 0.83 km^2 at the equator). Monthly climate models were calculated for annual climate: maximum, minimum, mean, and seasonal index of temperature and maximum, minimum, annual, and seasonal index of precipitation as described in Table 1. These climate variables were chosen for tree snail modelling as they are likely to explain their distribution. To examine changes in areas suitable for *Amphidromus* with climate warming, the climate model for the years 1950–2000 and the future climate (the 2050 time period SRES Scenario A1B, as a balance across all sources that does not rely too heavily on fossil intensive (A1F1) or non-fossil energy sources (A1T) were downloaded from WORLDCLIM (http://www.worldclim.org) and CGIAR Research Program on Climate Change, Agriculture, and Food Security (CCAFS) (http://www.ccafs-climate.org), respectively. The climate data were downloaded at a 30 Arc-second resolution. Climate models were used for projecting species distributions and comparing changes in suitable areas for *Amphidromus*. The future climate models were output from The Hadley Centre Global Environmental Model version 1 (HadGEM1), which simulated the tropical climate better than the previous climate model (HadCM3) (Johns et al., 2006). The variables from WORLDCLIM were mean monthly precipitation, maximum monthly temperature, mean monthly temperature, and minimum monthly temperature. The downloaded variables were calculated for the variables in Table 1 to project the species distribution.

Other GIS data. To examine the relationship between species and land type, forest area and elevation were considered. Information on forest areas were obtained from the Department of National Parks, Wildlife, and Plant Conservation, Thailand. The forest areas were from aerial photographs and revised by ground survey in the year 2004. The data were a shape file for forest and non-forest areas. The map was converted into grids at a 30 Arc-second resolution. The elevation of Thailand came from the digital elevation model GTOPO30 (http://eros.usgs.gov/products elevation/gtopo30/gtopo30.html) provided by the U.S. Geological Survey's Center for Earth Resources Observation and Science (EROS). The elevation model was at a 30 Arc-second resolution. The areas were classified in 250 m elevation bands resulting in nine bands across Thailand.

Species distribution modelling. To model *Amphidromus* distributions, MaxEnt software version 3.3.3k was used to examine the probability of the species distributions. The potential distributions of *Amphidromus* species were predicted in relation to eight climate variables for the years 2001–2010 (Table 1) at a 30 Arc-sec resolution. Background data were randomly selected for 10,000 points across Thailand (620,521 grids). The models had multiple runs performed using the subsample method. This method randomly divided the species records into training and test data. The test data were 30% of the species records. The models were run 100 times for each species. The evaluation of the models was based on the mean test-AUC (Area under ROC curve) – 95% confidence interval (CI) (Kremen et al., 2008). The models with a value higher than 0.75 were used in subsequent analyses. To examine changes in the potential distribution, MaxEnt probabilities were projected for the climates of the years 1950–2000, and 2050. The projections of potential species distributions were determined using the species ranges with prevalence (average of logistic output over background sites) as a threshold (Liu et al., 2005). The changes in the species distribution range over time were computed as an absolute change in the number of grid squares occupied and percent changes in the area.

RESULTS

Species records: Records of *Amphidromus* (*Amphidromus*) occurrences across Thailand from 2001–2010 were found in seven publications. There were 89 records of four species and seven subspecies, i.e. *A.* (*A.*) *atricallosus atricallosus*, *A.* (*A.*) *atricallosus classiarius*, *A.* (*A.*) *atricallosus leucoxanthus*, *A.* (*A.*) *givenchyi*, *A.* (*A.*) *inversus annamiticus*, *A.* (*A.*) *schomburgki dextrochlorus*, and *A.* (*A.*) *schomburgki schomburgki*. The records were from 76 locations throughout Thailand. However, only 73 records in 60 locations had a geo-reference precision better than 5 km. Finally, 72 records of six subspecies were used in the species distribution modelling (Fig. 2); *A.* (*A.*) *atricallosus classiarius* was excluded from the analysis as only one location was recorded.

