TACCIMO
Template for Assessing Climate Change Impacts and Management Options

TACCIMO Literature Report
Literature Report – Annotated Bibliography Format
Report Date: April 1, 2013

Content Selections:
FACTORS – Invasive Species
CATEGORIES – ALL
REGIONS – National, East, R9: Eastern, North Atlantic, R8: Southern, South Atlantic, South Central

How to cite the information contained within this report

Each source found within the TACICMO literature report should be cited individually. APA 6th edition formatted citations are given for each source. The use of TACCIMO may be recognized using the following acknowledgement:

"*We acknowledge the Template for Assessing Climate Change Impacts and Management Options (TACCIMO) for its role in making available their database of climate change science. Support of this database is provided by the Eastern Forest Environmental Threat Assessment Center, USDA Forest Service.*"

Best available scientific information justification

Content in this Literature report is based on peer reviewed literature available and reviewed as of the date of this report. The inclusion of information in TACCIMO is performed following documented methods and criteria designed to ensure scientific credibility. This information reflects a comprehensive literature review process concentrating on focal resources within the geographic areas of interest.

Suggested next steps

TACCIMO provides information to support the initial phase of a more comprehensive and rigorous evaluation of climate change within a broader science assessment and decision support framework. Possible next steps include:

1. Highlighting key sources and excerpts
2. Reviewing primary sources where needed
3. Consulting with local experts
4. Summarizing excerpts within a broader context

More information can be found in the user guide. The section entitled Content Guidance provides a detailed explanation of the purpose, strengths, limitations, and intended applications of the provided information.

Where this document goes

The TACCIMO literature report may be appropriate as an appendix to the main document or may simply be included in the administrative record.

Brief content methods

Content in the Literature Reports is the product of a rigorous literature review process focused on cataloguing sources describing the effects of climate change on natural resources and adaptive management options to use in the face of climate change. Excerpts are selected from the body of the source papers to capture key points, focusing on the results and discussions sections and those results that are most pertinent to land managers and natural resource planners. Both primary effects (e.g., increasing temperatures and changing precipitation patterns) and secondary effects (e.g., impacts of high temperatures on biological communities) are considered. Guidelines and other background information are documented in the user guide. The section entitled Content Production System fully explains methods and criteria for the inclusion of content in TACCIMO.

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Effects by Source

Monday, April 01, 2013

RESOURCE AREA (FACTOR): INVASIVE SPECIES

GENERAL IMPACTS

NATIONAL

Abler, D., Shortle, J., Carmichael, J., & Horan, R. (2002). Climate change, agriculture, and water quality in the Chesapeake Bay region. Climate Change, 339-359.

"Increased vigor and rate of spread of invasive plant species has been identified as a potential problem under certain climate-change scenarios (Truscott et al. 2006; Yamalis & Young 2007), and innovative management strategies will probably be needed to address this problem."

Bernazzani, P., Bradley, B., and Opperman, J. (2012). Integrating climate change into habitat conservation plans under the U.S. Endangered Species Act. Environmental Management, 49(6), 1103-1114. doi:10.1007/s00267-012-9853-2

"Climate change is also likely to alter the distribution and abundance of invasive plants & animals (Dukes and Mooney 1999; Bradley and others 2010), which directly threaten many rare and endangered species (Wilcove and others 1998)."

Dukes, J. S., & Mooney, H. A. (1999). Does global change increase the success of biological invaders? TREE, 135-139.

"Experimental studies have demonstrated that, under some circumstances, a short-term increase in water availability can facilitate the long-term establishment of alien plant species. "

Funk, J. L., Cleland, E. E., Suding, K. N., & Zavaleta, E. S. (2008). Restoration through reassembly: plant traits and invasion resistance. Trends in Ecology & Evolution, 23(12), 695-703. doi:10.1016/j.tree.2008.07.013

"As an example of these opposing forces, low water availability is a strong environmental filter that decreases the breadth of plant traits (closer to the environmental optimum) in a community, but causes more intense competition for the limiting resource because species are more similar with respect to key traits (e.g. water-use efficiency; Box 2). The existence of empty niche space in these systems will determine whether a species can invade and, if so, the abundance it can achieve [MacArthur and Levins 1967]. Thus, communities containing native species that are functionally similar to invasive species with respect to these traits should be the most resistant to invasion."

"Numerous studies have found that invasive species are more phenotypically plastic than native species (e.g. [Callaway et al. 2003, Daehler 2003]) and differences in phenotypic plasticity among native and invasive species will influence how restored communities will respond to altered environmental conditions associated with climate change or deliberate manipulations of abiotic filters for the purpose of restoration."

Hellmann, J. J., Byers, J. E., Bierwagen, B. G., & Dukes, J. S. (2008). Five potential consequences of climate change for invasive species. Conservation Biology, 22(3), 534-543.

"Many invasive species also have characteristics that differ from non-invasive species. For example, many invasive plants have broad climatic tolerances and large geographic ranges and these characteristics may affect their responses to climate change."

"Climate change also will challenge the definition of invasive species because some taxa that were previously invasive may diminish in impact; other, previously noninvasive species, may become invasive; and many native species will shift their geographic distributions, moving into areas where they were previously absent."

