Risk Analysis of the Invasive Potential of 6 Species in Iowa

Utilizing Ecological Niche Modeling to Assess Climatic Suitability in 2050 and 2090

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1. EXECUTIVE SUMMARY

Ecological niche modeling is a fairly new and rapidly evolving technique being utilized by environmental managers to assess invasion risk by non-native species under the impending risk of climate change. The Iowa Department of Natural Resources (DNR) is interested in exploring the invasive potential of a broad diversity of species within the state's boundaries. In response to a call for proposals, the ecological niche modeling group at the University of Kansas developed a series of ecological niche models to assess invasion potential for six target species. The species selected for risk analysis were the Round goby (*Neogobius melanostromus*), Red swamp crayfish (*Procambarus clarkii*), Asian rock pool mosquito (*Aedes japonicus*), Parrot-feather (*Myriophyllum aquaticum*), Chinese bushclover (*Lespedeza cuneata*) and the New Zealand mudsnail (*Potamopyrgus antipodarum*). Selection of species was based on three criteria of general invasiveness: (i) history of colonization in regions outside of their native habitat, (ii) potential threat to Iowa's biodiversity, and (iii) data availability.

Invasion risk potential was projected for each target species using the two most common ecological niche modeling algorithms: GARP and MaxEnt. Model parameters were standardized and projections made using present-day WorldClim climatic data and future climatic projections as provided in the BCCR climatic model for three emissions scenarios (A1B, A2, and B1) for the years 2050 and 2090. Additionally, a calculation of climatic similarity of the state of Iowa with respect to the rest of the world (MESS analysis) was performed in order to identify global regions that, based upon climatic similarity, could serve as sources of future invasive species. These approaches are complementary to each other in that the potential for invasibility may emerge as the individual response of a species to its environment, but the general context of the environment in which these species may appear and establish is best assessed if there is contextual environmental and geographical information for interpretation.

The results of the algorithms utilized (GARP and MaxEnt) are independent of one another as they are derived from different probability distributions, and as such, yield unique results (Stockwell et al. 1999, Phillips et al. 2006). MaxEnt appeared to perform poorly for several species, overfitting the model and potential distributions for both the New Zealand mudsnail and Asian rock pool mosquito, and apparently underfitting potential distributions for the red swamp crayfish. Conversely, the GARP algorithm appeared to fit nearly all populations with outputs performing above random across all species. Where minimal species presence data were available, the overall projections of neither model appeared overly strong. Based upon the overall performance of the algorithms, the projections of GARP appear more reasonable owing to their consistency with *a priori* hypotheses of species distribution. Thusly, the projections provided by GARP were accepted for analysis and became the basis for risk assessment. Species considered to have a high invasion risk are the Red swamp crayfish and the Asian rock-pool mosquito. The New Zealand mudsnail and Chinese bushclover are considered to be of moderate-high risk. And the remaining two species—Parrot-feather and Round goby —are considered of moderate risk.

2. INTRODUCTION

In a world rapidly changing through the rise of globalization, range expansion and subsequent colonization of species in nonnative regions is one of growing concern. Invasive species threaten not only indigenous biodiversity, but can impose costly economic consequences and public health risks. Climate change can exacerbate these risks as some species actively track newly emerging suitable habitat. A successful invasive species is one that can colonize a new area as a result of introduction or environmental change. Ecological niche modeling (ENM) is a useful tool to for predicting areas outside a species' native range that it may find suitable (Peterson and Vieglais 2001). This method has become popular not only to identify areas that may be vulnerable to colonization by non-indigenous species as a result of artificial introductions (e.g. DeVaney et al. 2009, Kulhanek et al. 2011), but that may become suitable for colonization in the future due to climate change (Roura-Pascual et al. 2004).

Presently, over 50,000 documented invasive species exist in the United States, with a diversity of consequences ranging from the closing of recreational areas, to crop and livestock loss, and emerging zoonotic disease(Pimentel et al. 2004) . These species cost the United States over $120 billion annually (Pimentel et al. 2004). At least 95 invasive species currently occupy Iowa's waterways alone (USGS, http://nas.er.usgs.gov/). Through predictive modeling of invasive species, it may be possible to develop policies and strategies to prevent or mitigate the negative impacts of invasive species on the environment (natural, human, and agricultural) and the economy.

In response to concerns of invasive species of Iowa in the future, Iowa's Department of Natural Resources extended a bid to parties in the niche modeling community to investigate invasive risk potential. The Ecological Niche Modeling Group (ENMG) at the University of Kansas selected six species for modeling of potential invasiveness in Iowa in response to future projected climatic changes. The following report details the results of these analyses.

3. METHODOLOGY

A risk assessment of potential invasion for six species was conducted using modern ecological niche modeling (ENM) techniques. Study species were selected based upon three primary criteria:

(i) Overall colonization ability of the species as exhibited in other regions.
(ii) Risk to native flora and fauna of Iowa pending invasion.
(iii) Availability of adequate and reliable data for use in modeling applications.

The species selected for assessment – Round goby (*Neogobius melanostromus*), Swamp red crayfish (*Procambarus clarkii*), Asian rock pool mosquito (*Aedes japonicus)*, Parrot-feather (*Myriophyllum aquaticum*), Chinese bushclover (*Lespedeza cuneata*) and the New Zealand mudsnail (*Potamopyrgus antipodarum*) – represent a variety of known species with invasion potential.

3.1 Data & Model Standardization

Species occurrence data were collected from a variety of data sources and are referenced with each species description. The data were curated for localities and georeferenced. For each species modeled, 20% of the complete data set were randomly selected and set aside for use in partial ROC testing. The remaining 80% of data points were subsequently utilized for model training.

Model training regions (M) were defined based upon knowledge of the natural history of each species. Using the 80% of locality data set aside for training, a buffer was created to connect all data points in a contiguous region. Where a standardized buffer appeared to cause overfitting of the model, training regions were delimited by hand using knowledge of species specific natural history. When possible, the native species range was utilized for training; however for a few select and highly invasive species (and depending on the availability of adequate occurrence data), either a combination of the native and invaded ranges, or just the invaded ranges were utilized. Occurrence data were then further refined through clipping to one data point per cell at 2.5 minute resolution using ENMTools (http://enmtools.blogspot.com/).

Seven bioclimatic variables were selected for use in modeling. These variables represent a range of both temperature (annual mean temperature, mean diurnal range, maximum temperature of warmest month, minimum temperature of coldest month) and precipitation (annual precipitation, precipitation of wettest month, precipitation of driest month) factors. Current environmental data were taken from WorldClim (Hijmans et al., 2005).

Three standard emissions scenarios from the BCCR future bioclimatic model were utilized in the modeling of future climate. The three scenarios – A1B, A2, and B1 – represent three standard potential emissions scenarios: moderate (utilization of an equal balance of fossil and non-fossil energy resources), the most extreme (continued dependence upon fossil fuels), and the most environmentally friendly (predominantly non-fossil fuel based energy usage) scenarios respectively (Tabor & Williams, 2010). ENM analyses were conducted for each species for all three models for the years 2050 and 2090.

Models were projected to a region including Iowa as well as adjacent states. The projection region was selected to provide a wider view of potential invasiveness (i.e. knowledge of the potential for a species to invade adjacent regions in the near future may provide an indicator of invasive potential in Iowa itself).

Results for current climatic conditions and model A1B are presented with each species report. Results from models of scenarios A2 and B1 are presented as supplemental material at the end of this report.

3.2 Algorithms & Model Parameters

Modeling was conducted using the two most common ENM algorithms: Genetic Algorithm for Rule-Set Production (GARP; Stockwell & Noble 1992, Stockwell & Peters 1999) and Maximum Entropy (MaxEnt, Phillips et al., 2006). GARP was run through the free program openModeller (http://openmodeller.sourceforge.net/index.php?option=com_frontpage&Itemid=1) and set to conduct 100 runs for 1000 iterations. A soft omission threshold was set for 20% with a commission threshold of 50%. Training percent ranged for 20-50% depending upon the amount of species occurrence data available. Optimization parameters were left at the default settings. Replicates were bootstrapped and the twenty best model subsets retained for analysis. MaxEnt models were set to 10 runs of 1000 iterations with bootstrapping. The remaining default settings were accepted.

3.2 Analysis

Model outputs were thresholded to a minimum training presence. Training points were compared to the predicted suitability for each model within the training region. The minimum suitability value obtained (or the 5-10th percentile depending on the species) was taken as a baseline “presence” threshold. This suitability value was then applied to all model projections to determine areas of suitability. A partial ROC analysis was conducted for each algorithm run to assess model significance (Peterson et al. 2008).

Using multivariate climatic similarity measures, the climatic envelope of Iowa was quantified and compared to that of the entire globe. To do this, the Euclidean distance of each climatic point in Iowa to the rest of the world (or another desired geographic extent) in a standardized environmental space (e.g., using principal components as variables) was measured. This allowed for the quantification of the climatic similarity between the climate of Iowa and any target geographical region in the world. The method utilized is a form of, but less arbitrary than the environmental similarity metric – Multivariate Environmental Similarity Surface (MESS) – from Elith et al. (2010), allowing for a clearer mathematical and biological interpretation (in prep).

4. ECOLOGICAL NICHE MODELLING: INDIVIDUAL SPECIES RESULTS

4.1 ROUND GOBY (*Neogobius melanostomus*)

The Round goby, *Neogobius melanostomus*, is a benthic fish native to the Black and Caspian Seas that, like other gobies, is tolerant of a wide range of environmental conditions (Jude et al. 1991). This species was introduced to the Great Lakes via ballast water from the Black Sea, and successfully established breeding populations in the area by the early 1990s (Jude et al. 1991). Since then, Round gobies have expanded their range as far south as the La Grange Reach of the Illinois River, 178 river miles from Lake Michigan (Irons et al. 2006). In the ecosystems to which they have been introduced, Round gobies compete with native benthic fishes for food and habitat; they are voracious predators of native benthic fishes and mussels. Studies have shown that Round gobies pose a direct threat to seven endangered native species (one fish and six mussels) in Great Lakes tributaries (Poos et al. 2010).

Round goby occurrence data were acquired from FishBase (www.fishbase.org), the Global Biodiversity Information Facility (www.gbif.org), and the National Institute of Invasive Species Science (www.niiss.org). Once the data quality control as described in the parameter standardization section was completed, six datapoints in the species' native range and 185 points in its colonized range in North America remained. Owing to the greater robustness of the North American (invaded region) dataset, these locality data were selected for use in modeling. 37 data points were set aside for extrinsic model verification as described above, and the remainder (148) used in model training. The training region (M) that was employed incorporated a combination of the extent of the natural Great Lakes drainages as acquired from the Great Lakes Information Network (glin.net) and a buffer of 1 degree around the locality points of individuals that dispersed out of the Great Lakes basin via the Chicago Sanitary and Ship Canal (Charlebois et al. 2001).

Both GARP and MaxEnt models indicate a band of suitability stretching from east to west across the state at present, although the GARP suitability band extends farther to the north than that of MaxEnt. Both models predict a severe retraction of suitability due to climate change in southern and central Iowa, with only small patches of suitable environments persisting in eastern and northeastern Iowa in 2050. However, the models disagree in the 2090 projections, with GARP projecting high climatic suitability statewide and MaxEnt indicating zero suitability in all but a single persistent area in the northwest along the Big Sioux River drainage (Figure 1). Projections indicate minimal suitability for both of the more extreme scenarios (Figures S-1 and S-2).

Regarding potential invisibility in Iowa, it is unlikely that, , given the long stretches of unsuitable rivers between its current distribution and the Big Sioux, Round gobies could disperse to the Big Sioux on their own. However, the species may indeed thrive in the event of artificial introduction.

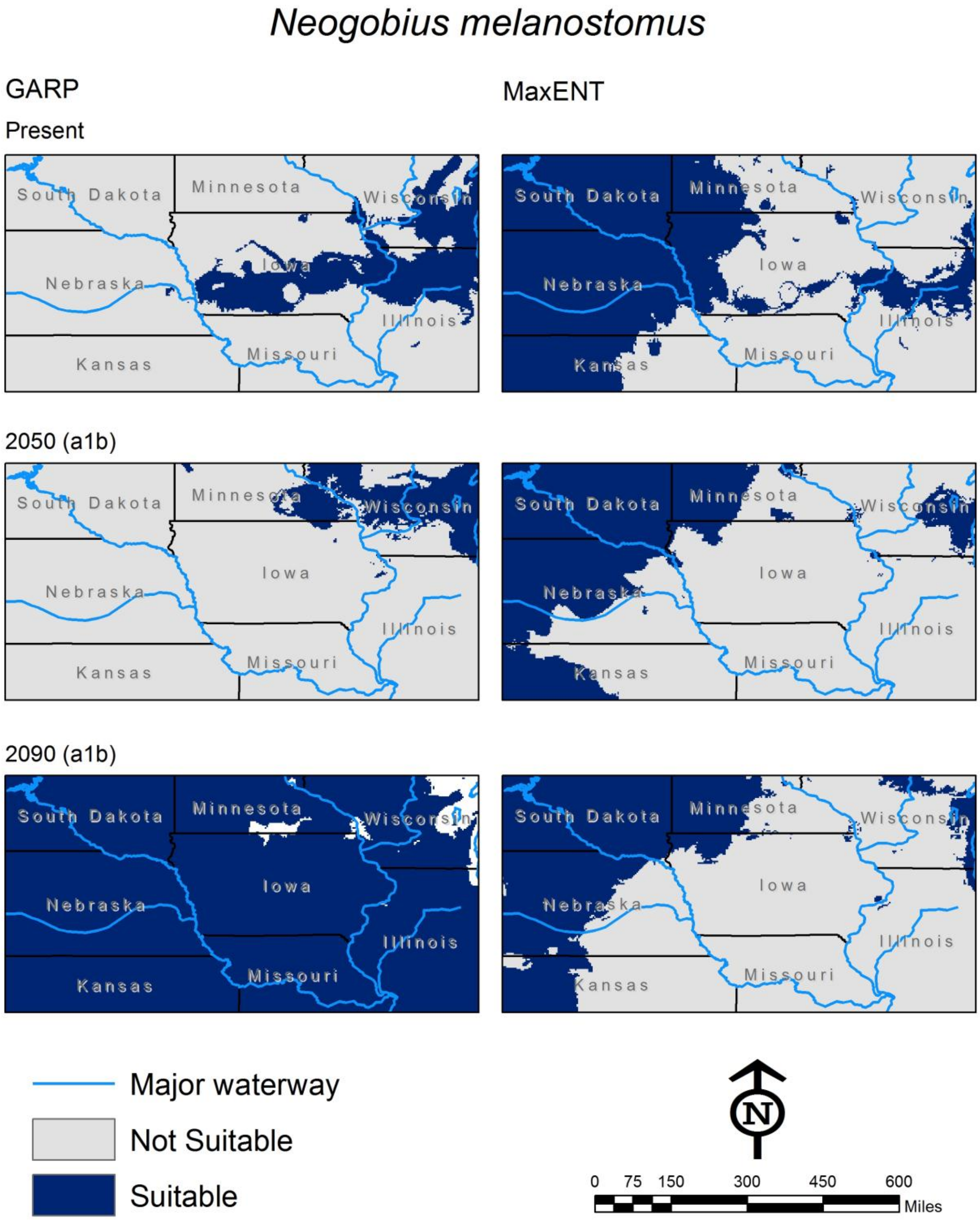


Figure 1. MaxEnt and GARP climatic suitability projections for the Round goby (*Neogobius melanostomus*) in Iowa for the present and the BCCR model scenario A1B in the years 2050 and 2090.