Climate of Thailand. Climate models for Thailand for the years 2001–2010 were created using the Kriging method. The annual precipitation across Thailand was 1,476 mm (S.D. = 355.7 mm, n = 620,521 grid cells). The mean monthly maximum and minimum precipitations across Thailand were 297 and 7 mm, respectively. The seasonality index of the precipitation was 95.8 mm. The mean annual temperature in the years 2001–2010 was 26.9°C (S.D. = 0.8°C, n = 620,521 grid cells). Mean monthly maximum and minimum temperatures across Thailand were 36.2 and 18.0°C, respectively. The seasonality index of the temperature was 1.7°C. To compare the change in climate suitability, which may change in the future, climate models from the same source (WORLDCLIM) were downloaded to compare the year 2000 (1950–2000) and the year 2050 (SRES A1B). The climate model from WorldClim predicted that Thailand would be warmer and drier in the year 2050 compared to the years 1950–2000 under the SRES A1B scenario (Table 2). Annual precipitation is predicted to decrease slightly (approximately 1%). The mean temperature of Thailand is predicted to be warmer by 2.1°C. Maximum and minimum temperatures are also predicted to warm by 2.6 and 2.8°C, respectively. In the future, the climate of Thailand is predicted to have less variation according to the decline in the seasonality indexes of both precipitation and temperature.

Table 1. Definition of climate variables used in species distribution modelling.

Variables	Definition
Maximum temperature (Tmax)	Maximum of mean monthly temperature across the year.
Minimum temperature (Tmin)	Minimum of mean monthly temperature across the year.
Mean temperature (Tmean)	Mean of mean monthly temperature across the year.
Seasonal index of temperature (Tssn)	Standard deviation of mean monthly temperature across the year.
Maximum precipitation (Pmax)	Maximum of monthly precipitation across the year.
Minimum precipitation (Pmin)	Minimum of monthly precipitation across the year.
Annual precipitation (Pann)	Accumulation of monthly precipitation across the year.
Seasonal index of precipitation (Pssn)	Standard deviation of monthly precipitation across the year.

Table 2. Climate variables across Thailand for years 1950–2000 and variable changes in year 2050 under SRES A1B scenario. The values show means and standard deviations of variables across Thailand.

Variables	Year 2000	2050 (change from year 2000)
Tmax (°C)	34.5 ± 1.7	2.6 ± 0.3
Tmin (°C)	15.5 ± 3.2	2.8 ± 0.5
Tmean (°C)	26.1 ± 1.5	2.1 ± 0.2
Tssn (°C)	1.9 ± 0.6	–0.1 ± 0.1
Pmax (mm)	299.4 ± 78.8	–1.0 ± 20.6
Pmin (mm)	10.1 ± 13.6	–1.3 ± 3.2
Pann (mm)	1,493.7 ± 456.9	–15.0 ± 70.5
Pssn (mm)	98.3 ± 30.4	0.2 ± 6.1

Species distribution modelling. The probabilities of a suitable climate for *Amphidromus* species were modelled using MaxEnt in relation to eight climate variables. Five out of six subspecies of *Amphidromus* had shown that their distributions were closely related to climate variables in term of the AUC value. The mean test AUCs of the five subspecies ranged from 0.86 to 0.99. According to the percent contribution explaining of the species distribution models, all subspecies had responses to climate variables idiosyncratically (Table 3). Maximum temperature has the strongest impact on the distribution of the snail species. The temperature variables are more likely to affect tree snails than the precipitation variables considering the top three climate variables of each species.

Species distribution and distribution changes over time periods. The probabilities of species distribution areas are projected for the years 2000 and 2050 (Fig. 3). The areas with high probabilities of suitable habitats for the species are different. *Amphidromus* (*Amphidromus*) *atricallosus atricallosus* and *A.* (*A.*) *inversus annamiticus* has suitable climate across Thailand. The suitable climate for *A.* (*A.*) *atricallosus leucoxanthus* is found in the central part of Thailand. *Amphidromus* (*A.*) *givenchyi* and *A.* (*A.*) *schomburgki dextrochlorus* has suitable climate in central, north, and northeastern parts of Thailand. The suitable habitat probabilities for *Amphidromus* species are likely related with forest area and elevation. The forest areas has higher probabilities of species occurrence than non-forest area in all subspecies (Table 4). The probability of suitable habitat was correlated with elevation. *Amphidromus* (*A.*) *atricallosus*