"In general, climate change may put native species at a disadvantage because they will no longer experience the ranges of environmental variables to which they are best adapted (Byers 2002)."

Joyce, L. A., Blate, G. M., Littell, J. S., McNulty, S. G., Millar, C. I., Moser, S. C., . . . Peterson, D. L. (2008). National forests. in: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. a report by the U.S. climate change science program and the subcommittee on global change research. U.S.Environmental Protection Agency, 1-127.

"Plant species of greatest concern include purple loosestrife [Lythrum salicaria], garlic mustard [Alliaria petiolata], Japanese barberry [Berberis thunbergii], kudzu [Pueraria montana var. lobata], knapweed [Centaurea stoebe L. subsp. micranthos], buckthorns [Rhamnus spp.] , olives [Olea spp.], leafy spurge [Euphorbia esula], and reed [Phragmites australis]and stilt grass [Microstegium vimineum] (USDA Forest Service, 2003)."

"Climate change is expected to compound [the invasive species] problem, due to its direct influence on native species' distributions and the effects of its interactions with other stressors (Chornesky et al., 2005)."

"Increasing concentrations of CO_2 in the atmosphere may also create a competitive advantage to some invasive species (Dukes, 2000; Smith et al., 2000; Ziska, 2003; Weltzin, Belote, and Sanders, 2003)."

"Because increasing CO_2 concentrations allow invasive species to allocate additional carbon to root biomass, efforts to control invasive species with some currently used herbicides may be less effective under climate change (Ziska, Faulkner, and Lydon, 2004)."

"Although C3 species (e.g., lamb's quarters, Chenopodium album) are likely to grow faster under elevated CO_2 concentrations (Bazzaz, 1990; Drake, Gonzalez-Meler, and Long, 1997; Nowak, Ellsworth, and Smith, 2004; Ainsworth and Long, 2005; Erickson et al., 2007), C4 species seem to respond better to warmer temperatures (Alberto et al., 1996; Weltzin, Belote, and Sanders, 2003), probably because the optimum temperature for photosynthesis is higher in C4 species (Dukes and Mooney, 1999)."

"Some of the dispersing native species will likely become problematic invaders that place many threatened and endangered species at greater risk of local extinction due to enhanced competition, herbivory, predation, and parasitism (Neilson et al., 2005a; 2005b)."

Malcolm, J. R., Markham, A., Neilson, R. P., & Garaci, M. (2002). Estimated migration rates under scenarios of global climate change. Journal of Biogeography, 29, 835-849.

"At present, it appears safe to conclude that whereas some organisms will be able to keep up with these shifts, others will not. For invasive species and others with high dispersal capabilities, migration rates exceeding 1000 m year-1 may be common. "

Morrison, L. W., Korzukhin, M. D., & Porter, S. D. (2005). Predicted range expansion of the invasive fire ant, Solenopsis invicta, in the eastern United States based on the VEMAP global warming scenario. Diversity and Distributions, 11(3), 199-204. doi:10.1111/j.1366-9516.2005.00142.x

"In addition to impacts on native species, global warming may allow range expansion in many exotic species. For example, many invasive species in the United States have tropical or subtropical origins, and their current northward distribution is limited by cold. Yet range expansion due to climate change has been modelled for only a handful of invasive species (e.g. Beerling et al ., 1995; Kremer et al., 1996; Zavaleta & Royval, 2002; Kriticos et al., 2003)."

Rahel, F. J., & Olden, J. D. (2008). Assessing the Effects of Climate Change on Aquatic Invasive Species. Conservation Biology, 22(3), 521–533. doi: 10.1111/j.1523-1739.2008.00950.x

"Aspects of climate change that may affect aquatic invasive species include altered thermal regimes, reduced ice cover in lakes, altered streamflow regimes, increased salinity, and increased water-development activities in the form of canal and reservoir construction (Poff et al. 2002). These changes may, in turn, alter the pool of potential colonists, influence the chance that non-native species will establish, alter the impact of established invasive species, and require the initiation or expansion of prevention and control efforts (Fig. 1)."

EAST

Morrison, L. W., Korzukhin, M. D., & Porter, S. D. (2005). Predicted range expansion of the invasive fire ant, Solenopsis invicta, in the eastern United States based on the VEMAP global warming scenario. Diversity and Distributions, 11(3), 199-204. doi:10.1111/j.1366-9516.2005.00142.x

"Our model considers only temperature as a limiting factor to S. invicta [fire ant, Solenopsis invicta] survival. Arid conditions will also limit the distribution of this species. Over the area of the south-eastern USA considered, however, only the western edge and parts of south Texas may be too dry for S. invicta survival (Korzukhin et al., 2001). Extension of this model to other areas (e.g. the western USA) would require consideration of precipitation data (as in Morrison et al., 2004) to accurately predict occurrence probabilities of S. invicta."

INTERACTIONS WITH OTHER FACTORS

NATIONAL

Hellmann, J. J., Byers, J. E., Bierwagen, B. G., & Dukes, J. S. (2008). Five potential consequences of climate change for invasive species. Conservation Biology, 22(3), 534-543.

"Because of its pervasiveness and potential effect on fundamental biological processes, climate change will interact with other existing stressors to affect the distribution, spread, abundance, and impact of invasive species (Gritti et al. 2006)."