4.2 NEW ZEALAND MUDNSAIL (*Potamopyrgus antipodarum*)

The New Zealand mudsnail (*Potamopyrgus antipodarum*) is an aquatic snail originally native to the lakes and rivers of New Zealand and the proximal islands. A small species, it reaches a maximum size of 6-7mm and has a generation time ranging from 6 months to 6 years. Mudsnails occur in sexually reproductive and parthenogenic (clonal) varieties, both of which reproduce to high densities, with each snail capable of producing upwards of 230 offspring annually (Alonso and Castro-Diez 2008).

The New Zealand mudsnail has dispersed well beyond the reaches of it native range and is presently found in Tasmania, southeastern Australia, much of the western United States, and Japan (Alonso and Castro-Diez 2008). More recently, it has been documented in Lake Ontario, Lake Erie, and Lake Superior (Benson and Kipp 2011). The species has a very flexible niche preference resulting from high phenotypic plasticity (Dybdahl and Kane 2005). Prior studies indicate it to be a species of ecological concern owing to its tendency to reproduce to very high densities. Because of high production rates, it has been shown to possess significant competitive impact on native snail species in the United States (Hall, Dybdahl et al. 2006).

Geo-referenced presence data were obtained through GBIF (www.gbif.org) and cleaned for duplicates and errors beyond land-masses or in deserts. After appropriate curation, 511 points were used for model training and 125 reserved for model testing using partial-ROC analysis. The training region for the models was generated using a 3-degree buffer around the presence points in Australia, Tasmania, and New Zealand, producing a contiguous native range, connecting all points on each island respectively. Outputs obtained from the models were thresholded to the minimum 10th percentile training point to account for errors in the accuracy of the occurrence data. Pixels that had suitability values above this threshold were coded as a potential presence; otherwise they were coded as absence.

Across all models, the New Zealand mudsnail appears to have zero to limited invasive potential for Iowa or the surrounding regions (Figures 2, S-3, S-4). This trend was conserved across modeling algorithms and climate change scenarios. Each model showed statistically significant predictions of reserved presence points in the native range (MaxEnt and GARP, $p<0.01$). Despite the models being predictive of points within the native range, the models fail to capture points of known occurrence within the projection region. No region in Minnesota nor Illinois was predicted suitable, despite validated occurrences in both states (Benson and Kipp 2011). It is likely that the under-prediction of both modeling algorithms is being promoted by the high phenotypic plasticity of the species.

Even in environments outside of native range parameters, the New Zealand mudsnail invades easily. Ideally, the availability of better presence data within the United States would lend to a more informative models for Iowa and the surrounding states. However, until such data is available to improve modeling outputs, a proactive and vigilant approach is recommended when considering the invasive potential of the New Zealand mudsnail in Iowa.

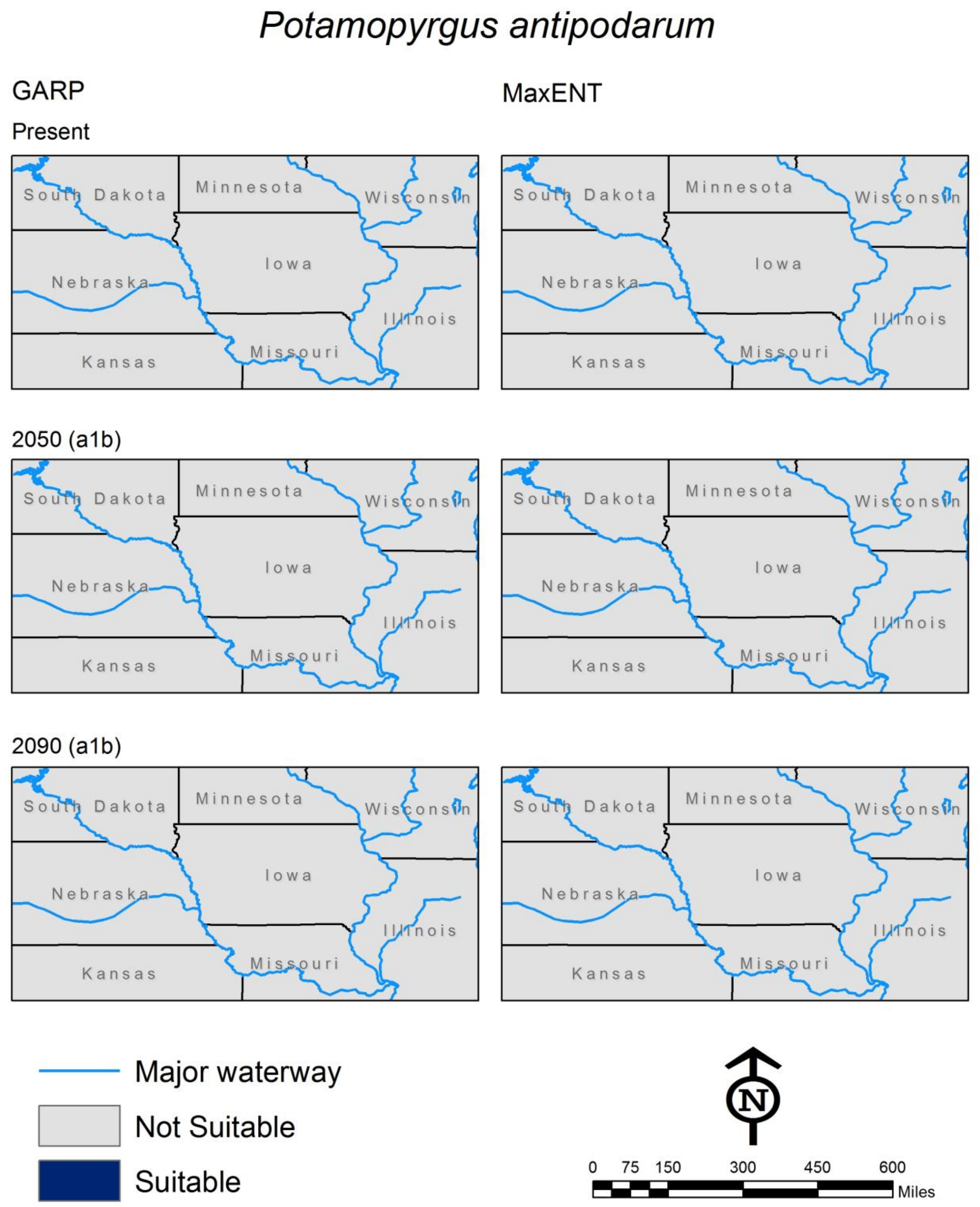


Figure 2. MaxEnt and GARP climatic suitability projections for the New Zealand mudsnail (*Potamopyrgus antipodarum*) in Iowa for the present and the BCCR model scenario A1B in the years 2050 and 2090.

4.3 RED SWAMP CRAYFISH (*Procambarus clarkia*, Girard 1852)

The Red swamp crayfish (*Procambarus clarkii*, Girard 1852) was selected for invasion risk assessment in Iowa due to its history of colonization in non-native regions. Described by Barbaresi and Gherardi (2000) as "a large, prolific, aggressive species", the Red swamp crayfish is a freshwater decapod native to the south central United States and northern Mexico. Throughout the 1900s, the species was purposefully introduced to numerous states throughout the southeastern US and other countries for aquacultural endeavors. Escape of individuals from rearing enclosures were common and, in some regions (e.g., Spain), local farmers and fishermen purposefully assisted the dispersal of the species into local waterways. The species is now fully established on all continents excepting only Australia and Antarctica (Gherardi et al. 2000, Aquiloni et al. 2005).

The successful colonization of non-native habitats by *P. clarkii* is largely a result of the species' physiology and behavior. *P. clarkii* has a "R" reproductive strategy, including rapid growth, early maturation, and high fecundity (Barbaresi and Gherardi 2002, Correia 2002, Hernandez et al 2007). Other dominant factors enhancing the species invasive potential include their omnivorous feeding strategy –Red crayfish are known to consume detritus, plants, and animal products such as aquatic macro-invertebrates and amphibian eggs (Correia 2002, Hernandez et al. 2007)– a general disease resistance, and a documented active dispersal behavior with cyclical periods of high activity interspersed with sedentary periods. Despite being classified as a freshwater species, Red crayfish are capable of tolerating slightly saline water, waters with low concentrations of dissolved oxygen, periods of draught, and a broad range of water temperatures. They have been found in habitats ranging from natural waterways and streams to intermittent streams, irrigation ditches, agricultural areas and ephemeral water bodies (Barbaresi and Gherardi 2000, Correia 2002, Hernandez et al. 2007). Though considered an extensive burrower (and known for destroying rice crops and the vegetative communities of invaded region due to burrowing), a small scale study of invasive *P. clarkii* in Portugal (Aquiloni et al. 2005) found that an inability to burrow (due to lack of appropriate substrate) did not prohibit invasion potential. Crayfish instead utilized complex microhabitats and could be found hiding beneath rocks and within/underneath dense aquatic and shoreline vegetation (Gherardi et al. 2000).

In modeling the Red swamp crayfish for its invasive potential in Iowa, the most robust datasets were those from invasive populations in Europe. Presuming that use of the invaded regions provides a greater characterization of the species niche, this dataset was utilized. After performing the quality control measures as outline in the methodology, 100 unique locality points were available for training. Data points were buffered with a 2 degree buffer and run with the standardized projection parameters for both the GARP and MaxEnt algorithms.

The two algorithms yielded vastly different projections of suitability. GARP, which consistently performed better than random, indicated increasing areas of suitability across Iowa for all three model scenarios with the progression of time. MaxEnt projections appeared to underfit the model, indicating little to no suitable regions within Iowa for even the most extreme scenarios and performing with a reliability approximately equivalent to random (Figure 3, S-5, S-6, Table 1). In regards to Iowa, considering the invasion history of the species, it is strongly recommended that natural resource planners pay considerable attention to the invasive potential indicated by the GARP models as these in combination with background knowledge of the species' natural history and prior colonization success across five continents appear an acceptable projection of *P. clarkii's* potential invasiveness within the state.