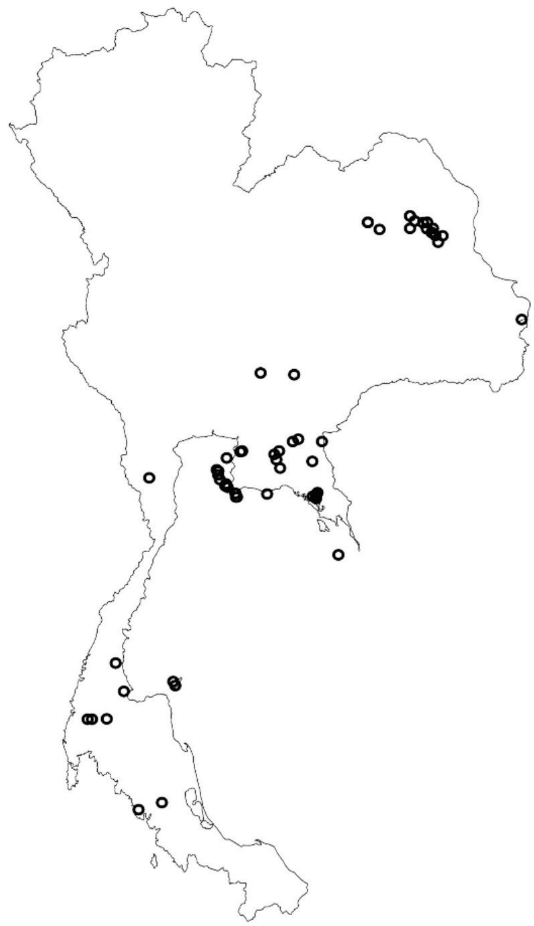

Fig. 2. Locations of *Amphidromus* (*Amphidromus*) records from literature. Open circles show reported locations of *Amphidromus*.

Table 3. Mean percent contribution of eight climate variables from 100 MaxEnt outputs.

Species	Variables							
	Tmax	**Tmin**	**Tmean**	**Tssn**	**Pmax**	**Pmin**	**Pann**	**Pssn**
A. atricallosus atricallosus	2.80	0.52	35.08	59.30	0.79	0.22	1.17	0.12
A. atricallosus leucoxanthus	0.09	0.03	11.54	57.16	0.00	30.46	0.59	0.13
A. givenchyi	0.00	9.74	23.30	4.67	0.84	56.07	4.04	1.34
A. inversus annamiticus	0.59	0.06	77.10	0.07	0.40	2.95	18.82	0.01
A. schomburgki dextrochlorus	4.76	27.07	30.30	2.20	4.71	30.92	0.04	0.00

Table 4. Suitable habitat areas for *Amphidromus* species under current and future climate as classified by land cover of Thailand. Areas were classified as forest and non-forest. Numbers are grid cells for forest and non-forest areas. Percent change refers to the change in suitable habitat area for each land type related to the year 2000.

Species	Forest Area			Non-forest Area		
	Year 2000	**Year 2050**	**Percent Change**	**Year 2000**	**Year 2050**	**Percent Change**
A. atricallosus atricallosus	101,885	54,001	–47	301,023	94,360	–69
A. atricallosus leucoxanthus	22,708	25,275	11	43,159	42,924	–0.5
A. givenchyi	91,510	53,549	–41	316,780	47,672	–85
A. inversus annamiticus	90,479	30,231	–67	218,022	13,895	–94
A. schomburgki dextrochlorus	94,786	57,742	–39	350,973	13,895	–77