Joyce, L. A., Blate, G. M., Littell, J. S., McNulty, S. G., Millar, C. I., Moser, S. C., . . . Peterson, D. L. (2008). National forests. in: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. a report by the U.S. climate change science program and the subcommittee on global change research. U.S.Environmental Protection Agency, 1-127.

"Invasive species are currently a problem throughout NFs [National Forests], and disturbances such as fire, insects, hurricanes, ice storms, and floods create opportunities for invasive species to become established on areas ranging from multiple stands to landscapes."

"Invasive plants alter the nature of fire regimes (Williams and Baruch, 2000; Lippincott, 2000; Pimentel et al., 2000; Ziska, Reeves, and Blank, 2005) as well as hydrological patterns (Pimentel et al., 2000), in some cases increasing runoff, erosion, and sediment loads (e.g., Lacey, Marlow, and Lane, 1989). Potential increases in these disturbances under climate change will heighten the challenges of managing invasive species."

"Flooding facilitates biotic invasions, both by creating sites for invasive species to become established and by dispersing these species to the sites (Barden, 1987; Miller, 2003; Decruyenaere and Holt, 2005; Truscott et al., 2006; Watterson and Jones, 2006; Oswalt and Oswalt, 2007)."

SOUTH ATLANTIC

Joyce, L. A., Blate, G. M., Littell, J. S., McNulty, S. G., Millar, C. I., Moser, S. C., . . . Peterson, D. L. (2008). National forests. in: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. a report by the U.S. climate change science program and the subcommittee on global change research. U.S.Environmental Protection Agency, 1-127.

"Cogongrass (Imperata cylindrica (L.) Beauv.) invasions have altered fire regimes in pine savannas in the southeastern United States (Lippincott, 2000)."

INVASIVE ANIMALS: AQUATIC

NAIONAL

Brown, J. H., & Sax, D. F. (2004). An essay on some topics concerning invasive species. Austral Ecology, 530-536.

"For another, extinctions of many native species cannot be attributed solely to invading aliens. The exotics may have played a role, but other human impacts, such as habitat destruction and fragmentation also contributed. For example, Gido and Brown (1999) reported that invading exotic fishes increased net species richness in 100 of 124 watersheds in temperate North America. Species richness decreased in 20 of the 24 remaining watersheds, but dams, water diversion, and pollution almost certainly contributed to these extinctions."

Joyce, L. A., Blate, G. M., Littell, J. S., McNulty, S. G., Millar, C. I., Moser, S. C., . . . Peterson, D. L. (2008). National forests. in: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. a report by the U.S. climate change science program and the subcommittee on global change research. U.S.Environmental Protection Agency, 1-127.

"Future warming may accelerate the northern expansion of European earthworms [Lumbricus rubellus], which have already substantially altered the structure, composition, and competitive relationships in North American temperate and boreal forests (Frelich et al., 2006)"

Rahel, F. J., Bierwagen, B., & Taniguchi, Y. (2008). Managing aquatic species of conservation concern in the face of climate change and invasive species. Conservation Biology, 22(3), 551-561.

"An example of an invasive species predicted to expand its distribution with climate change is the common carp (Cyprinus carpio). Across the United States, the number of stream sites with suitable thermal conditions for common carp is predicted to increase by 33% (Mohseni et al. 2003). This increase reflects both the northward expansion of streams with suitable thermal conditions and expansion of the species into higher elevation sites in the Rocky Mountains."

"In general the amount of food consumed by fish and other aquatic ectotherms increases with temperature until it declines sharply just before lethal temperatures are reached. At high latitudes or elevations, cold water temperatures limit food consumption by these species for much of the year. Climate warming will allow food consumption to increase and thus could exacerbate the effects of invasive, predatory species on native prey species."

Rahel, F. J., & Olden, J. D. (2008). Assessing the Effects of Climate Change on Aquatic Invasive Species. Conservation Biology, 22(3), 521–533. doi: 10.1111/j.1523-1739.2008.00950.x

"Many fishes raised in outdoor facilities for the aquarium trade are tropical species. With climate warming, their culture can expand northward. Water gardens, which are often stocked with non-native species, also could become more widespread as winters become milder (Maki & Galatowitsch 2004). Unfortunately, aquatic organisms often escape captive-breeding facilities and become invasive (e.g., bighead carp [Hypophthalmichthys nobilis], walking catfish [Clarias batrachus], American bullfrog [Rana catesbeiana]; Fuller et al. 1999; Orchard 1999; Padilla & Williams 2004, respectively). Climate warming will therefore likely increase the pool of invasive species by facilitating the spread of fish-culture facilities and water gardens to new areas."

"Mohseni et al. (2003) predict that the number of stream stations with suitable thermal habitat for warmwater fishes will increase by 31% across the coterminous United States. Sharma et al. (2007) estimate the distribution of smallmouth bass (Micropterus dolomieu) in Canada will advance northward to encompass much of the country by the year 2100, and a similar scenario is envisioned for the highly invasive common carp (Cyprinus carpio) (Minns & Moore 1995)."

