

REVIEW ARTICLE

Can meta-analysis be used as a decision-making tool for developing scenarios and causal chains in eco-hydrological systems? Case study in Florida

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Abstract

To date, there are a high volume of studies concerning climate change impact assessments in ecosystems. Meta-analysis, scenario development, and causal chains/loops have been used as tools in these assessments as well as in decision making either individually or combined in pairs. There exists a need to develop decision support tools that improve the linkage between climate-impacts research and planning, management, adaptation, and mitigation decisions by providing quantitative and timely information to stakeholders and managers. The overall goal is to address this need. A specific objective was to develop a decision support tool in eco-hydrological applications that combine three components: meta-analysis, scenario development, and causal chains/loop. The developed tool is novel, warranted, and timely. The use of the tool is demonstrated for Florida. The meta-analysis of 32 studies revealed precipitation changes ranged between +30% and -40%, and temperature changes ranged from +6°C to -3°C for Florida. Seven incremental scenarios were developed at 10% increments in the precipitation change range and nine scenarios with 1°C increments in the temperature change range (driving forces). The causal chains/loops were developed using Driver-Pressure-State-Impact-Response framework for selected ecosystems and environment (e.g., agroecosystem, mangroves, water resources, and sea turtles) in Florida. The driving force puts pressure on the ecosystem or environment impacting their state, which in turn had a response (e.g., mitigation and adaptation strategies). The framework used indicators selected from studies on climate impact assessments (meta-analysis and others) for the selected ecosystems as well as author expertise on the topic to develop the chains/loops. The decision tool is applicable to stakeholders and any ecosystem within and outside of Florida.

KEYWORDS

decision support tool, ecosystem, Florida climate change, meta-analysis, precipitation and temperature change in Florida, scenario development, reducing usability gap, adaptation and mitigation strategies, causal chains/loops

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1 | INTRODUCTION

Altered climate can impact the environment as well as affect natural and managed ecosystem processes. The potential impacts of altered climate when superimposed on other stressors such as pollution, habitat destruction, invasive species, land resource use, and extreme natural events may lead to significant consequences (Scavia et al., 2002). Decision tools can allow us to examine and predict impacts of altered climate on natural and managed ecosystems. Powerful analytical tools are useful in describing future risk, the marginality of systems, and guide actions to mitigate risk (Adger, 2006). Decades of studies have resulted in various tools for water and ecosystem management, for crop breeding, agricultural producer guidelines, and forestry management strategies. However, a few decision-making tools have been developed for planning and management of ecosystems due to future climate scenarios (Fowler, Blenkinsop, & Tebaldi, 2007). Further, there remains a disconnect between the supply and demand of climate information and the need for tailoring the information for decision-making purposes (Anandhi & Blocksome, 2017). This disconnect is exacerbated by the high volume of studies concerning climate change impacts to date and the availability of multiple methods for scenario development (Fowler et al., 2007).

Meta-analyses can be a powerful approach to assess and synthesize the high volume of studies on altered climate and its impact on various ecosystems (Mantyka-pringle, Martin, & Rhodes, 2012). It represents a systematic approach to identifying, appraising, synthesizing, and (if appropriate) combining the results of relevant studies to arrive at conclusions about how a body of research has been applied (Stroup et al., 2000). Meta-analyses has been used to explore common disconnects between knowledge and action by focusing on the relative prevalence of research questions asked, trends in study design, if and how these have changed over time, and whether any notable gaps remain that require new research (Mosteller & Colditz, 1996).

The future is uncertain and unknown; therefore, changes and variability in climate are not easily detected. Scenarios can be powerful tools for communicate climate alterations, for assessing potential vulnerabilities and directing the two major responses to climate-driven events—mitigation and adaptation (Anandhi, 2017; Anandhi, Omani, et al., 2016; Anandhi, Steiner, & Bailey, 2016). Scenarios must be coherent, internally consistent, and represent plausible descriptions of possible future climate states (Berkhout, Hertin, & Jordan, 2002). The Intergovernmental Panel on Climate Change (IPCC) has developed the most commonly used future climate scenarios from global climate models (GCMs). These IPCC scenarios continue to evolve from IS92, (Leggett et al., 1992), the Special Report on Emissions Scenarios, (Nakicenovic et al., 2000) and more recently from representative concentration pathways (Van Vuuren et al., 2011). These global scale climate scenarios are translated to regional and local scale climate scenarios using a number of statistical and dynamical downscaling tools and methodologies (Anandhi, 2010; Anandhi et al., 2018; Pan et al., 2011) with their own advantages and disadvantages.