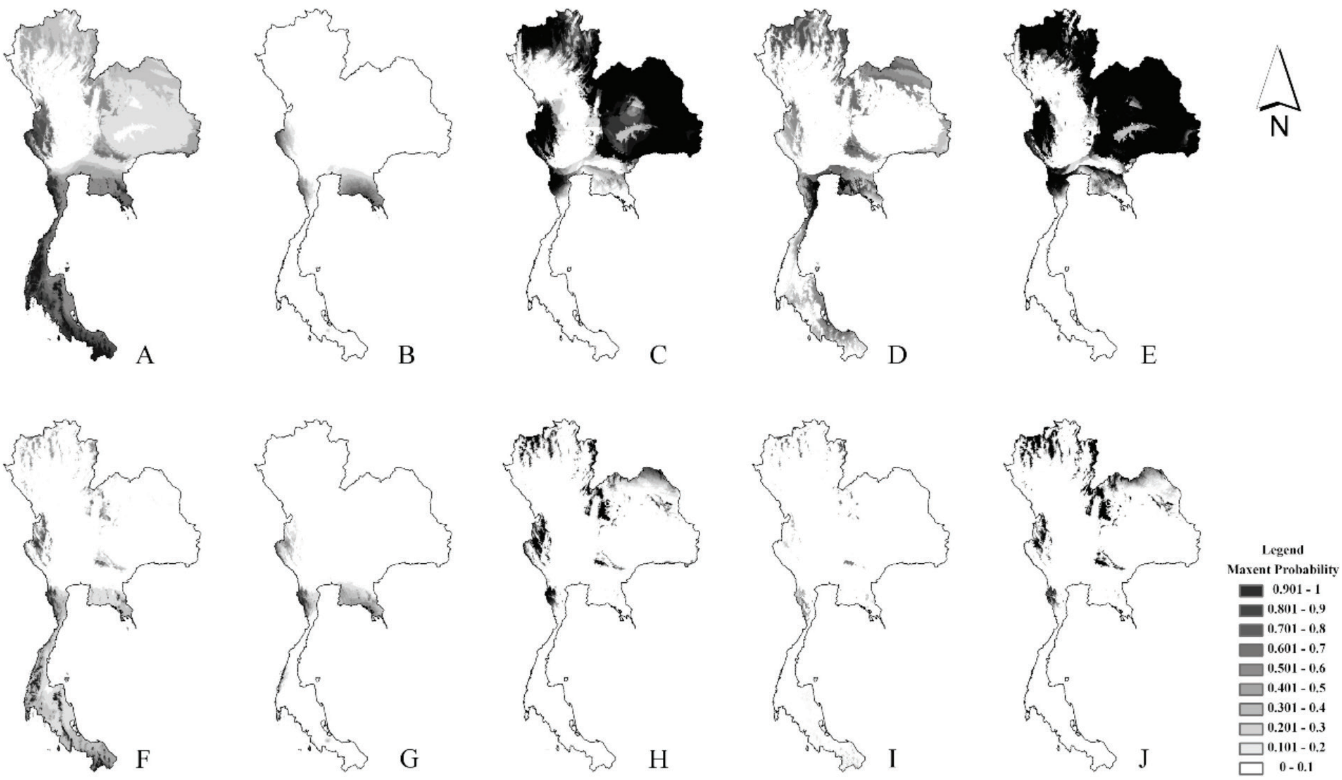

Fig. 3. Species distribution models of five *Amphidromus* subspecies. Darker colors represent higher probabilities of suitable habitat. Upper and lower rows are probabilities of suitable habitat in years 2000 and 2050, respectively. A and F are models of *A.* (*A.*) *atricallosus atricallosus*. B and G are models of *A.* (*A.*) *atricallosus leucoxanthus*. C and H are models of *A.* (*A.*) *givenchyi*. D and I are models of *A.* (*A.*) *inversus annamiticus*. E and J are models of *A.* (*A.*) *schomburgki dextrochlorus*.

Table 5. Suitable habitat area for *Amphidromus* spp. by elevation bands. Suitable habitat area was predicted using prevalence value. Numbers are grid cells of suitable habitat area under current climate, year 2000, (upper row) and percent area change under the future climate, year 2050, (lower row). Future suitable habitat area for *Amphidromus* species were predicted as if species had perfect migration.

Species	Elevation (m)								
	1–250	251–500	501–750	751–1,000	1,001–1,250	1,251–1,500	1,501–1,750	1,7511–2,000	>2,000
A. atricallosus	233,568	70,599	46,251	31,818	14,471	4,918	1,109	126	48
atricallosus	−64.8	−74.5	−70.6	−43.6	−27.4	−1.7	0.0	0.0	0.0
A. atricallosus	42,583	9,805	7,217	4,895	1,073	244	50	0	0
leucoxanthus	2.5	−1.9	−6.8	15.3	60.3	165.6	276.0	2,200	100.0
A. givenchyi	225,760	89,900	44,667	29,404	12,688	4,610	1,087	126	48
	−90.2	−80.9	−49.2	−22.1	−14.3	−8.5	−2.9	0.0	0.0
A. inversus	166,469	53,212	41,308	27,805	13,506	4,918	1,109	126	48
annamiticus	−96.9	−80.0	−83.4	−70.0	−41.2	−19.8	−0.7	0.0	0.0
A. schomburgki	254,760	93,257	46,987	30,967	13,638	4,872	1,104	126	48
dextrochlorus	−85.1	−72.6	−33.7	−19.5	−16.2	−7.6	−0.1	0.0	0.0