"Establishment of tropical species within the coterminous United States has generally been limited to southern states, but releases of tropical species into open waterways have been recorded throughout North America (Fuller et al. 1999). For example, piranha (Pygocentrus or Serrasalmus) have been recorded in 22 states, and although no populations have become established, areas where overwinter survival is possible may increase with climate warming (Fig. 4)."

"Climate warming will reduce the extent of ice cover and thus lessen the occurrence of winter hypoxia (Stefan et al. 2001). This could allow colonization of these lakes by piscivorous fish, such as bass (Micropterus spp.), that would, in turn, cause local extirpation of populations of small-bodied fishes (Jackson & Mandrak 2002) and amphibians (Kats & Ferrer 2003)."

"An increase in floods may increase the dispersal of non-native species, such as zebra mussels, whose planktonic larvae are transported through streams (Havel et al. 2005)."

"Reservoirs may also influence biotic interactions between native and non-native species. Non-native species may be minor components of the biota in streams but can become competitively dominant species in reservoirs (e.g., common carp and zebra mussels; Havel et al. 2005)."

NORTH CENTRAL

Rahel, F. J., Bierwagen, B., & Taniguchi, Y. (2008). Managing aquatic species of conservation concern in the face of climate change and invasive species. Conservation Biology, 22(3), 551-561.

" In the Laurentian Great Lakes basin warmer temperatures, especially in winter, are expected to favor expansion of invasive species, including alewife (Alosa pseudoharengus), round goby (Neogobius melanostomus), Eurasian ruffe (Gymnocephalus cernuus), and sea lamprey (Petromyzonmarinus) (Holmes 1990; Bronte et al. 2003). These invasions would be detrimental to native species such as yellow perch (Perca flavescens) and lake trout (S. namaycush)."

R8: SOUTHERN

Drake, J. M., & Bossenbroek, J. M. (2004). The potential distribution of zebra mussels in the United States. BioScience, 54(10), 931-941. doi:10.1641/00063568(2004)054[0931:TPDOZM]2.0.CO;2

"Turning to our projections of invasion risk in the Southeast [using a genetic algorithm for rule-set production (GARP) that includes the IPCC (Intergovernmental Panel on Climate Change) baseline climate dataset to select predictive models of species ranges], where the species richness of unionid mussels is especially high (figure 7), we observe that this region is highly susceptible to zebra mussel [Dreissena polymorpha] invasion, according to model I (with the risk of invasion approaching 100 percent). In the Southeast, unlike the western river systems, models II and III show a significantly lower invasion risk than model I, diminishing our confidence that the region is habitable by zebra mussels. However, this only reduces the risk from high (approaching 100 percent) to moderate (about 50 percent). Given the high density of endemic unionid species, even the lowest estimates of invasion risk in the Southeast are worrisome. We reiterate that even if our models suggest that a region is habitable by zebra mussels in only 50 of 100 models, this is unacceptably high in light of the high biodiversity losses to be expected from invasion by zebra mussels."

R9: EASTERN

Rahel, F. J., & Olden, J. D. (2008). Assessing the Effects of Climate Change on Aquatic Invasive Species. Conservation Biology, 22(3), 521–533. doi: 10.1111/j.1523-1739.2008.00950.x

"Mandrak (1989) predicts that with climate warming, 19 warmwater fish species from the Mississippi or Atlantic Coastal basins may invade the lower Laurentian Great Lakes (Ontario, Erie, and Michigan) and that 8 warmwater fish species currently present in the lower Great Lakes could invade the upper Great Lakes (Huron and Superior). These 27 fish species would bring with them 83 species of parasites that do not currently exist in the Great Lakes, opening the door for epizootic outbreaks of pathogens in immunologically na¨ıve native fishes (Marcogliese 2001)."

SOUTH ATLANTIC

Rahel, F. J., & Olden, J. D. (2008). Assessing the Effects of Climate Change on Aquatic Invasive Species. Conservation Biology, 22(3), 521–533. doi: 10.1111/j.1523-1739.2008.00950.x

"In freshwater systems climate change is associated with earlier breeding in amphibians (Beebee 1995), earlier emergence of dragonflies (Odonata) (Hassall et al. 2007), and compositional shifts of entire insect communities (Burgmer et al. 2007). There is speculation that the recent establishment of 2 species of tropical dragonflies in Florida represents a natural invasion from Cuba and the Bahamas that is related to climate change (Paulson 2001)."

INVASIVE ANIMALS: TERRESTRIAL

NATIONAL

Blaustein, A. R., Walls, S. C., Bancroft, B. A., Lawler, J. J., Searle, C. L., & Gervasi, S. S. (2010). Direct and indirect effects of climate change on amphibian populations. Diversity, 2(2), 281-313. doi:10.3390/d2020281

"As alien predators, various introduced species are known to be contributing to amphibian population declines around the world [Kats & Ferrer 2003]. Examples of introduced species of amphibians that are of particular concern include the Cuban treefrog (Osteopilus septentrionalis), the American bullfrog (Lithobates catesbeianus), and the cane toad (Rhinella marina), all of which prey upon, and compete with, native amphibians. Projections of various climate change scenarios indicate the likelihood of expansion of the current distribution of Cuban treefrogs in North America [Rödder & Weinsheimer 2009], cane toads in Australia [Kearney et al. 2008], and American bullfrogs in various parts of the world [Ficetola et al. 2007]."