Given the high volume of studies and lines of evidence, and the availability of a number of methods for developing scenarios (Fowler et al., 2007) and the need to develop decision support tools, that developing a tool that combines scenario development and meta-

analysis is novel, warranted, and timely. Additionally, it would improve the linkages between climate-impacts research and planning, management, adaptation, and mitigation by providing quantitative information to stakeholders and managers. The objective of this study was to develop and demonstrate the decision support tool that could reduce the disconnect between the supply and demand for climate information in making decisions from climate change impact assessment of natural and man-made ecosystems. The tool developed by this study has three major components: (a) perform meta-analysis—synthesize and combine recent relevant studies to arrive at conclusions about a body of research on temperature and precipitation changes, (b) develop climate scenario(s) (synthetic or incremental) from meta-analysis, and (c) development causal chain and loops (Figure 1). Although the developed decision tool is demonstrated by applying it to selected ecosystems and environments in Florida, USA, the tool can be used by multiple stakeholders in various ecosystems and environments throughout the world.

2 | STUDY REGION AND DATA USED

2.1 | Description of study region

Florida has been selected for this study (Figure 1) because it has many endemic plants, vertebrates, and insects that are only found in Florida and the tropics. (Reece, Noss, Oetting, Hoctor, & Volk, 2013). The state has approximately 2,000 miles of coastline, and the maximum distance from the coast less than 150 km (Hamed et al., 2016; Reece et al., 2013). Florida's coastline contains diverse ecosystems and landscapes which are suitable habitat for many endangered species for example, sea turtles (Hamed et al., 2016). In general, coastal estuaries and bays are of great ecological value and economic significance. They produce about 50% of global ecosystem services that benefit humans (Barbier et al., 2011).

Agricultural production is one of the most important economic drivers for Florida's economy (Cheng, Nnadi, & Liou, 2015). In 2016, Florida ranks first for fresh market snap bean, cucumber, grapefruit, oranges, sugarcane, tomatoes, and watermelon production; second in production of bell peppers, sweet corn, squash, and strawberries; third in production cabbage and honey; and fourth in peanuts. Overall, Florida accounts for roughly 54% of total U.S. citrus production (USDA-NASS, 2017) and ranks seventh in U.S. for agricultural exports, with over \$4 billion in agriculture commodities shipped in 2015 (FDACS, 2014; FDACS, 2016). Florida crops yield 63% of the winter vegetables for the United States with revenues of \$1.48 billion in 1995–1996 (Cheng et al., 2015).

Florida is the fourth most populous state in the United States and the third fastest growing state, with more than 17% net increase in population from 2000 to 2010. Florida's biodiversity is threatened by these related stressors including increasing urbanization (Reece et al., 2013), land-use change (Mulkey, 2007), increasing population, and socio-economic growth. Altered land use in turn has impacted the climate of the region (Misra, Mishra, Bhardwaj, Viswanthan, & Schmutz, 2018). Natural and anthropogenic disturbances vary in duration, frequency, size, and intensity. These stressors and play a crucial role in facilitating adaptive change (Alongi, 2008). Drought-induced