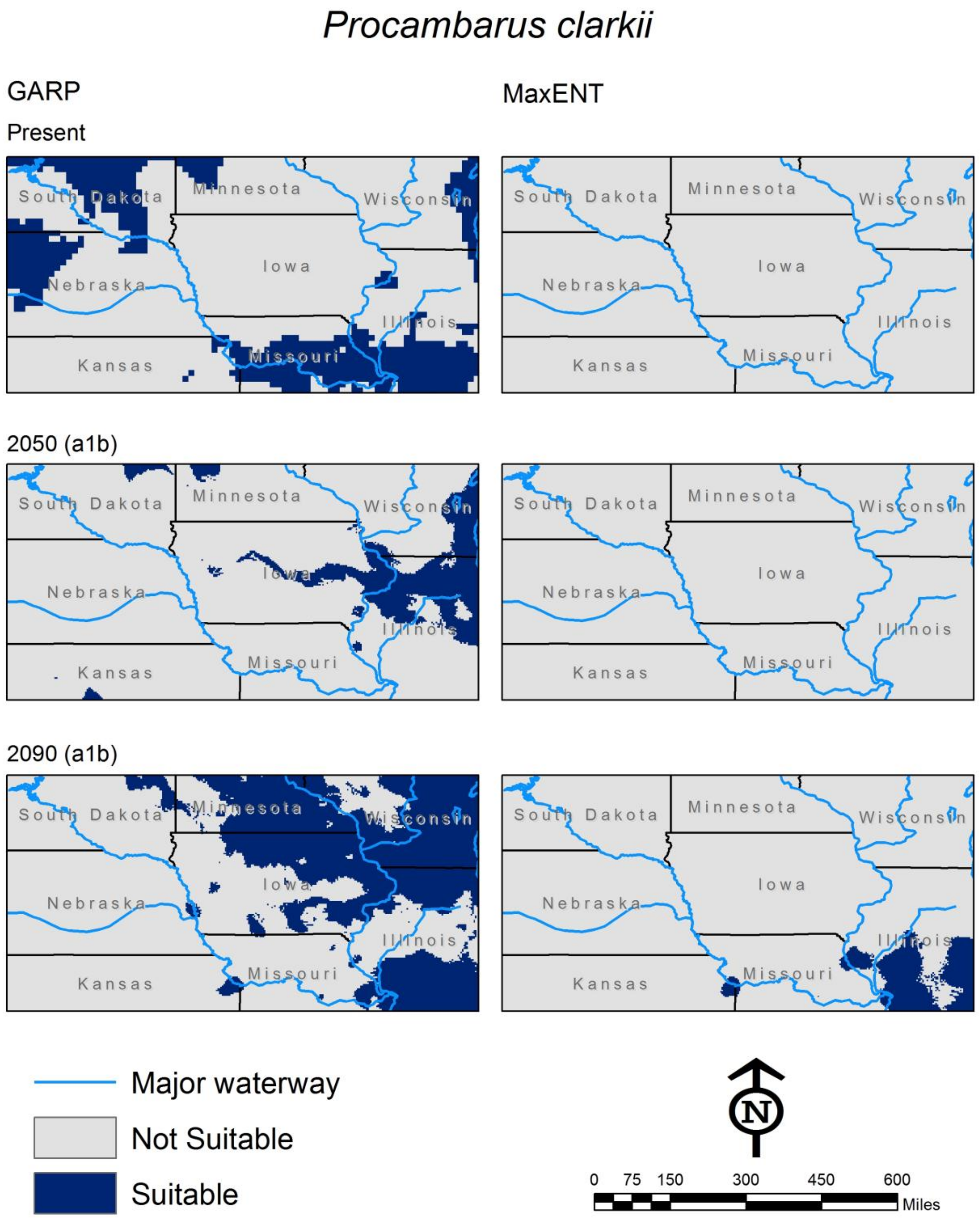


Figure 3. MaxEnt and GARP climatic suitability projections for the Red swamp crayfish (*Procambarus clarkii*) in Iowa for the present and the BCCR model scenario A1B in the years 2050 and 2090.

4.4 **ASIAN ROCK POOL MOSQUITO (*Aedes japonicus japonicus*)**

The Asian rock pool mosquito (*Aedes japonicus*), native to Japan and Korea, is a known carrier of several diseases, most notably West Nile Virus and La Crosse virus. Detected initially in the states of Connecticut, New York, and New Jersey in 1998, the species has since expanded its range to include 27 states including: Illinois (Morris et al. 2007), Wisconsin (Hughes et al. 2008), Minnesota (Neitzel et al. 2009), Iowa (Dunphy et al. 2009), the Pacific Northwest (Irish and Pierce 2008) and Hawaii (Larish and Savage 2005) (see Table 1 in Morris et al. 2007 for a chronological history of *A. japonicus* in North America). According to Dunphy et al. (2009), the Asian rock pool mosquito is a forest dweller. In its native habitat, larvae have been reported in human-fabricated stone and earthenware containers, in holes in bamboo stumps, and in streamside rock pools. In its invaded habitat in North America, larvae have been found in natural tree-holes, streamside rock pools, tires, and other artificial containers. Known blood hosts include birds and mammals primarily (see references in Dunphy et al. 2009).

Available datasets for the Asian rock pool mosquito were limited. A total of 23 unique occurrences were downloaded from the Mosquito Map data portal (http://www.mosquitomap.org/) after removing environmentally redundant data to a resolution of 2.5 minutes using ENMTools (http://enmtools.blogspot.com/). This was the only locality data available to the research team at the time model analysis, and corresponds to a very limited subsection of the species known invaded range (Washington and Illinois).

During a study conducted in 2007-2008, Dunphy et al. (2009) reported the presence of the Asian rock pool mosquito in 12 counties across the state of Iowa. The species was positively identified in Allamakee, Black Hawk, Clark, Dubuque, Johnson, Lucas, Linn, Polk, Scott, Story, Webster, and Winneshiek counties; voucher specimen are housed at the Iowa State Insect Collection (Iowa State University [ISU], Ames, IA). These occupied regions were accurately predicted as suitable during the modeling exercise by both algorithms indicating that despite the low number of locality data available, model training was adequate. While both GARP and MaxEnt accurately project current distributions of the species (MaxEnt indicates a band of suitability across the entire southern portion of the state), for future scenarios, the projections are incongruent. GARP projects no further advancement of suitable environment, even in most extreme scenarios, whereas MaxEnt suggests a continued expansion of suitable climatic environment eventually covering almost the full area of the projection region (Figures 4, S-7, S-8). Considering the current documented presence of the species within the eastern portions of the state, and the rapid expansion of distribution since its intro to the US, further spread of the Asian rock pool mosquito within the state of Iowa is likely.

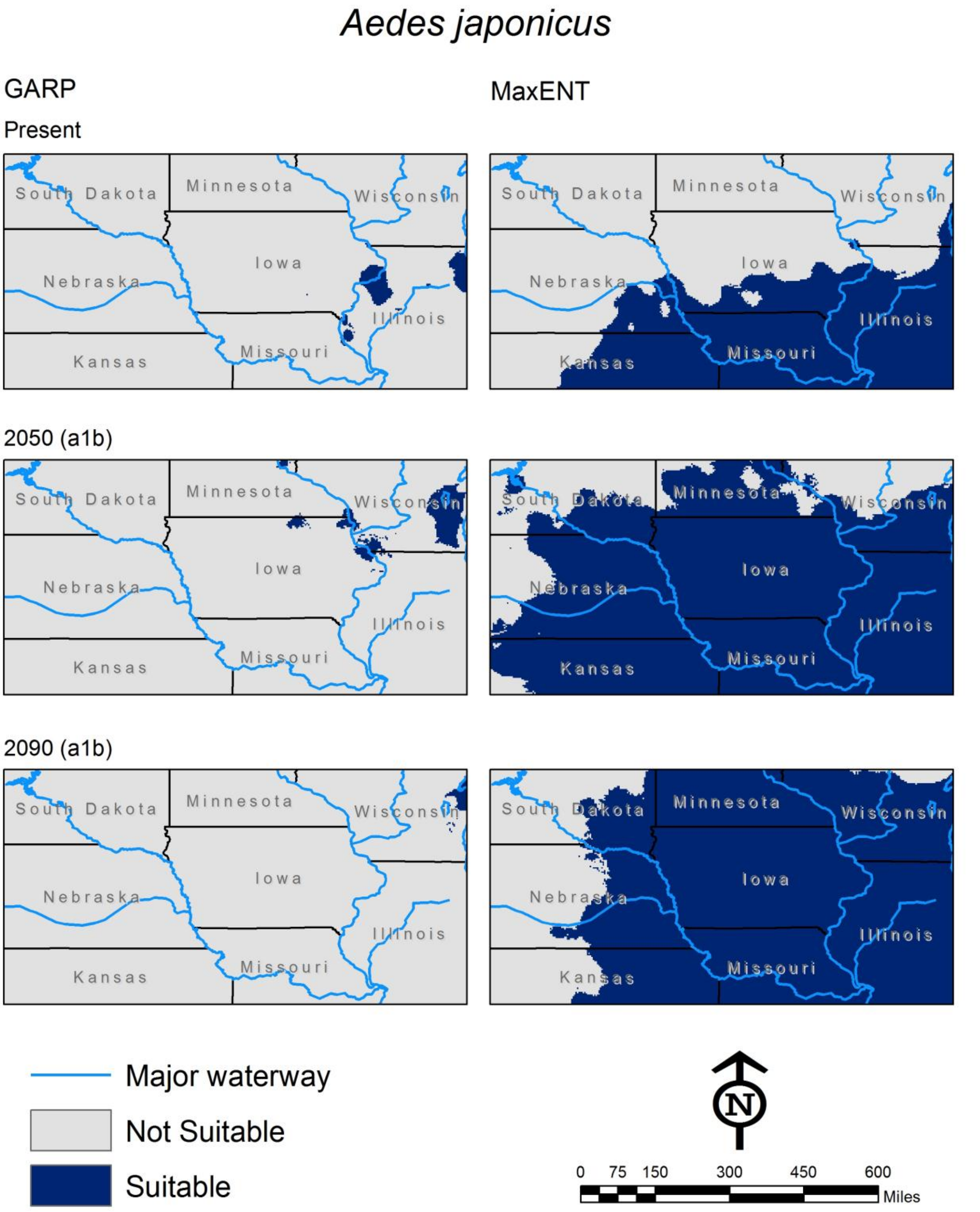


Figure 4. MaxEnt and GARP climatic suitability projections for the Asian rock pool mosquito (*Aedes japonicus*) in Iowa for the present and the BCCR model scenario A1B in the years 2050 and 2090.

4.5 PARROT-FEATHER (*Myriophyllum aquaticum*)

Parrot-feather (*Myriophyllum aquaticum*) is a perennial freshwater herb native to Argentina, Bolivia, Brazil, Chile, Ecuador, Paraguay and Peru. Capable of growing both as a submerged or an emergent plant, it is well adapted to high nutrient water bodies and can be commonly found in freshwater lakes, ponds, slow streams and canals. Parrot-feather tends to go dormant during the winter season, drying up into rhizomes which assist in regeneration the following summer; rhizomes do not store carbon or phosphorus and are thus incapable of surviving extreme winter conditions (Wersal, et al. 2011).

Popular worldwide as an ornamental and for use in aquariums, Parrot-feather has been dispersed largely via anthropogenic influence and presently has established populations in North America, Africa, Asia, Europe and Australia (GISD 2005). The species was introduced to the United States (New Jersey) in the late 1800s (Nelson and Couch, 1985) and, since that time, has rapidly expanded across the country (Sutton, 1985). Parrot-feather is currently found throughout the east coast, the south-east and south-west, the Pacific northwest, California, Texas, Okalahoma, Kansas, Missouri, and Hawaii. Parrot-feather is a bisexual species and all invasive populations are inherently female; further, new plants propagate quickly from cuttings.

Parrot-feather occurrence data were compiled from the Global Biodiversity Information Facility database (www.gbif.org) and speciesLink (http://splink.cria.org.br/). A total of 35 unique occurrence points within the native range were available for use in modeling analyses post curation – 28 points utilized in model training and 7 points reserved for partial-ROC analyses. The training area was masked by overlaying the occurrence points on the physical map of South America and using a 1 degree buffer.

Partial-ROC analyses of the model training indicate model performance to be significantly better than random, however the two algorithms, GARP and MaxENT, show little congruence in modeling results. GARP predicted zero to minimal climatic suitability for Parrot-feather within Iowa for all modeling scenarios. MaxEnt projections portray the opposite, indicating eventual climatic suitability across nearly the entire state of Iowa for all modeling scenarios, excepting the upper north-western region and a few patches in the north-central region (Figures 5, S-9, S-10). It is likely that inconsistencies in model projections are due to the use of a limited dataset. As Parrot-feather populations are currently found in the nearby states of Missouri and Kansas, invasion potential is possible if anthropogenic influences are not controlled and alterations in future climate continue to include milder winters that Parrot-feather rhizomes may survive.

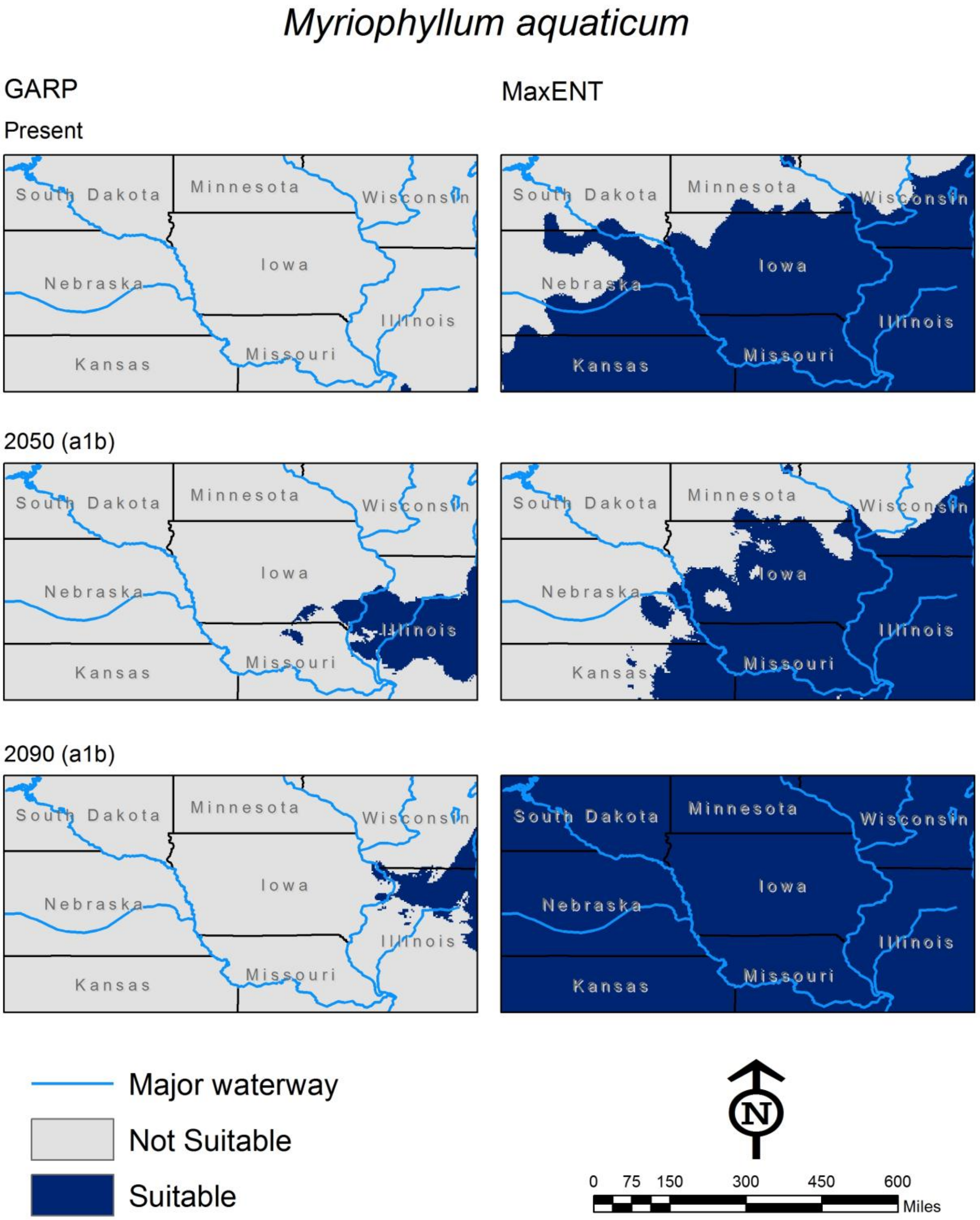


Figure 5. MaxEnt and GARP climatic suitability projections for parrot-feather (*Myriophyllum aquaticum*) in Iowa for the present and the BCCR model scenario A1B in the years 2050 and 2090.