R8: SOUTHERN

Rцdder, D. & Weinsheimer, F. (2009). Will future anthropogenic climate change increase the potential distribution of the alien invasive Cuban treefrog (Anura: Hylidae)? Journal of Natural History, 43(19-20), 1207-1217. doi:10.1080/00222930902783752

"Projections of the CEM [Climate Envelope Models] of O. septentrionalis [Osteopilus septentrionalis] onto the future climate change scenarios indicate that climatically suitable areas may become more widespread overall (Figure 4). These areas include the whole Atlantic coastline from the Mexican border to North Carolina, which may connect suitable areas with today’s potential distribution. In contrast the climatic suitability in its native range, as well as on the Yucatan Peninsula, will decrease."

"Our projections onto anthropogenic climate-change scenarios indicate a possible extension of the current potential distribution of the Cuban treefrog [Osteopilus septentrionalis] in Northern America. However, successful colonization of newly arising suitable areas may depend on the propagation speed of O. septentrionalis. Time series suggest that the frog was able to expand its range at about 10kmy21 in Florida (e.g., Key West– Miami, ,250 km/21y; Miami–Indian River Country, ,250 km/28y; Miami–Duval Country, 570 km/51y) and, assuming this spread rate, it could reach Louisiana and Virginia within the next 80 years."

EAST

Morrison, L. W., Korzukhin, M. D., & Porter, S. D. (2005). Predicted range expansion of the invasive fire ant, Solenopsis invicta, in the eastern United States based on the VEMAP global warming scenario. Diversity and Distributions, 11(3), 199-204. doi:10.1111/j.1366-9516.2005.00142.x

"States that would see relatively large increases in habitable area for S. invicta [fire ant, Solenopsis invicta] include Oklahoma, Arkansas, Tennessee, and Virginia. Expansion into the Texas panhandle may be limited by dry conditions (see Discussion). Further expansion in the eastern North Carolina region is not predicted by the model, probably due to the higher elevations and thus colder temperatures of the Appalachian Mountains. By 2080–89, Delaware and Maryland would be susceptible to invasion, and S. invicta may be able to inhabit areas north of 39° latitude along the Atlantic coast."

"Our model predicts an increase of c. 5% in the habitable area for S. invicta [fire ant, Solenopsis invicta] in the eastern United States within the next 40– 50 years based on the VEMAP [Vegetation-Ecosystem Modeling and Analysis Project] climate change scenario. As the pace of global warming is expected to quicken in the latter half of the century, however, the habitable area for S. invicta in the eastern United States is predicted to be c. 21% greater than it is currently."

"Zavaleta & Royval (2002) predicted the total area of infestation by S. invicta [fire ant, Solenopsis invicta] would increase from 1,261,000 km2 (currently) to 2,038,000 km2 given a 3 °C rise in temperature, and to 2,271,000 km2 given a 4 °C rise."

Rodda, G. H., Jarnevich, C. S., and Reed, R. N. (2009). What parts of the US mainland are climatically suitable for invasive alien pythons spreading from everglades national park? Biological Invasions, 11(2), 241-252. doi:10.1007/s10530-008-9228-z

"As expected, the climate model for the year 2100 projected additional suitable area [for the Burmese Python (Python molurus)] to the north of the current limit (Fig. 5). Additional states partially included under at least one scenario were: Washington, Colorado, Illinois, Indiana, Ohio, West Virginia, Pennsylvania, New Jersey, and New York."

"Although the python resides naturally in tropical sites straddling the equator, the more temperate parts of Indian Python native range correspond climatically to many southern and southwestern US states (Fig. 4). According to 2000 census figures, about 120 million Americans live in counties having climate similar to that found in the native range of the python. Many more Americans live in areas that could be colonized by Indian Pythons if the global climate warms as predicted by many models (Fig. 5)."

"Stopping the spread [of the Burmese Python (Python molurus)] in the relatively narrow confines of the Florida peninsula would appear to be easier than controlling a much wider invasion front that may occur if the python spreads beyond peninsular Florida, as this work suggests is climatically possible. Nonetheless, there appear to be no precedents for containing an expanding continental snake population. The large potential range of the python in the New World suggests that early control may be a preferred option."

INVASIVE PLANTS: AQUATIC & RIPARIAN

NATIONAL

Rahel, F. J., Bierwagen, B., & Taniguchi, Y. (2008). Managing aquatic species of conservation concern in the face of climate change and invasive species. Conservation Biology, 22(3), 551-561.

"Low light conditions under the ice can limit the occurrence of aquatic plants, and therefore a reduction in ice cover could allow colonization by new species. The recent invasion by threadleaf water-crowfoot (Ranunculus trichophyllus) into several high-elevation lakes in the Himalayas has been attributed to a decrease in the length of ice cover due to climate warming (Lacoul & Freedman 2006)."

Rahel, F. J., & Olden, J. D. (2008). Assessing the Effects of Climate Change on Aquatic Invasive Species. Conservation Biology, 22(3), 521–533. doi: 10.1111/j.1523-1739.2008.00950.x

"Climate change will reduce the extent of ice cover on lakes in the northern hemisphere (Magnuson et al. 2000), which may influence the invasion process by increasing light levels for aquatic plants, reducing the occurrence of low oxygen conditions in winter, and exposing aquatic organisms to longer periods of predation from terrestrial predators."