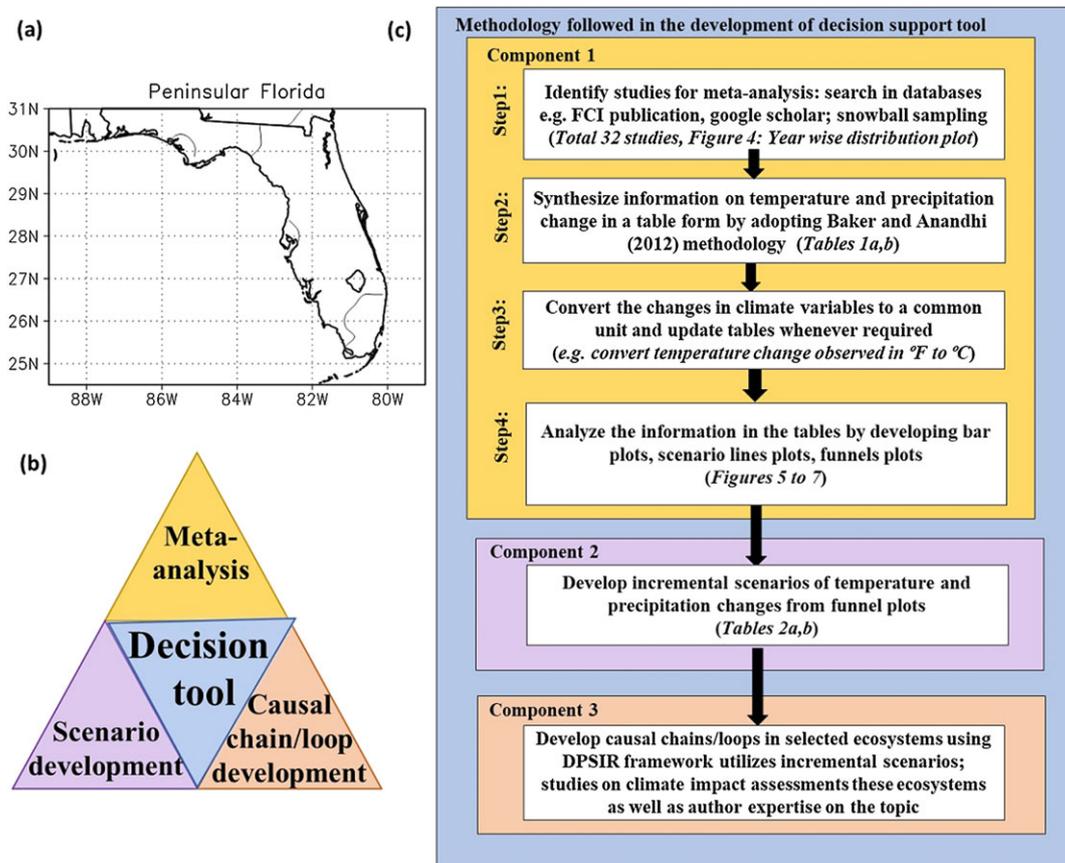


FIGURE 1 (a) Location map of study region: Florida, USA. (b) Three components of the decision support tool. (c) Steps followed in development of tool. In the figure, DPSIR refers to Driving Forces Pressure State Impacts Response. Snowball sampling refers to using the reference list of a paper or the citations to the paper to identify additional papers. Incremental scenario refers to a method of scenario development where a climatic variable is changed incrementally by arbitrary amounts (e.g., +1°C, +2°C, +3°C, +4°C change in temperature). That does not necessarily present a physically plausible or realistic set of changes. Causal chain is an ordered sequence of events in which any one event in the chain causes the next. Causal loop is when an event in the chain causes an earlier event in the chain then the loop developed is referred to as causal loop

wildfire also pose serious problems in Florida. Statistics show that 25,137 fires burned 1.5 million acres between 1998 and 2002 (Cheng et al., 2015). The close proximity of coastal ecosystems, large human populations, and high productivity make ecosystems in Florida some of the most heavily utilized and threatened on the planet (Barbier et al., 2011). The Everglades, located in South Florida, is one of the world's largest wetlands. The Everglades is an example of an estuary that has been substantially altered by humans (Kearney et al., 2015). El Niño Southern Oscillation also strongly influence the climate of Florida and agriculture (Cheng et al., 2015). Managed ecosystems have fared better than natural ecosystems to changes (Mulkey, 2007). Climate change and variability will interact symbiotically with existing and increased stresses, potentially accentuating negative impacts (Scavia et al., 2002). Florida was chosen to demonstrate the application of the decision support tool due to its unique economic, geographic, demographic, and ecological characteristics.

2.2 | Data used

The first step in using the decision support tool is the meta-analysis. In the meta-analysis, relevant data are collected from peer-reviewed published studies. These studies provide either observed or synthesized data about changes in temperature and precipitation, direction

of change as well as impacts from altered climate on Florida ecosystems. For example, Table 1a,b shows the citation and details about data sources, methodology, and how changes were estimated, time period of study, temporal scale (e.g., annual and seasonal), and spatial scale (e.g., local, state, regional, or national). Meta-analysis methodology is described in more detail in Section 3.1. Data derived in the meta-analysis were used as input in the second component for scenario development. Finally, expert knowledge, Table 1, and additional studies were used to develop causal chains and loops—the third component of the decision support tool.

3 | METHODOLOGY

The decision support tool has three components: meta-analysis, scenario development, and development of causal chains and loops (Figure 1). Each of the three components can be stand-alone or be combined with the other components (Figures 2 and 3).

3.1 | Component 1 of decision support tool: Meta-analysis

Meta-analysis is defined as the statistical analysis of relevant studies available in literature. The selected studies were analysed in a way