4.6 CHINESE BUSHCLOVER (*Lespedeza cuneata*)

Lespedeza cuneata, commonly known as Chinese bushclover, is an aggressive perennial shrub that thrives in disturbed habitats such as roadsides, pastures and grasslands, cultivated lands, and fallows. It also capable of tolerating a wide array of climatic and environmental conditions including draught and freezing temperatures as well as infertile and neutral to strongly acidic soils (Stevens 2002, GISD 2005). Chinese bushclover can grow to a height of two meters with roots stretching more than a meter; seeds are dispersed via vertebrate herbivores or during haying (Remaley 1998). A single plant may form a large stand, surviving up to 20 years.

Native to Korea, China, Taiwan, India, Japan and Australia, Chinese bushclover has succeeded in establishing populations in North America, Brazil and South Africa. Introduced to the southeastern United States in the 1800s as a means of erosion control, the species has become an invasive weed in rangelands and grasslands across the east and midwestern United States. Though not presently documented in Iowa, Chinese bushclover has a presence in the adjacent states of Missouri, Illinois, and Wisconsin.

Occurrence data for Chinese bushclover were compiled from Global Biodiversity Information Facility database (www.gbif.org). After curation following the protocol outlined, 69 data points were reserved for testing and the remaining 278 used in model training.

The results yielded by GARP and MaxEnt were inconsistent. Neither model projected current distributions in the current climate (Missouri, Illinois, and Wisconsin). GARP indicated zero to limited for all scenarios. MaxEnt projected zero suitability in the projection region for both the current climate and for 2090 but considered the northern half of the state as climatically suitable in 2050 (Figure 6); projections for the A2 scenario were similar, however, the B1 scenario indicated a band of suitability across the central and western portion of the state for 2050 and then for the entire northern half of the state in 2090 (Figures S-11 and S-12). It is likely that the indecisiveness of the models is due to the species high adaptability and preference for disturbed habitats.

Despite the incongruence of the model outputs, the chances of Chinese bushclover surviving the changing climatic conditions given an opportunity for introduction are high as the species is known to adapt to a wide variety of climatic and environmental extremes and thrives well in disturbed areas such as agricultural lands. Pathways of invasion may include intentional introduction or accidental introduction through wild herbivores or the transport of domestic livestock. It is recommended that Iowa environmental planners approach the species with a proactive view.

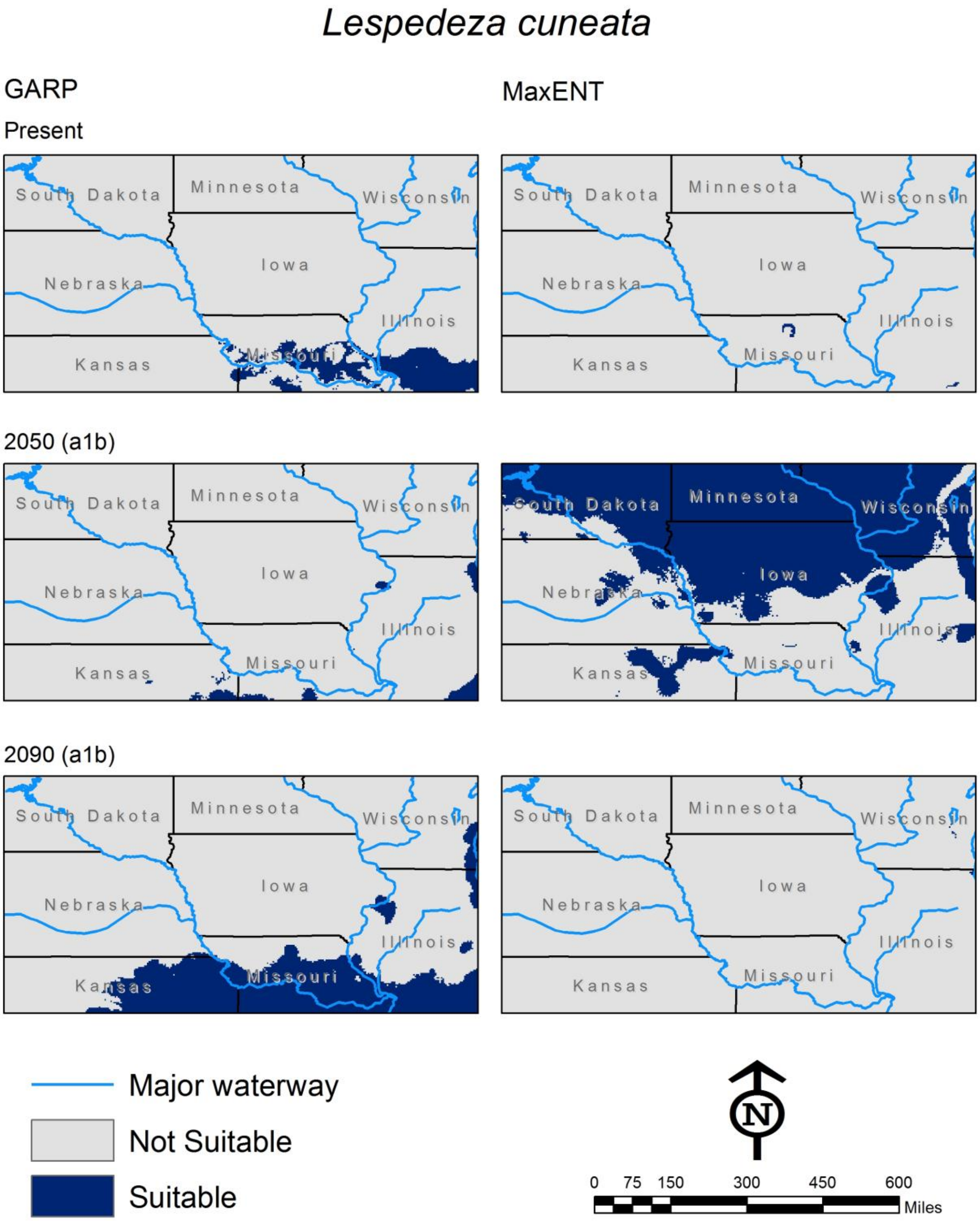


Figure 6. MaxEnt and GARP climatic suitability projections for Chinese bushclover (*Lespedeza cuneata*) in Iowa for the present and the BCCR model scenario A1B in the years 2050 and 2090.

5. PARTIAL-ROC

Partial-ROC analyses assessing the significance of the models were conducted. These analyses, which test the quality of the model within the training region not the projection area, were conducted each GARP and MaxEnt model across all six species. Almost all models performed better than random, with P-values well below 0.05. A single model tested no better than random: MaxEnt model for the Red swamp crayfish (*P. clarkii*)(Table 1).

Species	GARP	Maxent
Round Goby, *Neogobius melanostomus*	$p < 0.01$	$p < 0.01$
New Zealand Mudsnail, *Potomapyrgus antipodarum*	$p < 0.01$	$p < 0.01$
Red Swamp Crayfish, *Procambarus clarkii*	$p < 0.01$	$P = 1$
Asian Rock Pool Mosquito, *Aedes japonicus*	$p < 0.01$	$p < 0.01$
Chinese Bushclover, *Lespedeza cuneata*	$p < 0.01$	$p < 0.01$
Parrot-feather, *Myriophyllum aquaticum*	$p < 0.01$	$p < 0.01$

Table 1. P-values corresponding to each species for the modeling algorithm utilized. P-values were calculated from a z-test of bootstrapped values where x=1.

6. MESS ANALYSIS

The Euclidean distance in multidimensional space was calculated for the current and future (2090) climatic combinations within Iowa with respect to the rest of the world. First, the principal components were calculated with a correlation matrix using the suit of 19 bioclimatic variables (Hijmans et al. 2005) for current climate conditions and the 2090 A2 climatic scenario of the institution BCCR. This environmental distance was then used to calculate the similarity of the environmental conditions within Iowa with the rest of the world. Because of the large amount of computational resources that are required to calculate this measure, 10% of the points within the world domain (n = 225595) and 50% from the Iowa region (n = 1,475) were selected at random, specifying 50% of the average value closest to the Iowa projection region. This measure should be used to ascertain regions that share the greatest climatic similarity to Iowa and may therefore represent potential sources of invasive species (Figure 7 and 8).

The results of this analysis show that there are large extensions of the world that are similar to Iowa in both the present and future climatic projection scenarios. Regions of similarity include the vast majority of the United States and Canada, most of northeast Argentina, much of Eurasia, southeast South Africa, and southeast Australia. In contrast, very dissimilar regions of the world with respect to Iowa are the north of Canada and Greenland, Central America and the northern extent of South America, central Africa, India and South East Asia, and northeast Siberia.

Figure 7

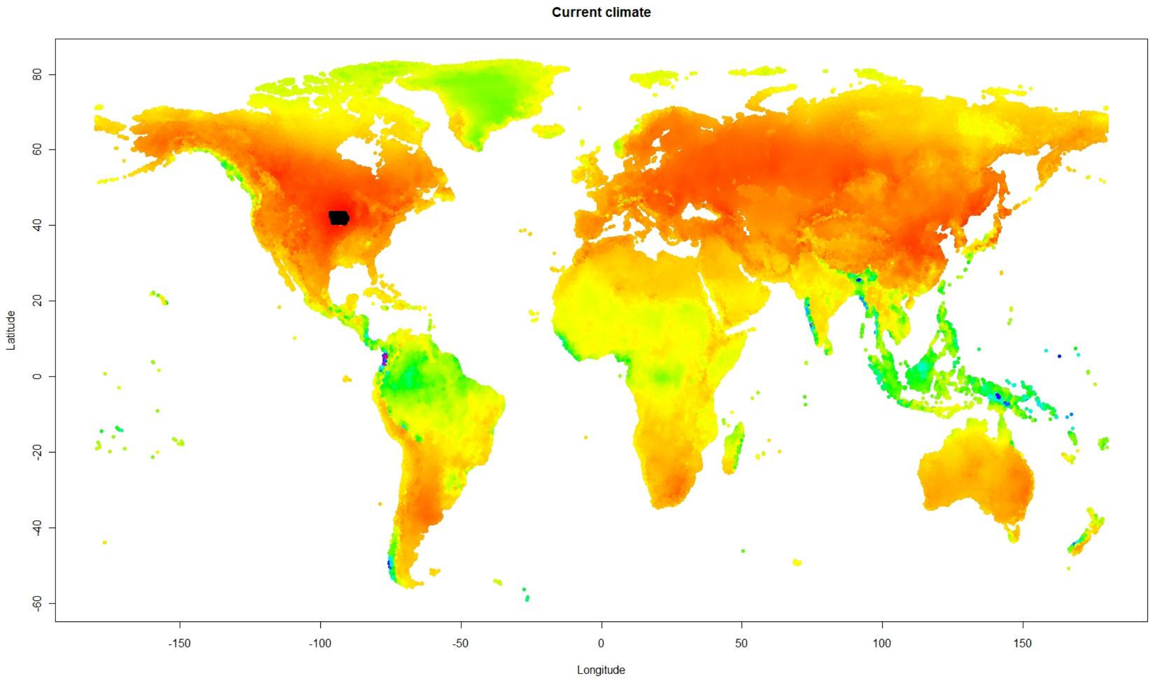
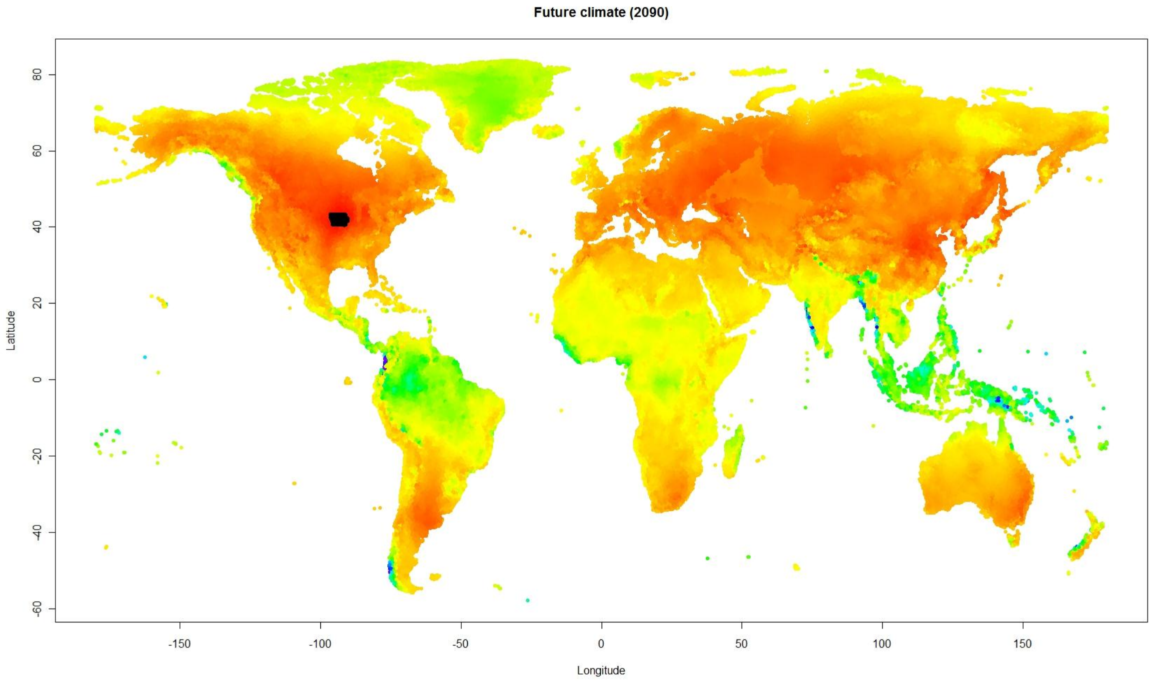


Figure 8



Figures 7 and 8. Climatic similarity of Iowa with respect to the world. Regions of similarity are represented using a standard thermal gradient: red denotes regions of higher similarity, yellow indicates medium similarity, and green and blue low similarity.