"Elevated salinity in floodplains may favor the ongoing invasion and impact of salt cedar [Tamarix spp.], and current efforts to eliminate it and reestablish native riparian species by flooding areas below dams may need to account for salt deposits in riparian soils."

R8: SOUTHERN

Pattison, R. R., & Mack, R. N. (2008). Potential distribution of the invasive tree triadica sebifera (euphorbiaceae) in the united states: Evaluating climex predictions with field trials. Global Change Biology, 813-826.

"The likelihood of this spread is heightened by factoring in the tree’s [Triadica sibifera] occurrence near perennial sources of water because the potential unoccupied range of T. sebifera includes some of the most dissected watersheds in the USA (Thornbury, 1965). Within major watersheds, such as those of the Tennessee and Cumberland Rivers, T. sebifera could spread extensively."

SOUTH ATLANTIC

Mulholland, P. J., Best, G. R., Coutant, C. C., Hornberger, G. M., Meyer, J. L., Robinson, P. J, Stenberg, J. R., … & Wetzel, R. G. (1997). Effects of climate change on freshwater ecosystems of the south-eastern United States and the Gulf Coast of Mexico. Hydrological Processes, 11, 949-970. doi: 10.1002/(SICI)1099-

1085(19970630)11:8<949::AID-HYP513>3.0.CO;2-G

"Increasing winter minimum temperatures (or more probably reduction in the frequency and severity of freezing conditions) will most likely produce a northward shift in the range of subtropical species [in Florida]. Range shifts would be expected for several recently introduced invasive species, such as the tree Melaleuca quinquenervia (Cajeput) and the shrub Schinus terebinthifolius (Brazilian pepper), that can quickly suppress native species. In central and northern portions of the state, freshwater marshes may become dominated by Melaleuca and hardwood swamps by Schinus, as has occurred in the south."

Pattison, R. R., & Mack, R. N. (2009). Environmental constraints on the invasion of Triadica sebifera in the eastern United States: an experimental field assessment. Oecologia, 158(4), 591-602. doi: 10.1007/s00442-008-1187-7

"These field trials [using seeds collected from approx. 50 trees near Georgetown, SC, USA] provide evidence for the likely spread of Chinese tallow tree [Triadica sebifera] to 38°N latitude and inland along the Savannah River."

"We had earlier found evidence for potential northward and inland spread for this invader [Chinese tallow tree, Triadica sebifera], based on projections from the CLIMEX model (Pattison and Mack 2008). Our field results [using seeds collected from approx. 50 trees near Georgetown, SC, USA] largely reinforce those predictions as well as provide insight into the tree's response to different microhabitats. Spread of T. sebifera, based on both lines of evidence, appears far from complete in the United States. But the extent to which on-going global atmospheric change will influence this range occupation complicates any predictions (Pattison and Mack 2008)."

INVASIVE PLANTS: TERRESTRIAL

NATIONAL

Bradley, B. A., Oppenheimer, M., & Wilcove, D. S. (2009). Climate change and plant invasions: restoration opportunities ahead? Global Change Biology, 15, 1511-1521.

"Climate change is likely to reduce risk from E. esula [Euphorbia esula] in states such as Colorado, Nebraska, Iowa, and Minnesota (Fig. 6b). However, it may expand risk into parts of Canada not included in this study. E. esula is likely to retreat from Nebraska and parts of Oregon and Idaho, creating strong potential for restoration (Fig. 6c). Of the currently invaded lands in the west, 18% are no longer climatically suitable by 2100 in any of the 10 AOGCMs [atmosphere ocean general circulation models] tested, and 13% are only climatically suitable in one of the 10 AOGCMs. Land area with restoration potential encompasses 67,000km2. Only 19% of invaded lands are highly likely to remain at risk, maintaining climatic suitability in five or more of the 10 AOGCMs tested (Table 1)."

Bradley, B. A., Blumenthal, D. M., Early, R., Grosholz, E. D., Lawler, J. J., Miller, L. P., … & Olden, J. D. (2012). Global change, global trade, and the next wave of plant invasions. Frontiers in Ecology and the Environment, 10 (1), 20 – 28.

"With concerted planting efforts, gardeners are already helping garden plants to shift their geographic distributions into newly suitable climatic regions ahead of non-propagated species (Van der Veken et al. 2008). Many invasive species are unintentionally taken along for the ride (Maki and Galatowitsch 2004), whereas others are actively planted in regions forecast to become suitable for invasion with climate change (eg Bradley et al. 2010b). Unless assisted migration is also used for native species (Richardson et al. 2009), these trends raise the prospect that both existing and new invasive species may be better able to shift their ranges to align with new climatic conditions, pre-empting and possibly precluding the establishment of native species. "

"Of further concern for invasive species biologists and managers are the novel sets of species that could be introduced in response to increasing demand for heat-tolerant [plant] species: warm hardiness zones 8 and 9 are projected to expand by 45% and 120%, respectively, and are likely to cover a substantial portion of US land area by 2050 (Figure 4c)."