leucoxanthus has a high probability of suitable habitat up to 1,000 m, while other subspecies increased in probability with a higher elevation (Table 5). The mean probabilities of suitable habitats across Thailand in the year 2000 are lowest in *A.* (*A.*) *atricallosus leucoxanthus* (0.0293) and highest in *A.* (*A.*) *schomburgki dextrochlorus* (0.5646) (Table 6). Under the future climate (2050 and A1B scenario), the mean probabilities of suitable habitats are predicted to decrease by more than 50% compared to the year 2000, except for *A.* (*A.*) *atricallosus leucoxanthus* that likely remains unchanged. *Amphidromus* (*A.*) *inversus annamiticus* is predicted to lose probably suitable habitat at the highest rate.

The potentially suitable habitat areas are determined using the prevalence as a threshold. The prevalence values of each subspecies ranged from 0.003 (*A.* (*A.*) *inversus annamiticus*) to 0.138 (*A.* (*A.*) *atricallosus atricallosus*). The prevalence values of the other three subspecies are 0.041, 0.093, and 0.013 for *A.* (*A.*) *atricallosus leucoxanthus*, *A.* (*A.*) *givenchyi*, and *A.* (*A.*) *schomburgki dextrochlorus*, respectively. The prevalence values for each particular species were applied for both time periods. The potentially suitable habitat areas showed larger geographic ranges compared to present species records (Fig. 3). The potentially suitable habitat areas of *Amphidromus* spp. were examined for changes in the area through time (Table 4). Under the future climate, the percentage of suitable area loss for the *Amphidromus* spp. outside the forest areas is higher than in the forest areas (Table 5). Only *A.* (*A.*) *atricallosus leucoxanthus* is predicted to increase its suitable area in the forest. According to the elevation gradient, all species, except *A.* (*A.*) *atricallosus leucoxanthus*, are predicted to lose their habitats at low elevations and the only remaining suitable areas would be at higher elevations. *Amphidromus* (*A.*) *atricallosus leucoxanthus* has suitable climates mostly in lowland areas in the year 2000 and it is predicted that their upper range would expand by up to 500 m (Table 6).

DISCUSSION

Species distribution model. The model outputs showed that five out of six *Amphidromus* subspecies have distributions across Thailand with close relationships to climate variables. Only one subspecies, *A.* (*A.*) *schomburgki schomburgki*, may be less related to climate but more related to other variables, such as land cover type. This species has been reported from dry evergreen, dry dipterocarp, and mixed deciduous forest (Jumlong et al., 2013; Srihata et al., 2010), but its abundance is likely to be higher in denser tree canopies (Srihata et al., 2010).

Predicting the suitable habitat areas using the prevalence as the threshold is a good criteria for *Amphidromus*. The predicted suitable habitat areas cover all available data including new records, such as *A.* (*A.*) *inversus annamiticus* in Surin (Jumlong et al., 2013), Ubon Ratchathani (Sutcharit et al., 2013), and Si Sa Ket (Sasang, 2015). *Amphidromus* (*Amphidromus*) *atricallosus atricallosus* was found in Hala-Bala Wildlife Sanctuary, which is the southern-most recorded location for this subspecies in Thailand (Dokchan,

Table 6. Mean probability of suitable habitat and potential suitable habitat areas for species distribution models in years 2000 and 2050. Suitable habitat areas were shown in number of grid cells. Percent area change was change in suitable habitat area from year 2000.

Species	Mean probability		Suitable habitat area		Percent Area Change
	2000	2050	2000	2050	
A. atricallosus atricallosus	0.2720	0.1023	402,908	148,361	–41.02
A. atricallosus leucoxanthus	0.0293	0.0276	65,867	68,199	0.38
A. givenchyi	0.5041	0.0893	408,290	101,221	–49.49
A. inversus annamiticus	0.1736	0.0142	308,501	44,126	–42.61
A. schomburgki dextrochlorus	0.5646	0.0925	445,759	136,882	–49.80

unpublished data). Another additional recorded species was *A.* (*A.*) *atricallosus leucoxanthus*. This species was found in Ang-Ed community forest, Chantaburi Province and Trat Agroforestry Research and Training Station, Trat Province (Klorvuttimontara, unpublished data).