7. CONCLUSIONS

Ecological niche models are an effective tool for assessing environmental similarity between regions, providing a single dimension of invasion potential. As discussed by Peterson et al., we must also possess an understanding of other factors including colonization opportunity, details of demographics, and dispersal ability of target species (2003). The ENM working group at the University of Kansas assessed invasion potential for six species using basic parameterization of two of the most common ENM algorithms, GARP and MaxEnt. These algorithms identify regions of environmental similarity to current known distributions.

ENM projections are based on the training of models to an environmental region using known occurrence (presence) data. The robustness of data sets is pivotal to model training and the use of small presence numbers, or data that do not fully encompass a species' climatic tolerances, may lead to over- or under- fitting of the models or to inaccurate projections of potentially suitable regions. Two species modeled in this analysis which reflect the issues associated with running the GARP and MaxEnt algorithms on limited data sets are the Asian rock pool mosquito and Parrot-feather. While reported occurrences for both species in their invaded regions are high, available specific locality data are limited thus models were trained and tested with a small amount of occurrence data unlikely to allow the algorithms to correlate presence with environment. Though model training tested statistically significant, model outputs were incongruent and thus, interpretations of projections required caution.

Further consideration in the development of any ecological niche modeling exercise is the assignment of the training region (Barve et al. 2011). The size and shape of the training region will determine the amount of environmental combinations that will be sampled by the algorithm. Additionally, previously invaded ranges may contain suitable environments outside of those available within the native range. In certain cases, the native range of a species contains insufficient data to conduct ENM analyses. The training regions for any invasive species may include more than one area (Jiménez-Valverde et al. 2011). For example, the training region of Parrot-feather was expanded to include a portion of the invaded range and training regions for both the Round goby and the Red swamp crayfish were conducted using only invaded region locality data. This was necessary because the species is known to be invasive in North America and its inclusion improved the model's predictivity over known distributions. A similar example was described by Beaumont et al. (2009).

The algorithms utilized (GARP and MaxEnt) are centered upon different probability distributions and yield independent and unique results (Stockwell et al. 1999, Phillips et al. 2006). Both GARP and MaxEnt proved somewhat inconsistent in model output, however, MaxEnt projections appeared to fluctuate more greatly than those provided by GARP. In the cases of the New Zealdand mudsnail and the Asian rock pool mosquito, MaxEnt over-predicted. Based upon the overall performance of both algorithms, the projections of GARP appear more reasonable because of consistency with *a priori* hypotheses of species distribution. Thusly the projections provided by GARP were accepted for analysis and became the basis for risk assessment (however, results from both algorithms were considered).

Species considered to have a high invasion risk are the Red swamp crayfish and the Asian rock-pool mosquito. Both species are considered to be high risk as they either (a) already have known occurrences within Iowa (Asian rock pool mosquito), or (b) through projected climatic suitability in Iowa in combination with other invasion variables (dispersal capability, colonization history, etc.) are an invasion concern sometime in the future. The New Zealand mudsnail and Chinese bushclover were considered to be of moderate-high risk. Model projections for both species were incongruent between algorithms, however, both are considered highly invasive in other regions, have distributions bordering or within the projection region (but not yet in Iowa), and are highly adaptable. The remaining species - Parrot-feather and Round goby - are considered of moderate. These species are known to possess the characteristics of successful colonizers of non-native ranges but will be limited by lack of environmental similarity or dispersal ability (Table 2).

Ecological niche modeling is largely an exercise in calculating environmental similarity. Considering this, environmental planning and legislation should not be based solely upon algorithm output, but should incorporate studies of each focal species' biology and natural history as well as significant efforts in ground truthing and field studies. Thus, model projections resulting from the risk assessment analyses summarized in this document should become a part of Iowa Department of Natural Resources' planning toolbox rather than the focal point of policy implementation.

Table 2. Assessment of invasion risk potential in Iowa for species modeled.

Species	Invasion Risk	Justification
Asian Rock Pool Mosquito (*Aedes japonicus)*	High	• Model projections accurately project areas of climatic suitability within Iowa where the species has already been positively identified • Successful colonizer of non-native regions, including portions of Iowa and adjacent states
Red Swamp Crayfish (*Procambarus clarkii*)	High	• GARP projections include large areas of climatic suitability within Iowa and adjacent regions • Successful colonizer on 5 continents in areas environmentally different from native range • Highly prolific with high rates of dispersal
New Zealand Mudsnail (*Potamopyrgus antipodarum*)	Moderate - High	• History of high invasion capability due to phenotypic plasticity • Generalist invader
Chinese Bushclover (*Lespedeza cuneata*)	Moderate - High	• Aggressive, hardy species; thrives in disturbed habitats and low quality soils. • Dispersed via wild/domesticated herbivores • Present in adjacent states
Round Goby (*Neogobius melanostomus*)	Moderate	• Models predict basins with established populations adjacent to Iowa • Future projections predict no suitability by 2050
Parrot-feather (*Myriophyllum aquaticum*)	Moderate	• Established populations present in nearby states • Dispersal via anthropogenic means (aquarium trade) • Hardy

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9. SUPPLEMENTAL MATERIAL

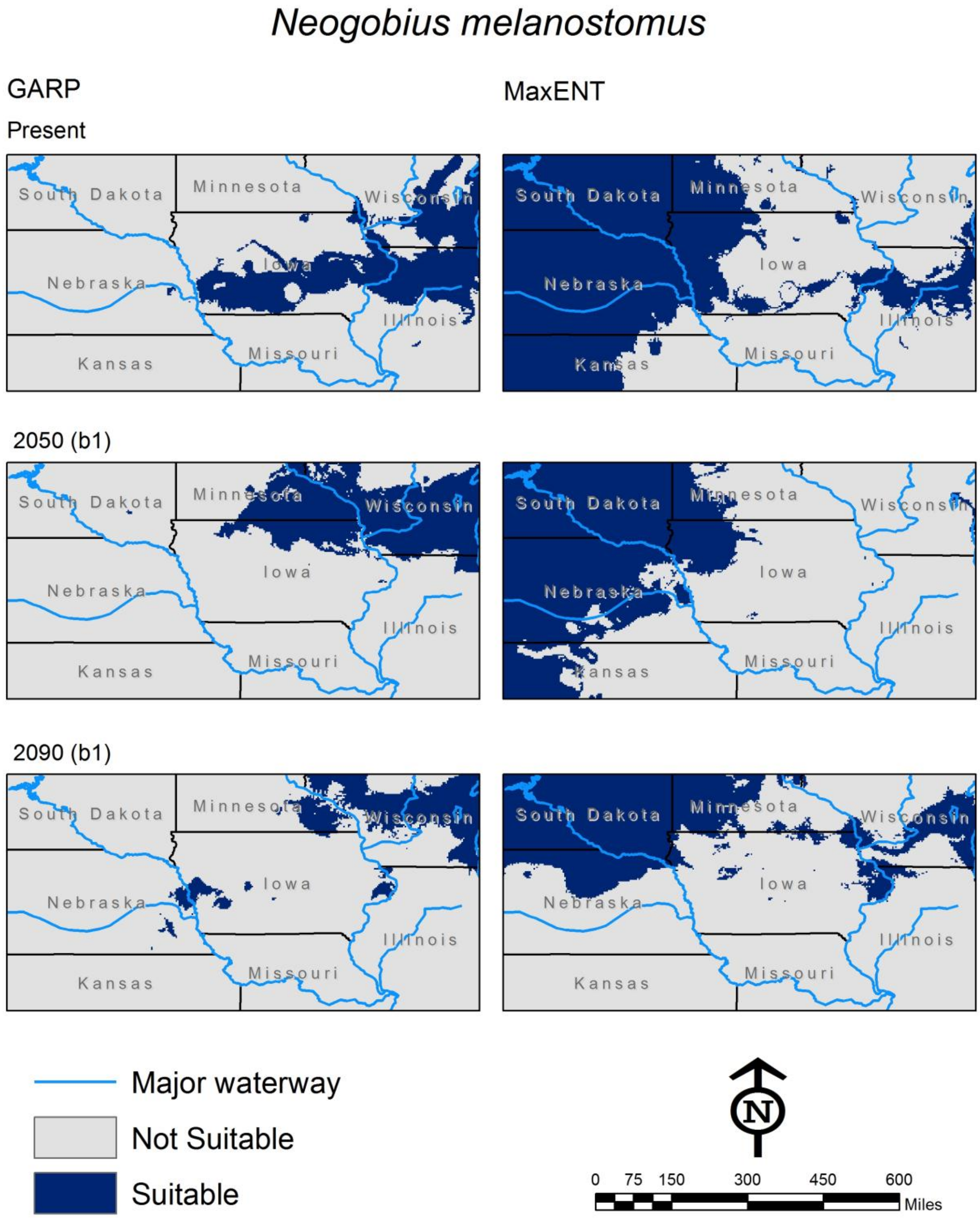

Figure S-1. MaxEnt and GARP climatic suitability projections for the Round goby (Neogobius *melanostomus*) in Iowa for the present and the BCCR model scenario A2 in the years 2050 and 2090.

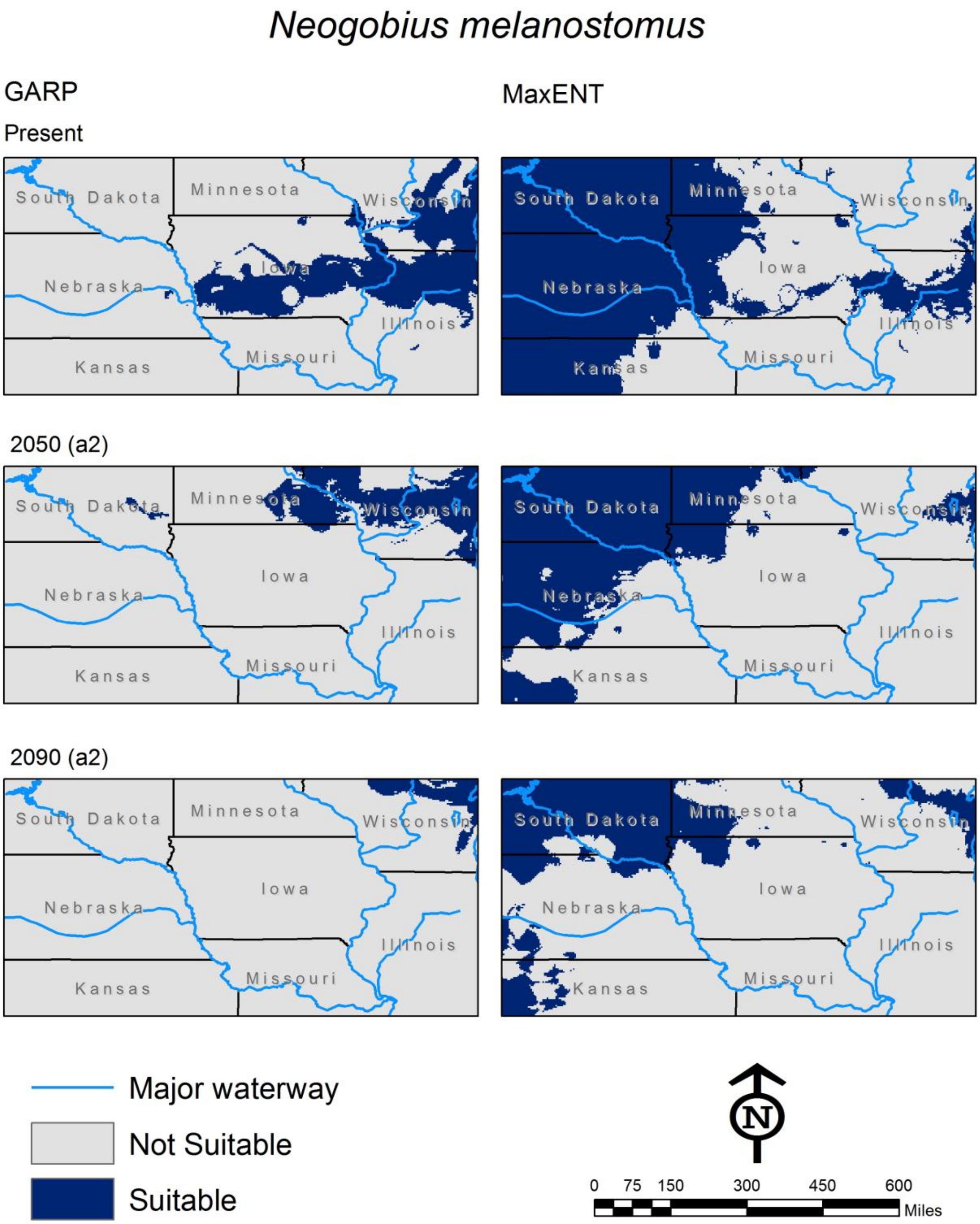

Figure S-2. MaxEnt and GARP climatic suitability projections for the Round goby (Neogobius *melanostomus*) in Iowa for the present and the BCCR model scenario B1 in the years 2050 and 2090.