Bradley, B. A., Wilcove, D. S., & Oppenheimer, M. (2010). Climate change increases risk of plant invasion in the Eastern United States. Biological Invasions, 12(6), 1855-1872. DOI 10.1007/s10530-009-9597-y

"In some locations, climate change could lead to expanded invasion risk from particular species. For example, higher precipitation may enable non-native grasses to spread in the western US (D'Antonio and Vitousek 1992; Martin-R et al. 1995), and higher temperatures may expand the range of invasive plants northward in the southeastern US (Rogers and McCarty 2000). Yet for other invasive species, climatic habitat could be reduced with climate change, creating unprecedented restoration opportunities (Bradley et al. 2009)."

Dukes, J. S., Chiarello, N. R., Loarie, S. R., & Field, C. B. (2011). Strong response of an invasive plant species (Centaurea solstitialis L.) to global environmental changes. Ecological Applications, 21 (6), 1887-1894.

"Many ongoing global changes are expected to affect the success of invasive plant species (i.e., nonnative plant species that become widespread and locally or regionally dominant), because these species commonly share certain traits. For instance, a rapidly changing climate could favor invasive species through a variety of little tested mechanisms relating to environmental tolerances, interspecific relationships, phenological plasticity, and seed dispersal distances (Dukes and Mooney 1999, Bradley et al. 2010, Willis et al. 2010)."

Joyce, L. A., Blate, G. M., Littell, J. S., McNulty, S. G., Millar, C. I., Moser, S. C., . . . Peterson, D. L. (2008). National forests. in: Preliminary review of adaptation options for climate-sensitive ecosystems and resources. a report by the U.S. climate change science program and the subcommittee on global change research. U.S.Environmental Protection Agency, 1-127.

"The positive response to current (from pre-industrial) levels of atmospheric CO_2 by six invasive weeds—Canada thistle (Cirsium arvense (L.) Scop.), field bindweed (Convolvulus arvensis L.), leafy spurge (Euphorbia esula L.), perennial sowthistle (Sonchus L.), spotted knapweed (Centaurea stoebe L.), and yellow star-thistle (Centaurea solstitialis L.)—suggests that 20th century increases in atmospheric CO_2 may have been a factor in the expansion of these invasives (Ziska, 2003)."

"The northward expansion of the range of invasive species currently restricted by minimum temperatures (e.g., kudzu and Japanese honeysuckle) is a particular concern (Sasek and Strain, 1990; Simberloff, 2000; Weltzin, Belote, and Sanders, 2003)."

"Invasive species with a C_4 photosynthetic pathway (e.g., itchgrass, Rottboellia cochinchinensis) are particularly likely to invade more northerly regions as frost hardiness zones shift northward (Dukes and Mooney, 1999)."

McDougall, K. L., Khuroo, A. A., Loope, L. L., Parks, C. G., Pauchard, A., Reshi, Z.A., … & Kueffer, C. (2011). Plant invasions in mountains: Global lessons for better management. Mountain Research and Development, 31 (4), 380-387.

"Because of their steep environmental and climatic gradients, mountains are recognized as being especially sensitive to climate change (Beniston 2003). The threat from invasive species in mountains is expected to markedly increase because of climate change (eg Pickering et al 2008; Petitpierre et al 2010), making effective preventive management, as recommended in this essay, especially timely. However, species movements will not necessarily be upward. The potential distribution of Hieracium spp in Australia, for instance, was modeled to contract under climate change scenarios (Beaumont et al 2009), and, in Hawaii, water availability (precipitation and evapotranspiration) seems to be more important than temperature in limiting alien species at high elevation (Jakobs et al 2010; Juvik et al 2011)."

"Climate change may also alter the composition of the invasive flora. For instance, the increase in atmospheric CO_2 is likely to make woody plants more competitive in grassland systems that evolved under low CO_2 levels (eg Kgope et al 2010)."

Simberloff, D. (2000). Global climate change and introduced species in United States forests. The Science of the Total Environment, 262, 253 – 261. doi: 10.1016/S0048-9697(00)00527-1

"A scan of past rates of migration of tree species with climate change (e.g. Davis, 1981) suggests the predicted climate change is fast enough that dispersal limitation alone will prevent many species from keeping pace with their changing potential ranges as the latter expand. However, invasive non-indigenous species should in general have an advantage in this race, as many are typified by good dispersal abilities and other 'weedy' traits that are, in fact, the very features that render them invasive, such as light seeds (Rejmanek and Richardson, 1996)."

"Some ecologists go further, and predict that, as climate changes and ranges even of native species do not shift in lock step with one another, longstanding, co-adapted communities of species will be sundered and the new communities that replace them will be inherently less stable and more invisible (Kareiva et al., 1993). This is a more speculative scenario, and there is debate about just how highly coadapted existing native communities are."

"Increased C02 , in addition to driving temperature change, could affect range and population sizes of forest invaders (Mooney, 1996; Dukes and Mooney, 1999). For plants, photosynthetic rates increase, and the effects differ for C_3 and C_4 plants. The C_4 plants saturate their photosynthetic capacity at relatively low concentrations. Thus, C_3 plants will gain an advantage that they currently lack. Most of the worst agricultural weeds are C_4 plants (e.g. Echinochloa crusgalli, Cyperus rotundus), but forest invaders can be C_4 also. For example, nepalgrass (Microstegium vimineum) as noted above invades large forest areas of the Great Smoky Mountains National Park, excluding native plants; it is a C_4 annual grass."