TABLE 1a Change in temperature observed from meta-analysis

References	Region	Variable	Observation (O)/Models (M)	Period	Value (°C)
Devitt and Tol (2012)	FL	T annual	O M	1880–2010 2010–2100	0.2 to 0.4 5
Solomon et al. (2007)	FL	T annual	O	1997–2007	0.1
Maul and Sims (2007)	SF	T annual	O	1860–2002	0.2 to 0.4
Obeyskera, Barnes, and Nungesser (2015)	SF	T annual	M	2011–2060	1.5
Obeyskera et al. (2011)	SF	T annual	M	1985–2055	1 to 2
Nungesser et al. (2015)	SF	T annual	O	1965–2003	1.5
Koch et al. (2015)	SF	T annual	M	2014–2060	1.5
Orem et al. (2015)	SF	T annual	M	2014–2060	1.5
USEPA (2016)	USA	T annual	M	1901–2015	0.05 to 1.38
Portmann et al. (2009)	USA	T min (May & June) T max (May & June)	O	1950–2006	0.02 to 0.4 0.00 to 0.2
Hansen et al. (2006)	G	T annual	O	2001–2005	0.2 to 0.4
Karl (2009)	USA	T winter T annual ^a T annual ^a T annual ^a T annual ^a T annual ^a T annual ^a	O M M M M M	1975–2007 1993–2008 2010–2029 2040–2059 2080–2099	1.11 0.55 1.11 1.11 to 2.22 0.55 to 1.66 2.77 to 3.88 1.11 to 2.22
Meehl and Tebaldi (2004)		T min (daily)	M	1975–2088	1.7 to 2.5
Walther et al. (2002)		T annual	O	1976–2002	0.7
Easterling et al. (1997)	G	T annual max T annual min T diurnal	O O O	1961–1990	3 1 3
Jones et al. (1999)	G	T annual	O O O	1925–1944 1978–1997 1961–1998	0.5 0.5 0.2 to 0.4
Fiedler et al. (2001)	FL	T annual	M	2001–2100	2.22 to 5.55
Stephenson et al. (2014)	SF	T annual	O	1961–2010	0.3
Kunkel et al. (2013)	USA	T annual T annual ^a T annual ^a T annual ^a T annual ^a T annual ^a	M M M M M	2071–2099 2021–2050 2041–2070 2070–2099	1.66 to 2.22 0.83 to 1.38 0.83 to 1.38 1.38 to 1.94 0.83 to 1.38 2.5 to 3.61 0.83 to 1.38
Sun et al. (2015)	USA	T annual ^b T annual ^b	M M M M M M M M M M M M	2021–2050 2021–2050 2021–2050 2021–2050 2041–2070 2041–2070 2041–2070 2041–2070 2070–2099 2070–2099 2070–2099 2070–2099 2070–2099	1.11 to 1.66 1.11 1.11 to 2.22 1.66 1.11 to 1.66 1.11 1.11 to 2.22 1.11 3.33 to 3.88 2.22 to 2.77 1.66 to 2.22 1.11
Karl et al. (1996)	USA	T annual	O	1900–1994	0.5
Williams (2010)	SEUS	T min winter T min summer T min spring T min fall T max winter T max summer T max spring T max fall	O O O O O O O O	1920–1998 1920–1998 1920–1998 1920–1998 1920–1988 1920–1988 1920–1988 1920–1988	–2.22 –1.11 to 1.11 –1.11 to 1.66 –0.55 to 1.66 –2.22 to –0.55 –0.55 to 1.11 –1.11 to 1.11 –0.55 to 1.11
Wuebbles et al. (2014)	USA USA USA USA	T min T max T min T max	M M M M	1996–2091 1997–2091 1998–2091 1999–2091	1 to 2 1 3 to 5 3 to 6
Soule (2005)	SEUS	T annual	O	1961–1990	–0.24 to 1.39

(Continues)

TABLE 1a (Continued)

References	Region	Variable	Observation (O)/Models (M)	Period	Value (°C)
Rosenzweig et al. (2014)	USA	T winter	M	1980–2050	1.5
		T summer	M	1980–2050	3
Rogers (2013)	USA	T annual	O	1895–2007	0.5 to 1
Parkinson et al. (2015)	FL	T annual	M	2014–2100	1 to 4
Martinez et al. (2012)	FL	T summer max (JJA)	O	1895–2009	–0.035
	FL	T summer max (JJA)	O	1970–2009	0.4
	FL	T summer min (JJA)	O	1895–2009	0.018
	FL	T summer min (JJA)	O	1970–2009	0.018 to 0.03
Pachauri et al. (2014)	G	T annual	M	1995–2090	0.5 to 1
		T annual	M	1995–2090	3 to 5
IPCC (2007)	G	T annual	O	1970–2004	–0.2 to 0.2
	USA	T annual	M	2080–2099	1.5 to 3

Note. The change values in the last column was used to develop the bar plots in Figures 5–7. FL: Florida; SF: South Florida; G: global.

^aRefers to CMIP3.

^bRefers to CMIP5.

so that the findings may be summarized and integrated to reveal valuable information. The number of studies in meta-analysis is often limited to a manageable number of relevant, important, and pertinent findings. In our meta-analysis, studies with changes in temperature and precipitation in Florida as well as studies with potential impacts of these changes on various natural and man-made ecosystems were considered. The results of the meta-analysis were used for the development of scenarios and causal chains and loops.

Step 1. The meta-analysis for this study began with 446 publications from faculty affiliated with Florida Climate Institute (<https://floridaclimateinstitute.org/resources>) published between 2000 and 2017. Studies were divided into three groups: (a) climate change studies that focused on portions or the entire state of Florida, (b) the entire south-eastern United States (SEUS), and (c) the rest of the world. Fourteen studies in Groups 1 and 2 cited temperature and precipitation change values. The snowball sampling approach (Goodman, 1961; Lynch et al., 2016) was used to obtain additional studies. Snowball sampling refers to using the reference list of a study (backward snowball sampling) or the citations to the study (forward snowball sampling) to identify additional studies. Using snowball sampling of the 14 studies, additional 11 more studies were downloaded from databases (e.g., web of science and google scholar). These 11 studies were either cited or were in the reference list of the 14 studies. Additionally, we used multiple search strings to identify more relevant studies (e.g., “climate change” and “vulnerability to ecosystem” and Florida; “global warming” and “vulnerability to ecosystem” and Florida; “precipitation and temperature change in Florida”) in google scholar database. Adding the study region “Florida” in the search string was useful to bring the number of studies to a manageable number. We found seven additional studies using this methodology. In general, for the study region, we used studies that explicitly mentioned temperature and precipitation change values and while in some cases, the information was extracted from the figures and tables. There were 32 studies with quantitative directional changes in temperature and precipitation for Florida (14 from Florida Climate Institute publications; 11 from

the snowball sampling approach; and 7 from string searches in databases). The frequency distribution plot of the studies based on the year of publication was carried out (Figure 4).