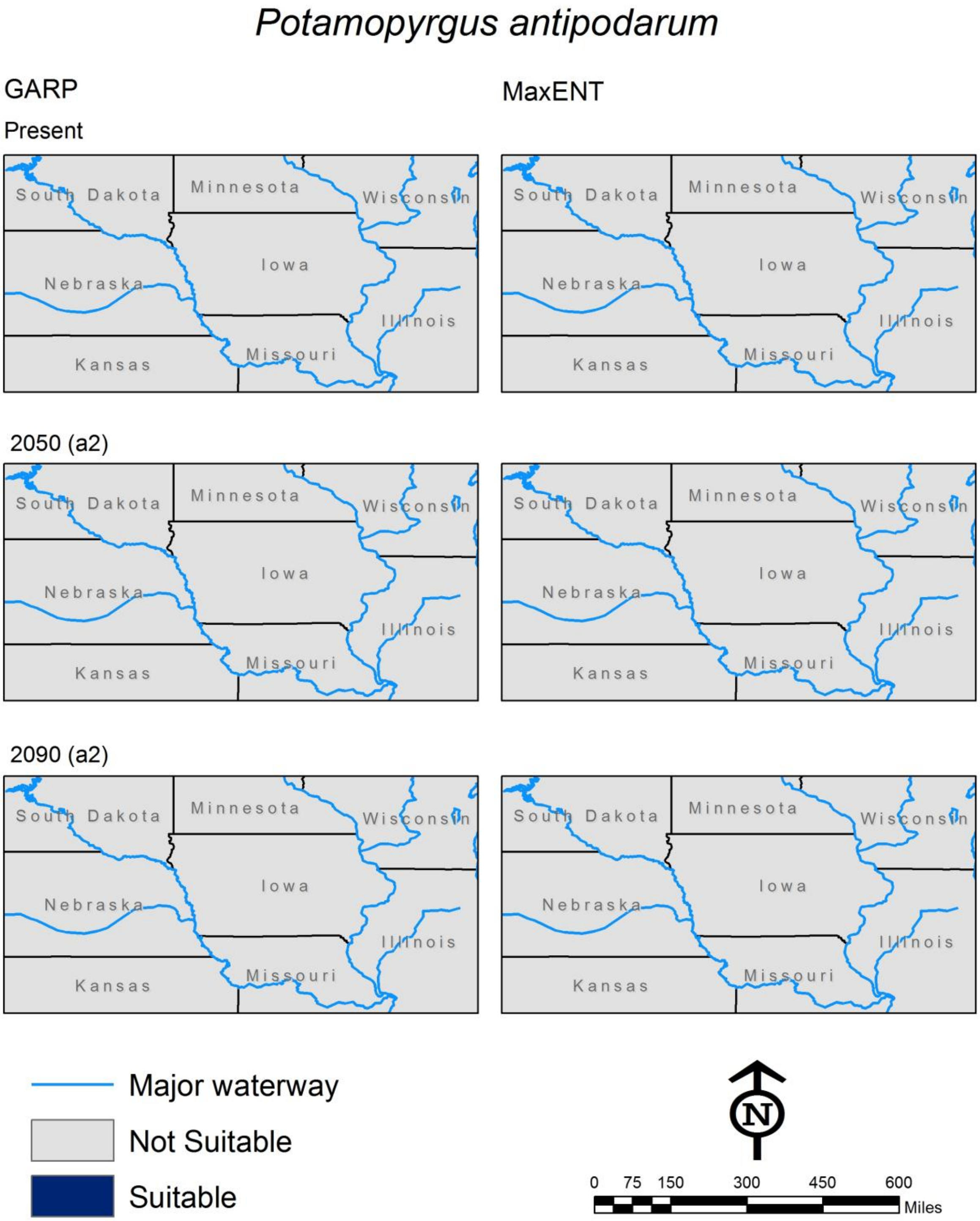

Figure S-3. MaxEnt and GARP climatic suitability projections for the New Zealand mudsnail (*Potamopyrgus antipodum*) in Iowa for the present and the BCCR model scenario A2 in the years 2050 and 2090.

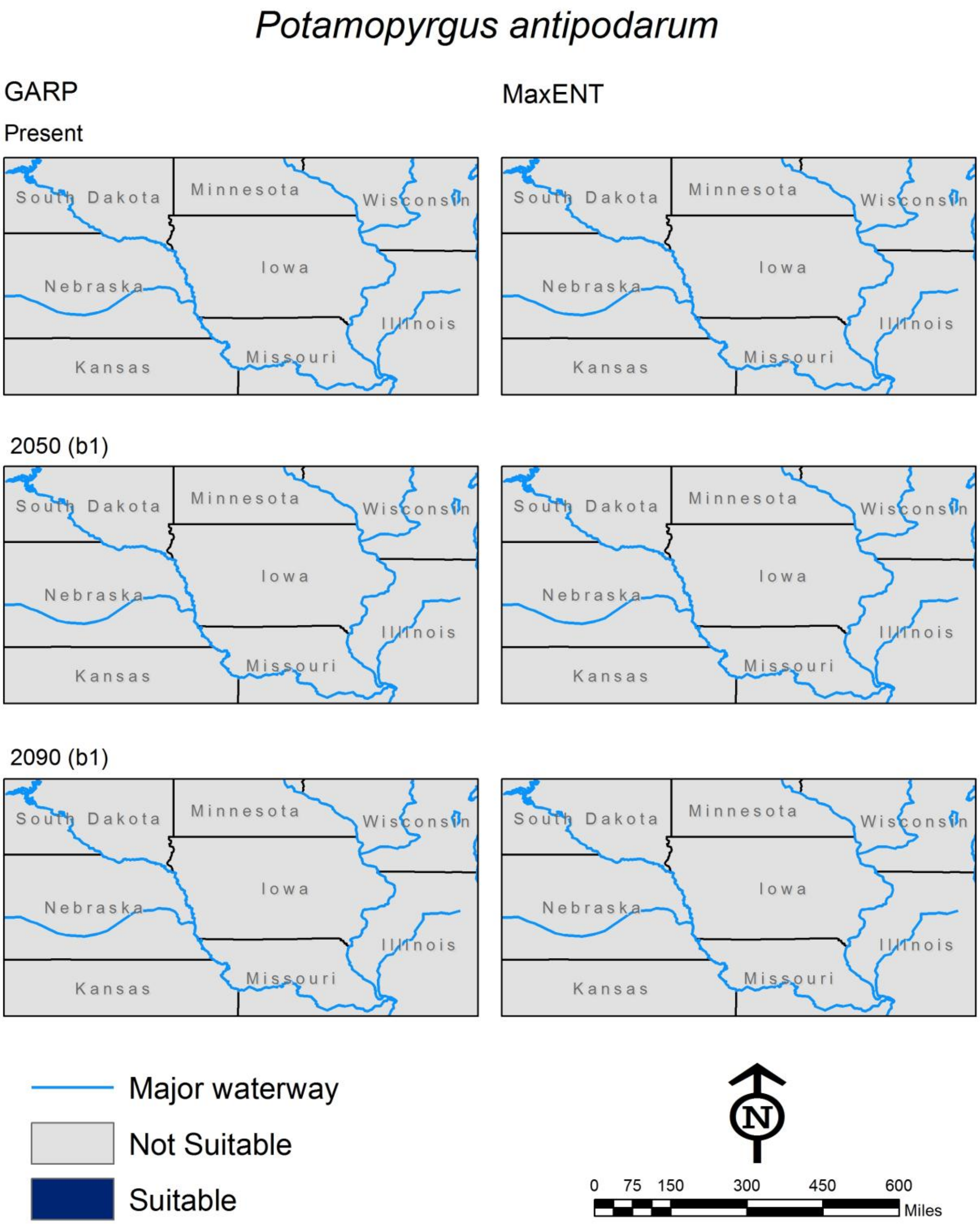

Figure S-4. MaxEnt and GARP climatic suitability projections for the New Zealand mudsnail (*Potamopyrgus antipodum*) in Iowa for the present and the BCCR model scenario B1 in the years 2050 and 2090.

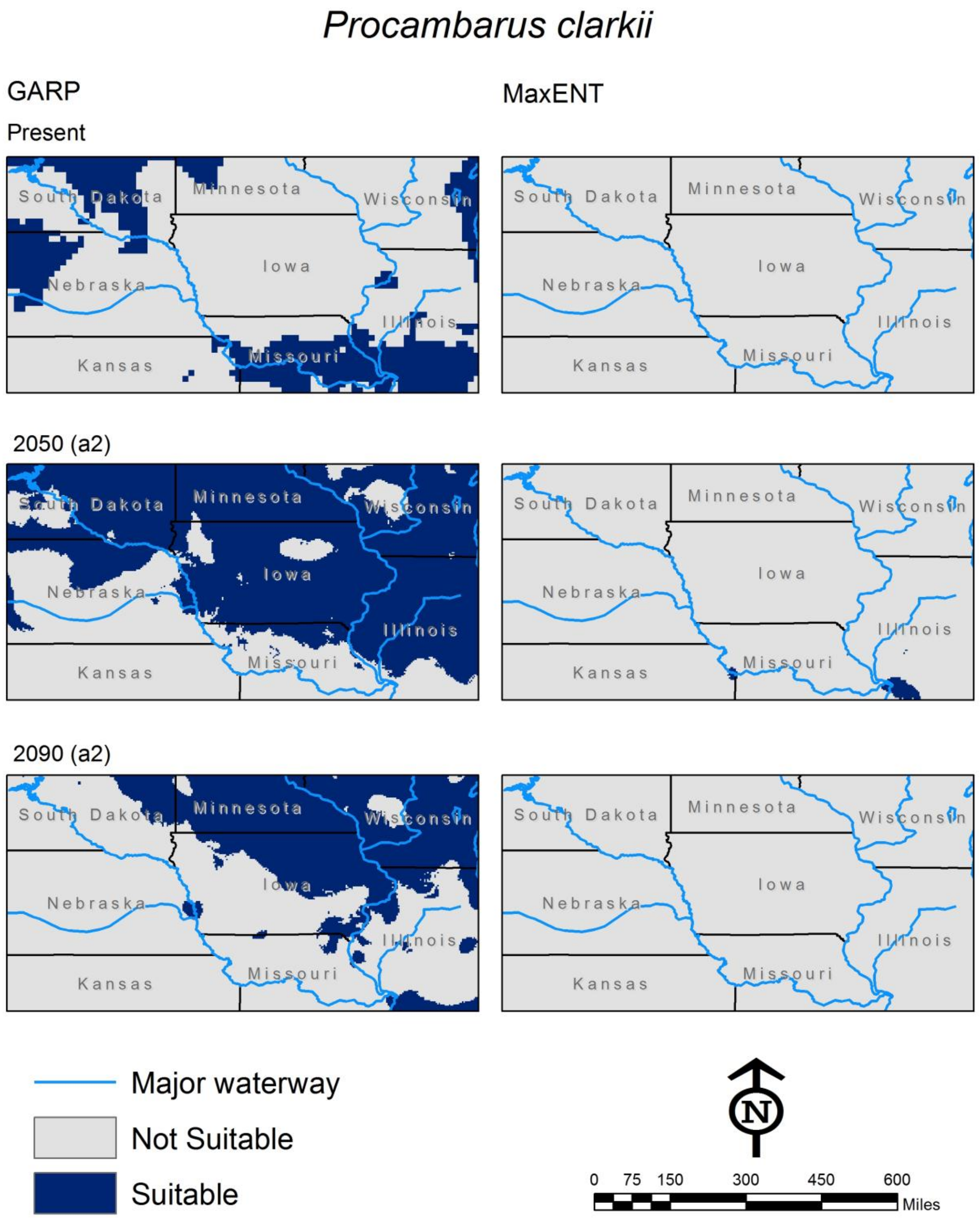

Figure S-5. MaxEnt and GARP climatic suitability projections for the Red swamp crayfish (*Procambarus clarkii*) in Iowa for the present and the BCCR model scenario A2 in the years 2050 and 2090.