According to percent contribution (Table 3), temperature variables may affect *Amphidromus* distribution negatively more than precipitation. Generally, a slightly warmer climate in a tropical region may have the most deleterious effects on many tropical species, especially ectotherms (Deutsch et al., 2008). The amount of precipitation in Thailand may already be higher than the minimum range for their requirement, and therefore of less importance in explaining *Amphidromus* distribution.

According to the prediction of potential suitable habitat data, distribution ranges of some *Amphidromus* species are larger than their actual known ranges, especially in Northern and Western parts of Thailand (Fig. 2) where the snails have never been recorded. The distribution of the *Amphidromus* subgenus *Syndromus* is generally wider and occasionally overlaps with the subgenus *Amphidromus* (Sutcharit et al., 2015; Jumlong et al., 2013; Srihata et al., 2010; Tumpeesuwan, 2007). In general, *Amphidromus* disperses through the tree canopy (Schilthuizen et al., 2005b), and the smaller and lighter snails of the subgenus *Syndromus* may possibly move across trees better. Moreover, snails that are bigger in size may possibly attract more local predators, which can limit their distribution. However, these remain speculative and further studies are required for a better understanding.

***Amphidromus* under climate warming.** In the year 2050, the climate across Thailand is predicted to be warmer by 2°C compared to the year 2000 under the A1B scenario. This level of warming is considered dangerous and at least 20% of known plant and animal species may face extinction (Smith et al., 2009). Our models show a similar direction. Four out of six *Amphidromus* species and subspecies (66.7%) will be highly threatened by a warmer future climate as loss of their suitable areas may be as high as 40% by 2050 (Table 4), and the figures suggest that *Amphidromus* are likely to be threatened. This could be due to tropical terrestrial snails already living near their upper threshold temperature and therefore could face extinction with only a slightly warmer climate. Müller et al. (2009) reported the effect of a warmer climate on temperate terrestrial snails to be the opposite (possibly an overall increase in species richness and density). However, high elevation snail may become extinct when the climate becomes a little warmer.

Amphidromus may also be threatened by human-induced habitat loss, over-exploitation, and competition from other species expanding their distribution ranges. Usually, *Amphidromus* species are found in closed-canopy forest (Schilthuizen et al., 2005a; Srihata et al., 2010). The closed-canopy is important to *Amphidromus* as a habitat, pathway for migration (Schilthuizen et al., 2005b), and food resource. Decreasing availability of closed-canopy habitats may limit *Amphidromus* movements when the areas become disconnected in the future (Fig. 3). The resulting habitat loss and fragmentation may accelerate the extinction rate through inbreeding and loss in genetic diversity (Craze, 2009). In addition, *Amphidromus* may lose their food resources, such as lichens that have lower productivity under warmer and drier climates (Song et al., 2012). Climate warming may cause ecological community changes, both in species richness and composition, including their interactions and organisation (Klanderud, 2005; Le Roux & McGeoch, 2008; Thomas, 2010). Invasive species may colonise the habitats of *Amphidromus* and compete with the native species. All these are threats to *Amphidromus* along with climate change.

Conservation of *Amphidromus* species. To conserve the *Amphidromus* species in Thailand, establishing their conservation statuses and according legal protection are necessary. Most *Amphidromus* species face possible extinction as suitable habitats are increasingly lost or fragmented. Habitat isolation is of particular concern for species with low dispersal rates, like land snails (Knop et al., 2011). Losing approximately half of the climatically suitable areas by 2050 may accelerate the extinction rate for *Amphidromus*. The preservation of forest area in protected areas to maintain habitat quality and the creation of connective forested patches between existing forests may mitigate extinction risks for *Amphidromus* species and other wildlife (Knop et al., 2011; Parkyn & Newell, 2013).

Further studies of wild *Amphidromus* populations related to their recovery may be needed to better understand the effects of human activities on their population sizes and extinction risk. Additional studies on the biological background, such as life cycle and limiting factors, may be useful in *Amphidromus* breeding programs.

CONCLUSION

Distributional records of *Amphidromus* are rare but useful in species distribution modelling. The distribution of snails of the subgenus *Amphidromus* is closely related to climate variables. The projected 2.1°C warming by 2050 may cause an approximate 40% decrease in its distribution range. The risk of extinction of *Amphidromus* species in the future may thus be increased due to this predicted loss of suitable habitats, fragmentation, over collection, and other human impacts. To better protect *Amphidromus*, the conservation statuses of these tree snails require urgent assessment and further detailed studies.

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