Step 2. The information from the 32 studies was synthesized into two tables, one for each climate variable (temperature and precipitation; Tables 1a and 1b) with the help of the Anandhi and Baker (2013) research tool. The table contains information on region (e.g., south Florida), variable of interest (e.g., annual temperature), whether the variable was observed or modelled (e.g., meteorological stations, GCM), period of data (e.g., 1960–2005), and the change value (e.g., 5% precipitation change).

Step 3. The changes were converted to a common unit. For example, some studies showed temperature change in degree Fahrenheit. These changes were converted to a common degree Celsius temperature scale.

Step 4. Changes in observed climates from the studies were synthesized using bar plots, scenario line plots, and funnel plots.

Individual changes observed were plotted using a bar plot. Each bar in the bar plot and row in the table (Tables 1a and 1b) represents a change in value for the variable (e.g., temperature and precipitation). This plot was used to report the overall changes and ranges observed across the 32 studies in Florida. The differences among the studies other than changes in variables were not very obvious from the bar plot. For example, two studies, both with a 10% precipitation change, appear the same on the bar plot, but their differences in time periods may not be seen. These differences can be observed from the scenario line plot and scenario funnel plot.

The scenario line plot (referred as a scenario line) combined all of the change values observed in the studies (Tables 1a and 1b). In this plot, lines are drawn between years (x-axis) and changes values of precipitation and temperature (y-axis; referred to as scenario lines). Although for this study, scenario lines are used for precipitation and temperature, the methodology is applicable to other types of variables as well, for example, changes in drought, frost, wind, and solar radiation). Each scenario line was plotted between the start and end year of the documented change. When the change values at the start was

TABLE 1b Percent change in precipitation observed from meta-analysis

References	Region	Variable	Observation (O)/Models (M)	Period	Value (%)
Devitt and Tol (2012)	FL	P annual	O	1895–2006	10
Orem et al. (2015)	SF	P annual	M	2014–2060	±10
Obeysekera et al. (2015)	SF	P annual	M	2011–2060	±10
Obeysekera et al. (2011)	SF	P annual	M	1985–2055	±10
Nungesser et al. (2015)		P annual	O	1965–2003	±10
Koch et al. (2015)	SF	P annual	M	2014–2060	±10
USEPA (2016)	USA	P annual	M	1901–2015	±10
Karl (2009)	SEUS	P summer	O	1901–2007	–15 to 10
	SEUS	P winter	O	1901–2007	–5 to 20
	SEUS	P spring	O	1901–2007	–15 to +5
	SEUS	P fall	O	1901–2007	–10 to +30
	USA	P very heavy	O	1958–2007	10 to 20
	USA	P winter	M	2080–2099	–10 to 0
	USA	P summer	M	2080–2099	–35 to 0
	USA	P spring	M	2080–2099	–30 to –15
	USA	P fall	M	2080–2099	5 to +15
	USA	P annual	O	1958–2008	–15 to 5
Walther et al. (2002)		P annual	O	1976–2002	0 to +10
Sun et al. (2015)	USA	P annual ^a	M	2021–2050	0 to 5
	USA	P annual ^a	M	2021–2050	0 to 5
	USA	P annual ^a	M	2021–2050	0 to 5
	USA	P annual ^a	M	2021–2050	0 to 5
	USA	P annual ^a	M	2041–2070	0 to 5
	USA	P annual ^a	M	2041–2070	0 to 5
	USA	P annual ^a	M	2041–2070	0 to 5
	USA	P annual ^a	M	2041–2070	0 to 5
	USA	P annual ^a	M	2070–2099	–5 to 0
	USA	P annual ^a	M	2070–2099	0 to 5
	USA	P annual ^a	M	2070–2099	5.0 to 10.0
	USA	P annual ^a	M	2070–2099	0 to 10
IPCC (2007)	USA	P annual	M	2080–2099	–5 to 5
Karl et al. (1996)	USA	P annual	O	1900–1994	10
Xiao, Wang, Hagen, Medeiros, and Hall (2016)	EC FL	P annual	M	2010–2050	–7 to 17
Wuebbles et al. (2014)	USA	P max daily	M	1996–2091	5 to 15
	USA	P max daily	M	1996–2091	10 to 25
Martinez et al. (2012)	FL	P annual	O	1895–2009	–2 to +5
	FL	P annual	O	1970–2009	–1 to +1
	FL	P summer (JJA)	O	1895–2009	–3 to +4
	FL	P summer (JJA)	O	1970–2009	0 to +1
	FL	P annual	O	1895–2009	0 to +2
	FL	P annual	O	1970–2009	0 to +1
	FL	P summer (JJA)	O	1895–2009	–3 to +4
	FL	P summer (JJA)	O	1970–2009	0 to +2
Pachauri et al. (2014)	G	P annual	M	1995–2090	10
	G	P annual	M	1995–2090	±10

Note. The change values in the last column was used to develop the bar plots in Figures 5–7. FL: Florida, SF: South Florida; G: global.