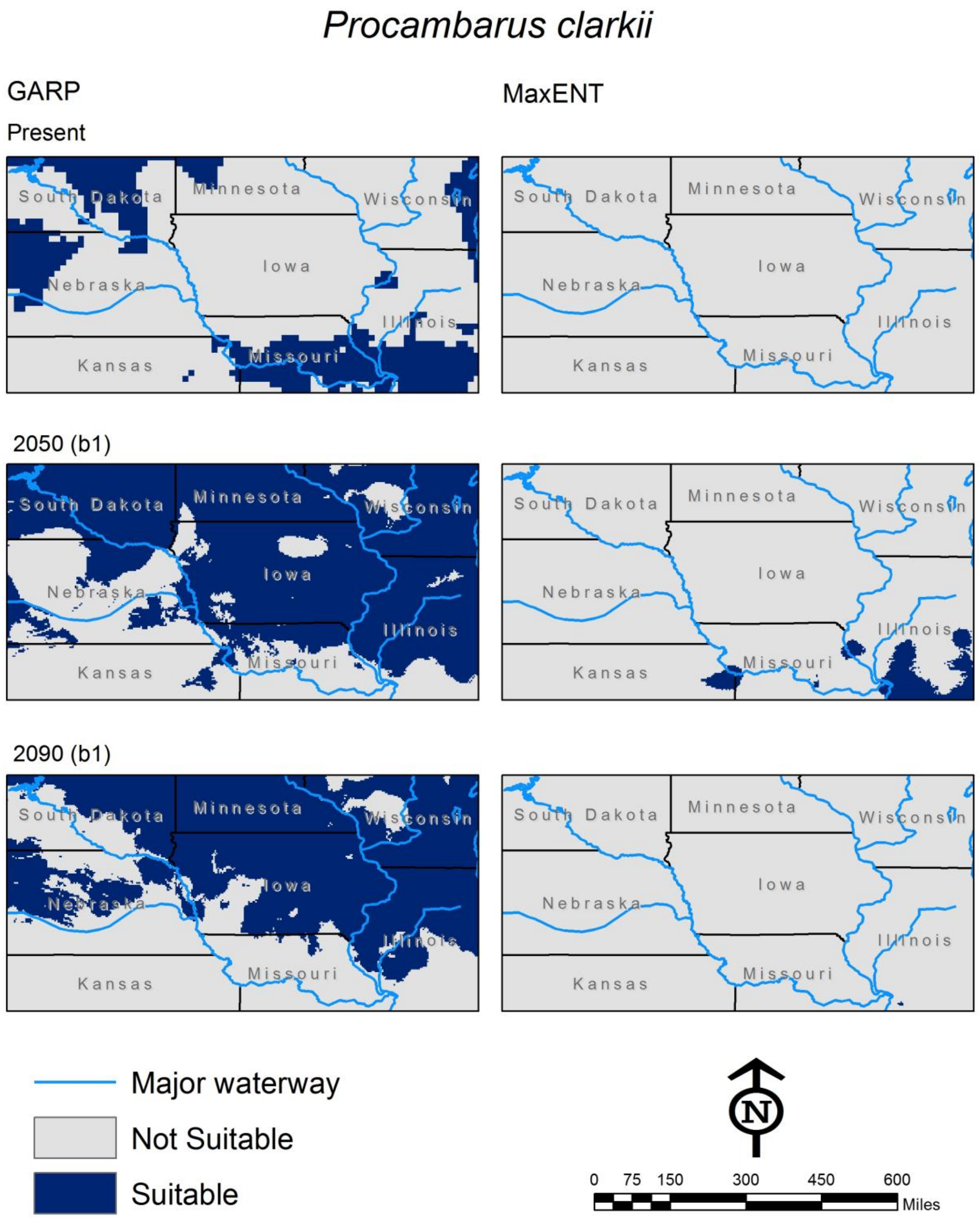

Figure S-6. MaxEnt and GARP climatic suitability projections for the Red swamp crayfish (*Procambarus clarkii*) in Iowa for the present and the BCCR model scenario B1 in the years 2050 and 2090.

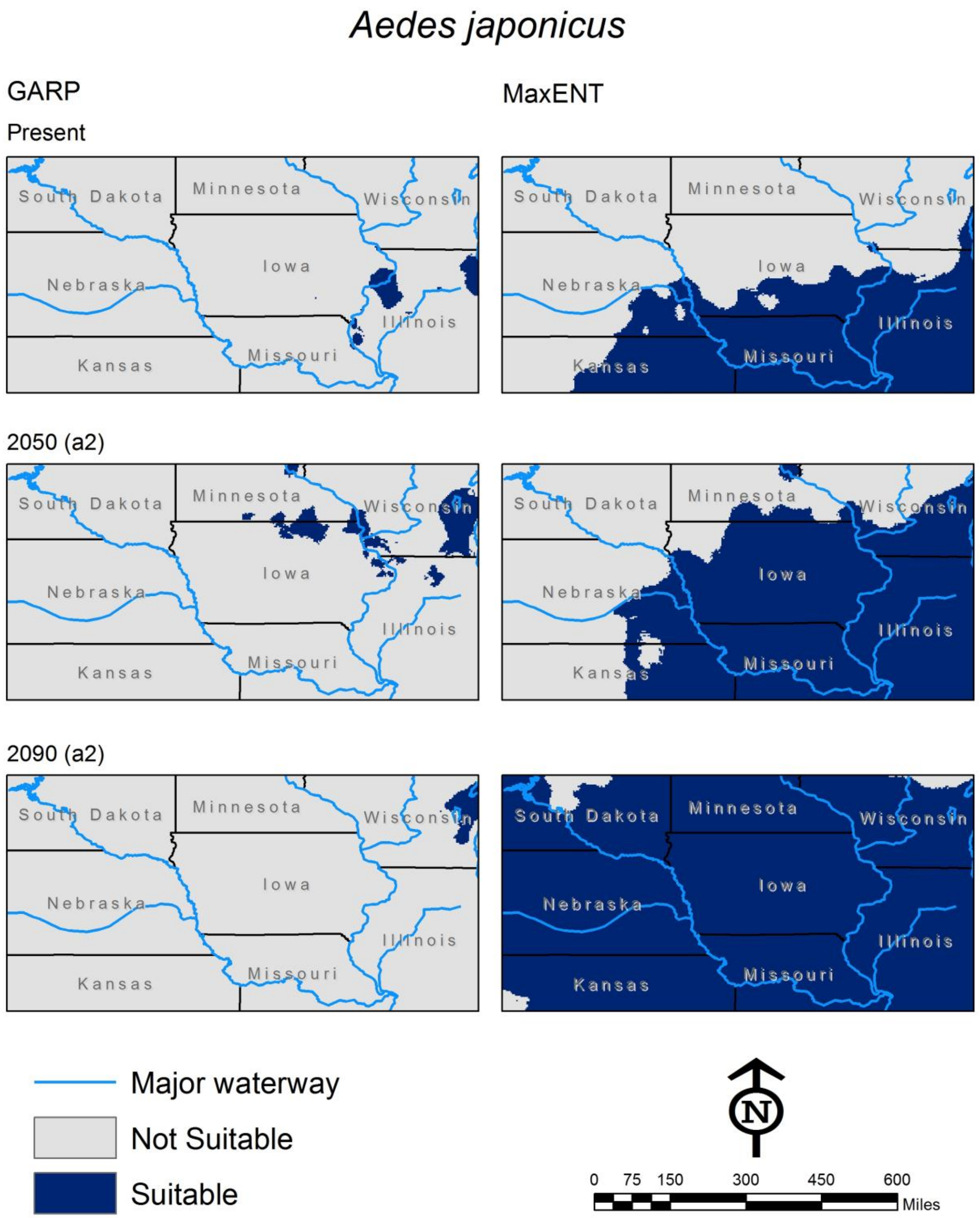

Figure S-7. MaxEnt and GARP climatic suitability projections for the Asian rock pool mosquito (*Aedes japonicus*) in Iowa for the present and the BCCR model scenario A2 in the years 2050 and 2090.

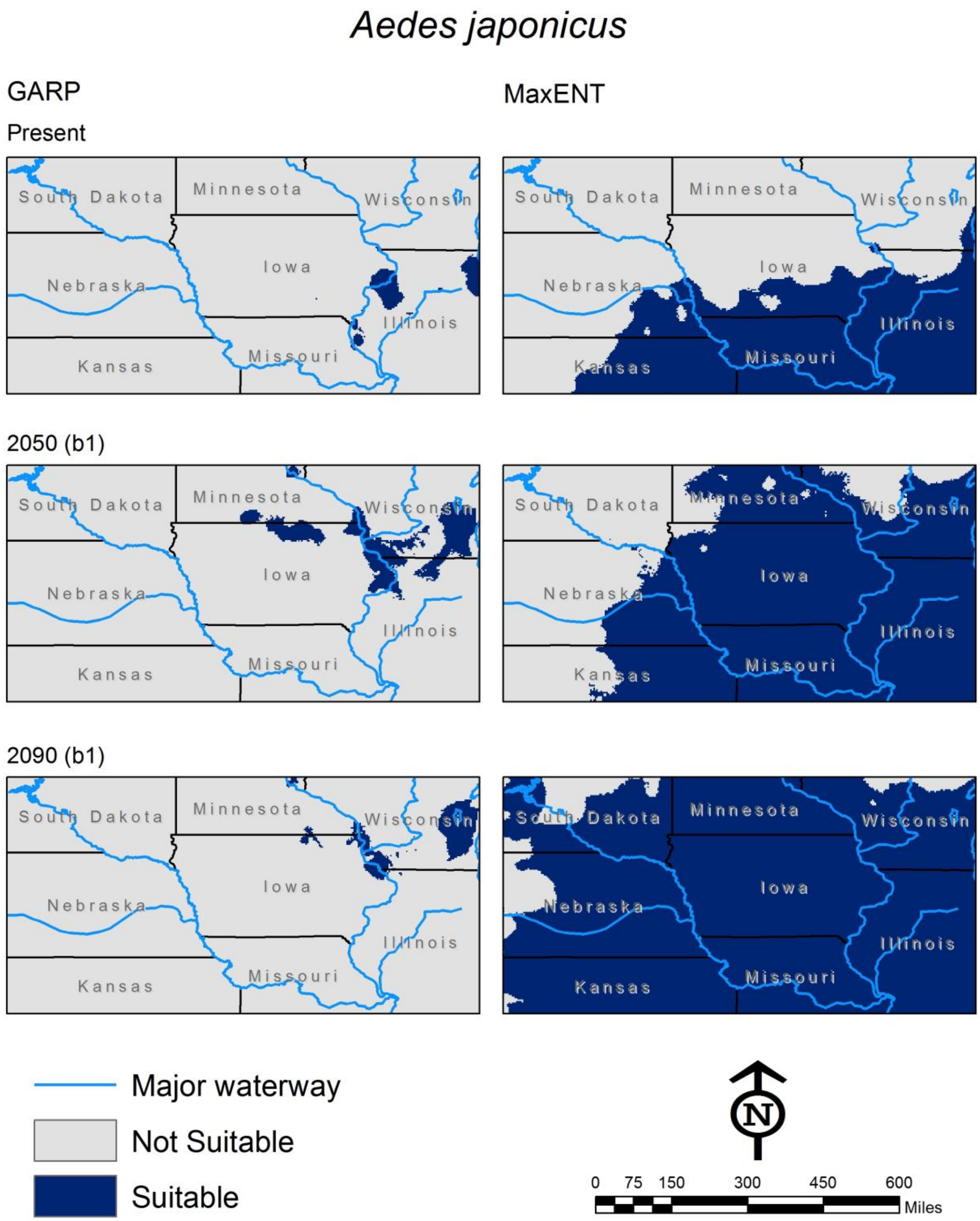

Figure S-8. MaxEnt and GARP climatic suitability projections for the Asian rock pool mosquito (*Aedes japonicus*) in Iowa for the present and the BCCR model scenario B1 in the years 2050 and 2090.

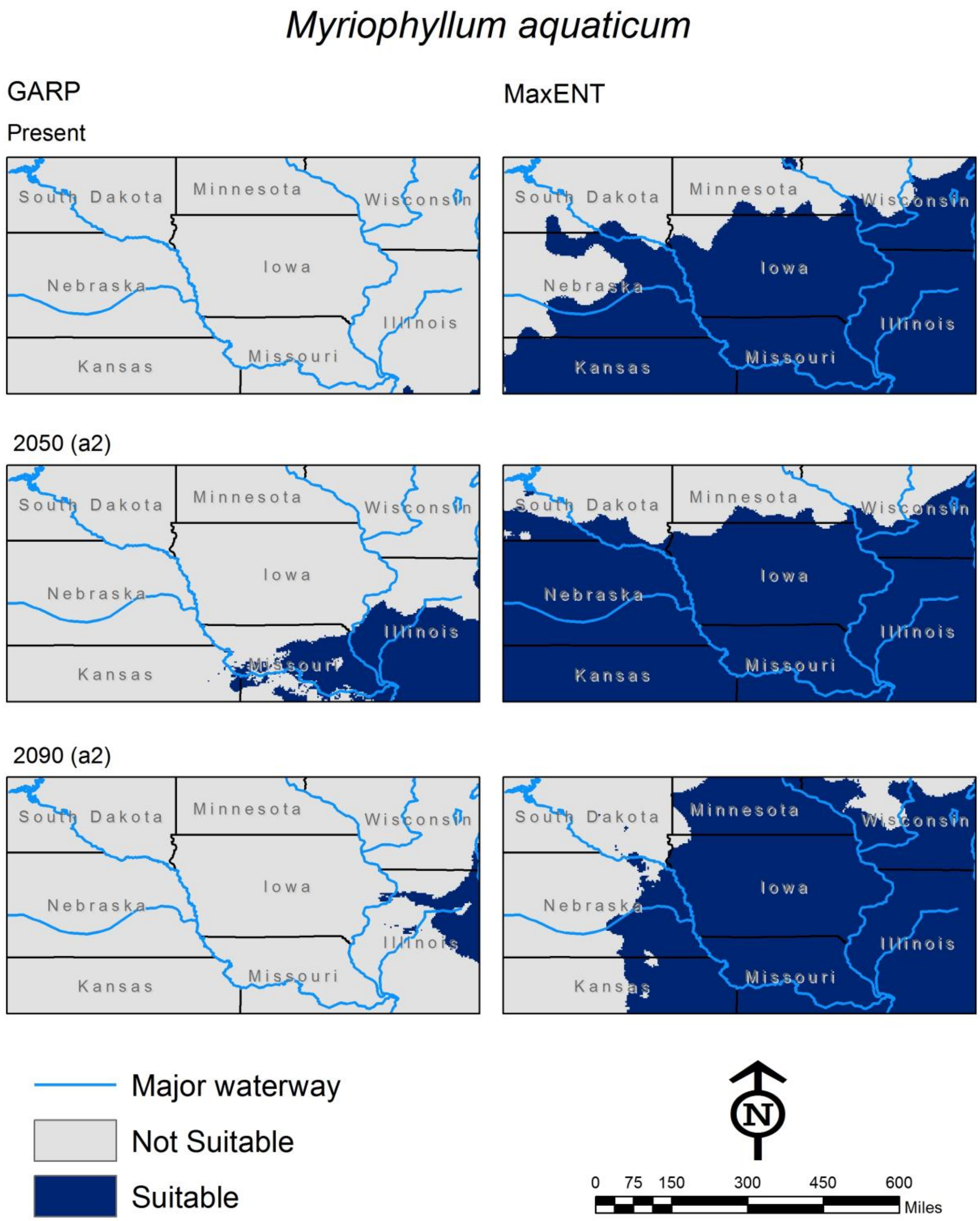

Figure S-9. MaxEnt and GARP climatic suitability projections for Parrot-feather (*Myriophyllum aquaticum*) in Iowa for the present and the BCCR model scenario A2 in the years 2050 and 2090.