R8: SOUTHERN

Bradley, B. A., Wilcove, D. S., & Oppenheimer, M. (2010). Climate change increases risk of plant invasion in the Eastern United States. Biological Invasions, 12(6), 1855-1872. DOI 10.1007/s10530-009-9597-y

"The spatial distribution of cogongrass [Imperata cylindrical] climatic habitat under 2100 climate conditions is shown in Fig. 8. Once again, all models show a northward expansion, but the Maxent models predict invasion risk under more AOGCM [atmosphere-ocean general circulation model] conditions than the MD [Mahalanobis distance] models. An ensemble of both models, variable sets, and all AOGCM projections shows that current atrisk areas along the Gulf Coast will continue to be vulnerable to invasion by cogongrass, while the invasion risk is likely to expand considerably northward into Kentucky, West Virginia, and Virginia."

SOUTH ATLANTIC

Drake, S. J., Weltzin, J. F., & Parr, P. D. (2003). Assessment of non-native invasive plant species on the united states department of energy oak ridge national environmental research park. Castanea, 15-30.

"Managers at the Great Smoky Mountains National Park in Tennessee and North Carolina have qualitatively ranked Microstegium [Microstegium vimineum] highest in potential impacts on natural ecosystems in the Park (out of a total of 35 problematic non-native, invasive plants), and lowest in feasibility of control because so little is known of its autecology or synecology (National Park Service 1999). Similarly, 18 of 35 federal, state, and private agencies in the Southern Appalachian region reported that of a total of 218 invasive plant species, Microstegium was one of their greatest ongoing or potential management problems, behind only kudzu [Pueraria lobata] and multiflora rose [Rosa multiflora]"

EAST

Bradley, B. A., Wilcove, D. S., & Oppenheimer, M. (2010). Climate change increases risk of plant invasion in the Eastern United States. Biological Invasions, 12(6), 1855-1872. DOI 10.1007/s10530-009-9597-y

"The spatial distribution of kudzu [Pueraria lobata] climatic habitat under 2100 climate conditions is shown in Fig. 6. Under the Maxent release and constraint models, climatic habitat expands northward and considerable land area is at high risk. A similar expansion is observed in the MD [Mahalanobis distance] release model, although overall risk is lower. Under the MD constraint model, climatic habitat shifts northward, but contracts from the current range. An ensemble of both models, variable sets, and all AOGCM [atmosphere-ocean general circulation model] projections shows the highest risk in southeast and mid-Atlantic states. Future invasion risk is shifted northwards by about 200 km from current risk, and is projected to expand well into Pennsylvania, New York, and New England states by 2100. "

"The spatial distribution of privet [Ligustrum sinense and Ligustrum vulgare] climatic habitat under 2100 climate conditions is shown in Fig. 7. Similar to kudzu, all models and variable sets show a northward shift, although MD [Mahalanobis distance] projections show less risk than Maxent projections. An ensemble of both models, variable sets, and all AOGCM [atmosphere-ocean general circulation model] projections shows the highest risk in central states of Kentucky, Tennessee, North Carolina, and Virginia. Future invasion risk is shifted northwards by over 300 km from current risk, but is substantially reduced in Gulf Coast states in the majority of projections. Invasion risk increases in Pennsylvania, New York, and New England states by 2100, and also expands westward into Missouri. "

"The bioclimatic envelope model results for kudzu [Pueraria lobata], privet [Ligustrum sinense and Ligustrum vulgare], and cogongrass [Imperata cylindrical] show that climate change is likely to substantially increase land area at risk of invasion. These results provide spatially explicit evidence that supports the previous hypothesis that warming temperatures will expand risk northwards (Rogers and McCarty 2000), and previous projections and observations of expansion with rising temperatures (Jarnevich and Stohlgren 2009)."

"For all three species, invasion risk with climate change expands northward by several hundred kilometers by the year 2100. Expansions of climatic habitat are likely to occur gradually for kudzu [Pueraria lobata] and cogongrass [Imperata cylindrical], with invasive species moving north through short (e.g., wind, water, or animal-borne) and long-distance (e.g., accidentally via transportation corridors) seed dispersal. In the case of privet [Ligustrum sinense and Ligustrum vulgare], seed sources in northern states may already exist due to privet's use in landscaping, making rapid invasion of forested areas more likely with climate change."

Dukes, J. S., Pontius, J., Orwig, D., Garnas, J. R., Rodgers, V. L., Brazee, N. ., . . . Stange, E. E. (2008). Responses of insect pests, pathogens, and invasive plant species to climate change in the forests of Northeastern North America: What can we predict?. Canadian Journal of Forest Research, 39(2), 231-248.

"Celastrus orbiculatus may have a similar restriction [as Hemlock Woolly Adelgid [Adelges tsugae] because its northern range boundary is cold-limited], although its tolerances are less well tested. Other nuisance species such as F. alnus (Alder buckthorn) and Armillaria are already widespread within the region, and their potential response is less clear. We have not presented any species likely to become less problematic across northeastern forests because of climate change, but we cannot rule out the possibility that such species exist."