^aRefers to CMIP5.

not provided, a zero-change value was assumed; the change value for the end year of change was obtained from the study. Each value (row) in the table (Tables 1a and 1b) was used to draw one scenario line. The number of scenario lines was based on the number of studies identified as well as the number of change values available in each study.

Scenario funnel plot (referred as funnel plots) are derived by combining one or more scenario lines. Similar to scenario lines, the x-axis in funnel plots represented the time (e.g., years) whereas y-axis represented the changes in precipitation and temperature. In general, there are several ways funnel plots could be developed. A funnel plot could be developed with a minimum of two scenario lines, or with several scenario lines (e.g., Rows 1 to 3 in Figure 2). In other words, we need at least two change values for a variable or two bars in a bar plot to

develop a scenario funnel. Similarly, the multiple scenario lines could be used to form one or more scenario funnels (e.g., Rows 4 and 5 in Figure 2). When there were multiple change values for a variable or bar, they can be translated into one or more scenario funnels for each variable as observed in Rows 4 and 5 in Figure 2. The number of scenario funnels is subjective based on the distribution of the scenario lines (Rows 1 to 3 or Rows 4 and 5 in Figure 2), level of detail required, resources available as well as spatial and temporal scales (Rows 4 and 5 in Figure 2) of the study. Depending on the scenario lines, the funnel plots could be symmetrical (funnels in Rows 1 to 3) or asymmetrical (funnels in Rows 4 and 5) along x-axis. The width of the funnel mouth represents the differences among various predictions in the studies. For example, the broader funnels represent larger difference among