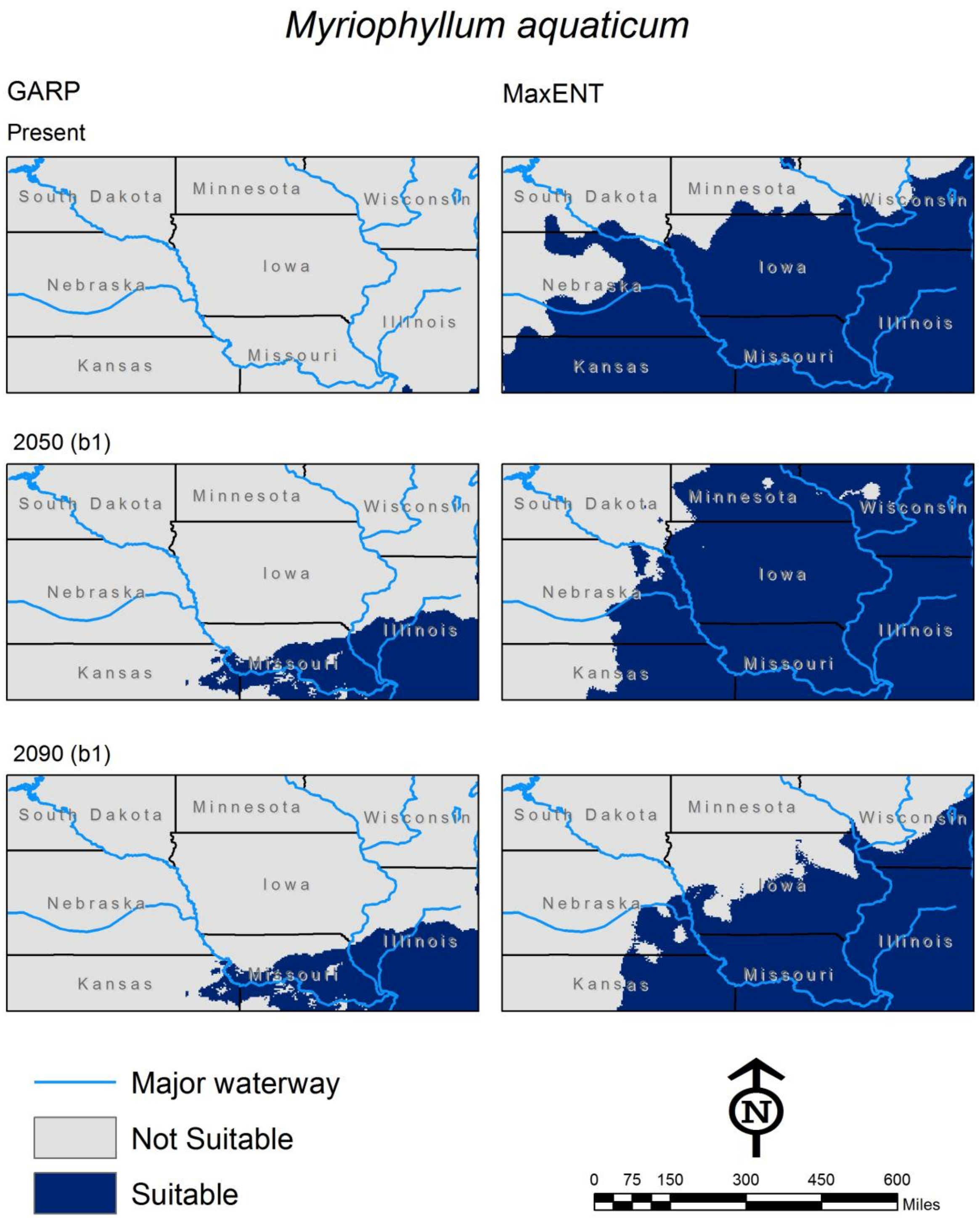

Figure S10. MaxEnt and GARP climatic suitability projections for Parrot-feather (*Myriophyllum aquaticum*) in Iowa for the present and the BCCR model scenario B1 in the years 2050 and 2090.

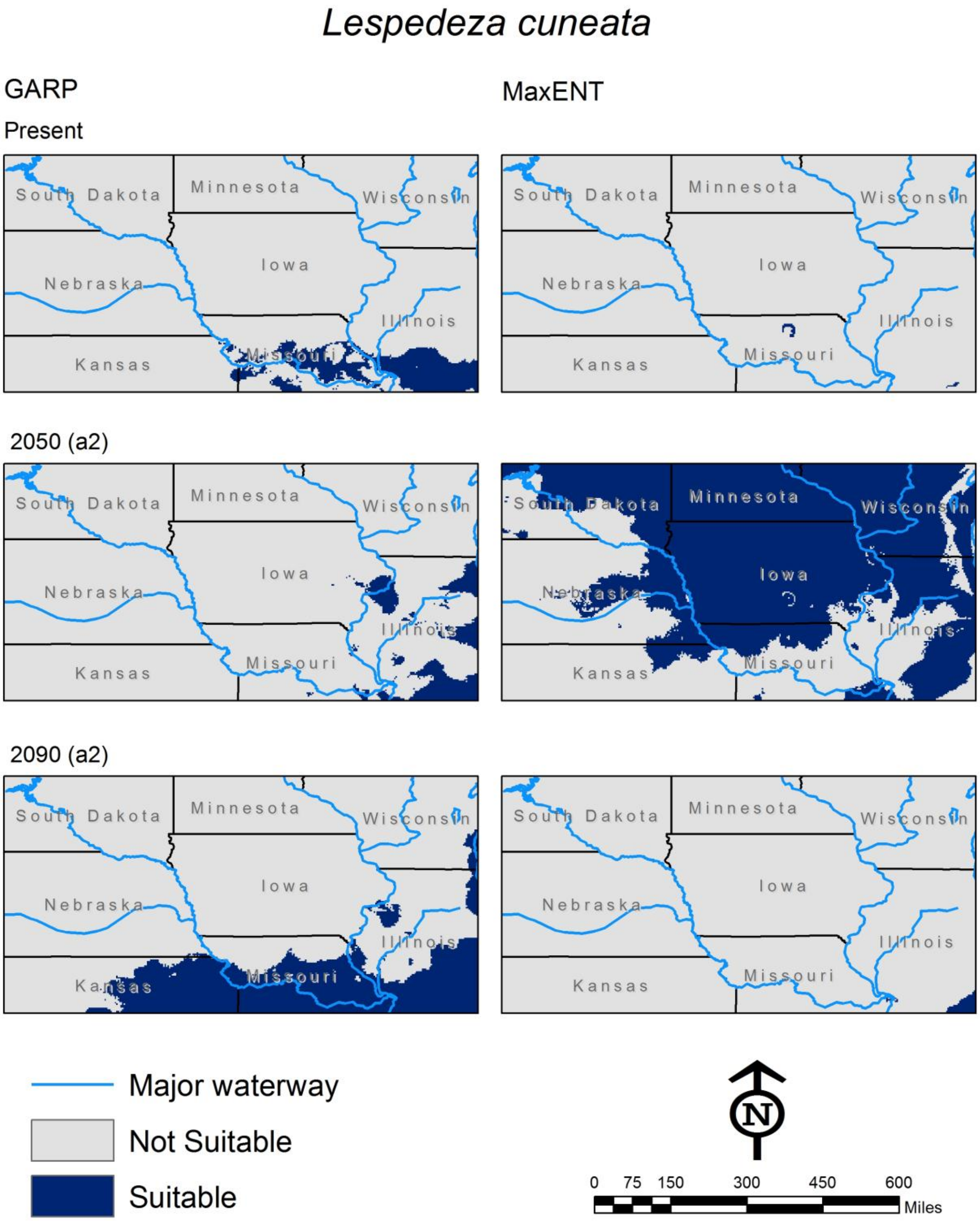

Figure S-11. MaxEnt and GARP climatic suitability projections for Chinese bushclover (*Lespedeza cuneata*) in Iowa for the present and the BCCR model scenario A2 in the years 2050 and 2090.

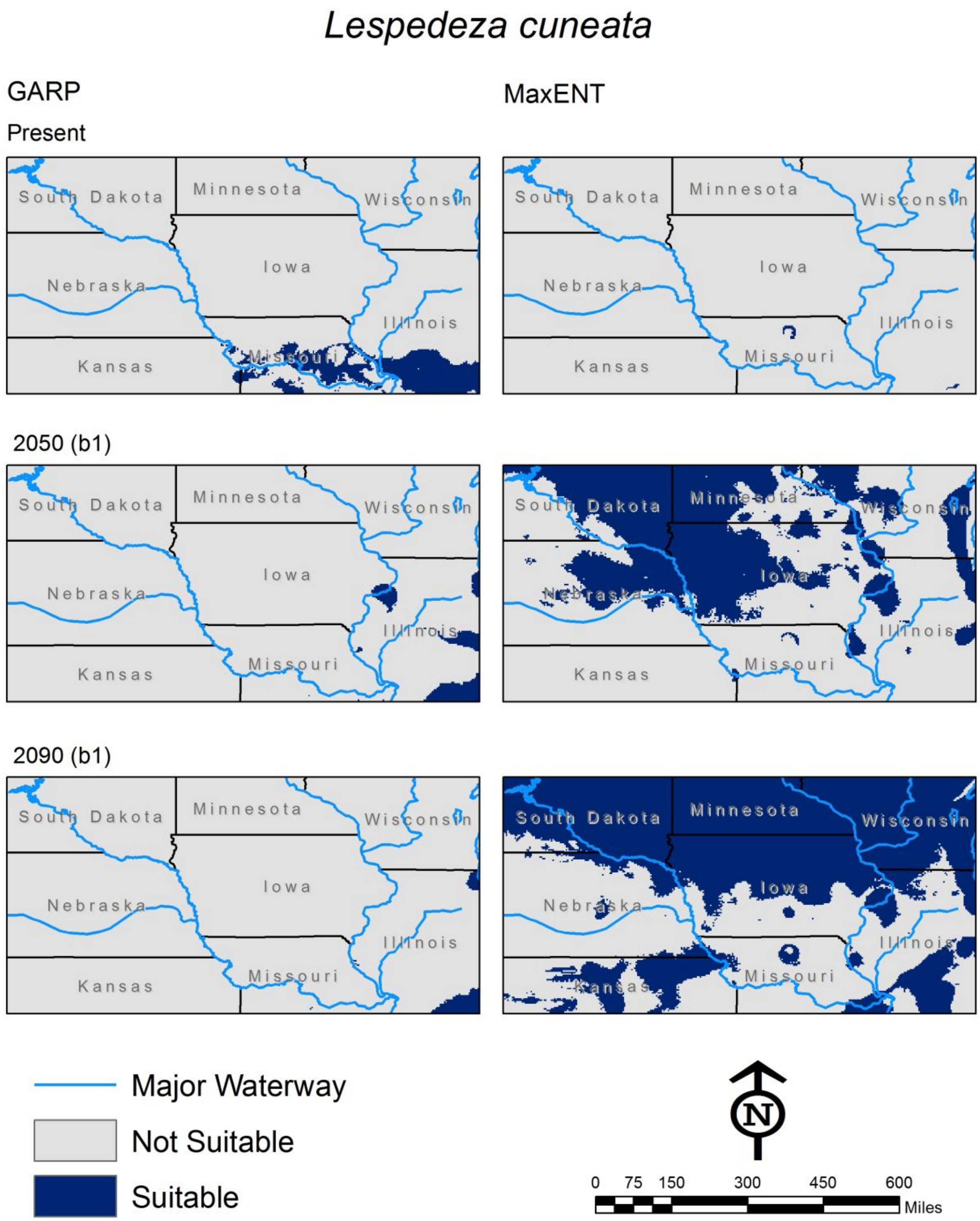

Figure S-12. MaxEnt and GARP climatic suitability projections for Chinese bushclover (*Lespedeza cuneata*) in Iowa for the present and the BCCR model scenario B1 in the years 2050 and 2090.