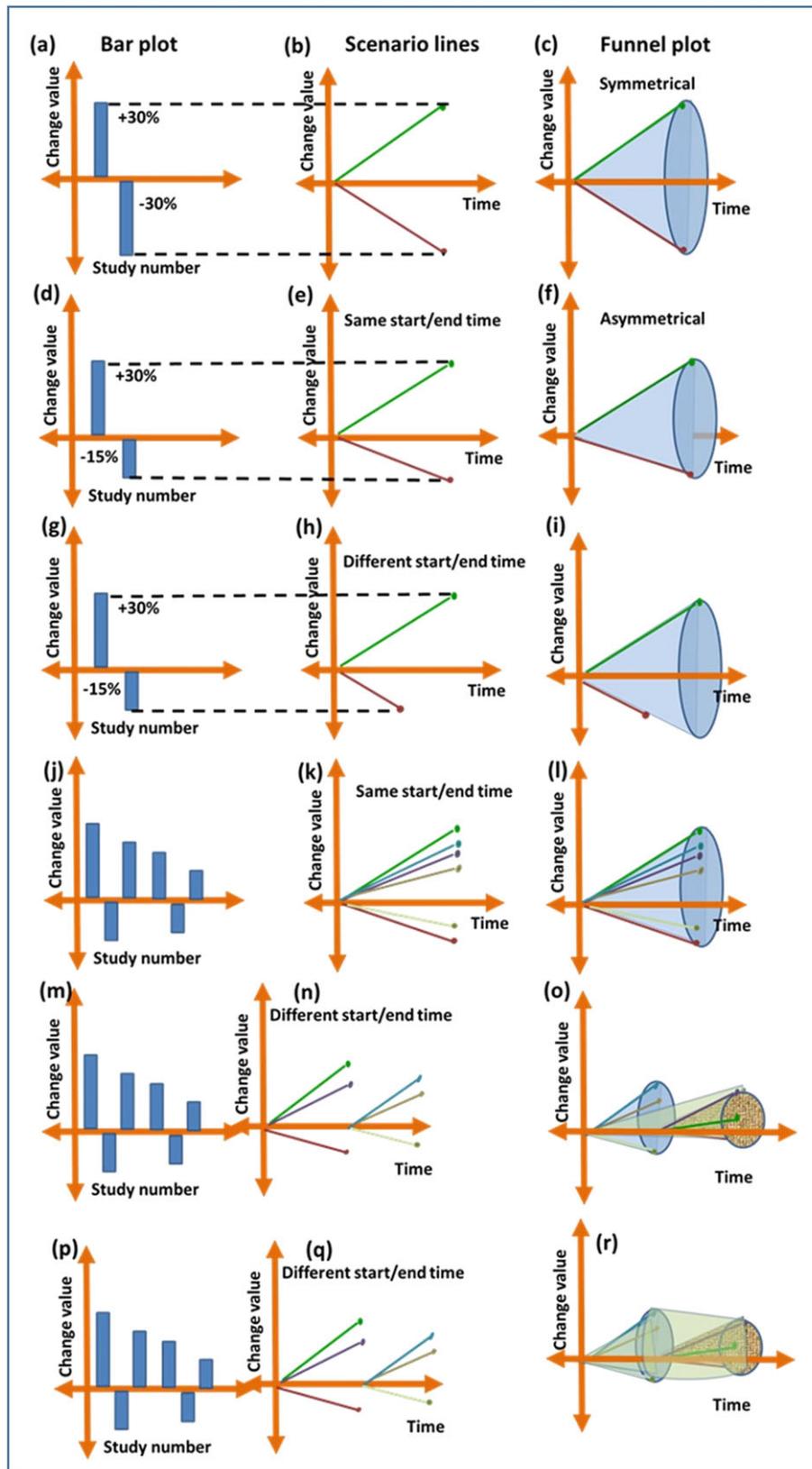


FIGURE 2 Methodology in developing scenario funnel plots (Column 3) from bar plots (Column 1) and scenario lines (Column 2) using theoretical change values. Row 1 is an example of symmetrical funnel plot (equal change values in both directions) and Row 2 is for asymmetrical funnel plot. Rows 1, 2, and 4 are examples with change values having same start and end times, and Rows 3 and 5 are examples with change values having different times. Rows 1 to 4 are examples in developing a single funnel plot whereas Row 5 is an example with multiple funnel plots (blue, brown, and green). Funnel plot in Rows 1 to 5 are examples of funnels with increasing width, whereas funnel in Row 6 (green funnel) represents a funnel that is increasing initially and later decreasing

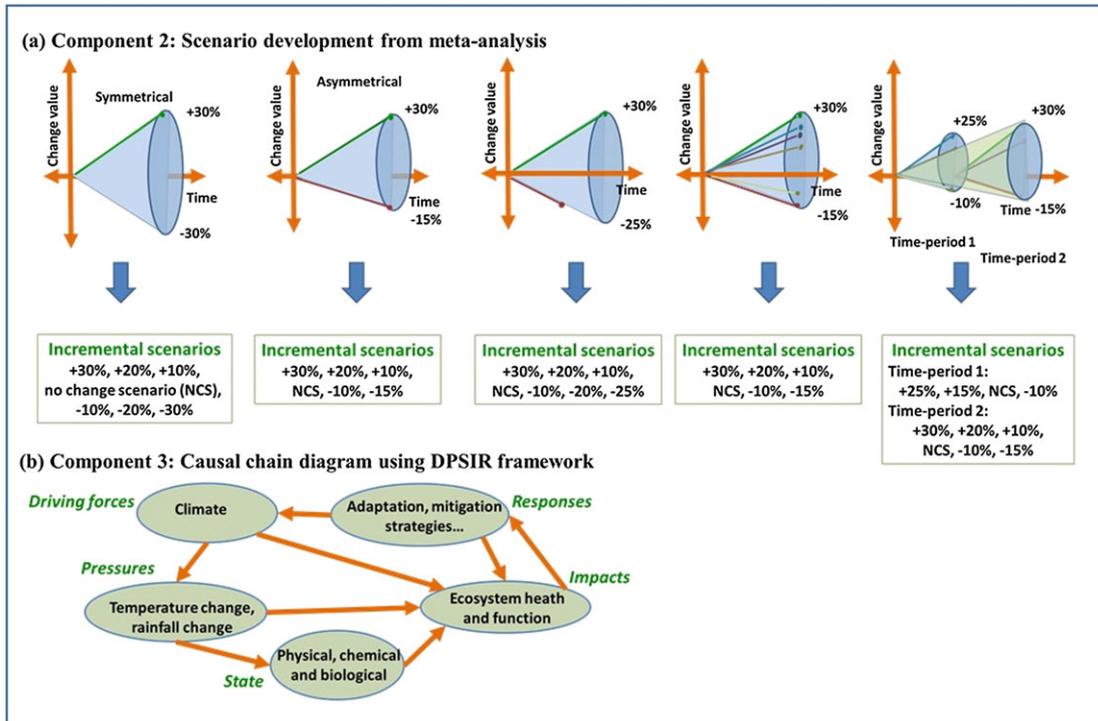


FIGURE 3 Methodology for Components 2 and 3. The scenario funnel plots (Column 3) from Figure 2c,d,i,l,f with theoretical change values and those in the first row in the figure are the same

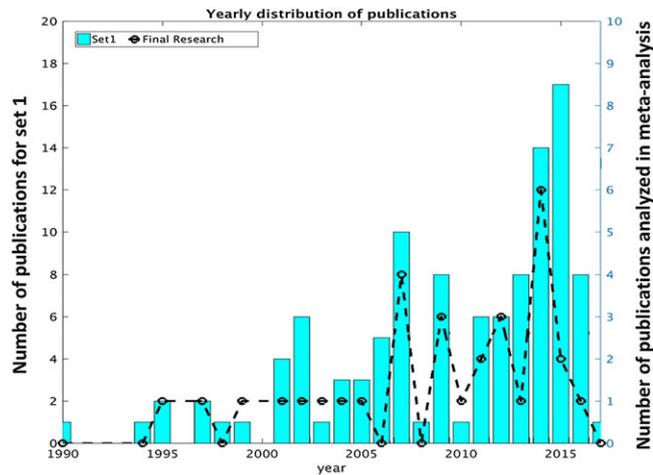


FIGURE 4 Year wise distribution of publications observed in this study. The two y-axes are different

various predictions, whereas the narrow funnel represent lesser difference among predictions. The width of the funnel can change with time. The funnel width can increase with time (funnel in Rows 1 to 4) showing that the differences among various predictions increase with time. The funnel width can also first increase and then decrease with time (funnel in Row 6). The different funnel plots were illustrated using theoretical change values. These types of funnel plots are further discussed in sections (Section 4) showing actual change values. Multiple funnel plots were developed for Florida from 32 studies and used in the development of incremental scenarios.

3.2 | Methodology followed for Component 2: Scenario development from meta-analysis

In this study, incremental scenarios were derived from funnel plots (Figure 3). In general, incremental or synthetic scenario generation (IPCC, 1994) refers to a method of scenario development where a climatic variable is changed incrementally by arbitrary amounts. For example, a temperature can be changed incrementally by arbitrary amounts of 1°C (e.g., +1, +2, +3, +4°C) change in temperature. These arbitrary amounts need not necessarily present a physically plausible or realistic set of changes. In this study, the incremental amounts were based on the range of changes observed during the synthesis of existing literature (Component 1: meta-analysis). They are usually adapted for exploring system sensitivity prior to the application of more credible, model-based scenarios (Anandhi et al., 2011). Studies included in meta-analysis combine change values from the GCMs as well as observations. In a broad sense, this method can be classified as scenarios generated from GCMs using simple manipulation of climate observations (e.g., change factors). Other methods used in the development of future climate scenarios are (a) based on analogy with different climatic zones or historical time periods and (b) from more sophisticated statistical and dynamic downscaling of variables (Anandhi, 2010; Anandhi et al., 2011). The most commonly used scenario type is based on outputs from the GCMs. These methods have been applied with reference to or in conjunction with model-based scenarios.

Scenario funnels provide a dynamic view of the future through exploring various paths of change in variables (Mahmoud et al., 2009; Timpe & Scheepers, 2003). This leads to a wide range of alternative futures. For example, a typical scenario funnel for temperature and precipitation change is observed in Figure 5c,f. The plot provides

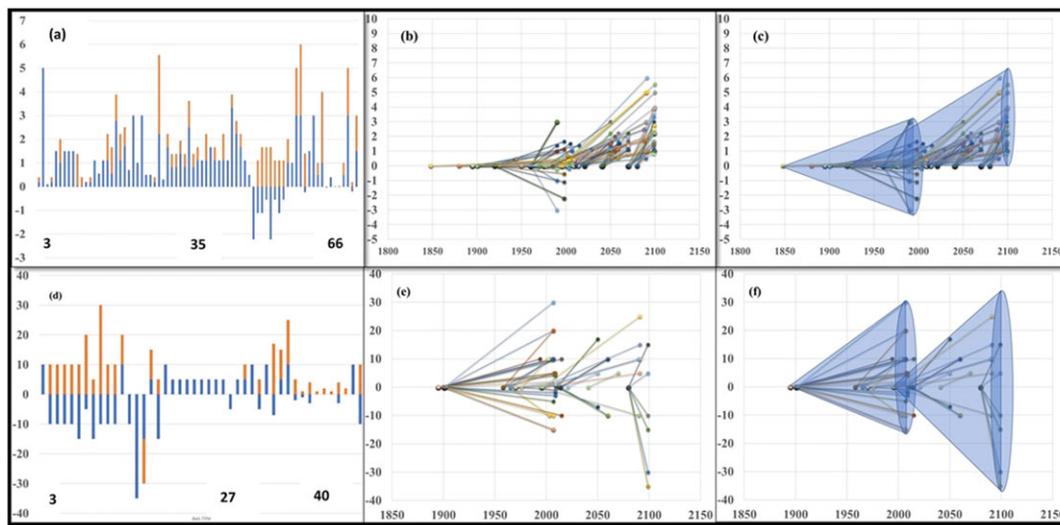


FIGURE 5 (a–c) Bar plot, scenario lines, and funnel plots for temperature change in °C (y-axis). (d–f) Bar plots, scenario lines, and funnel plots for precipitation change in percent (y-axis), respectively. X-axis in bar plots (a,d) were for individual studies (serial numbers) whereas in scenario lines and funnel plots, they were years. In bar plots, blue bars represent values cited and orange bars represent a range from value cited if applicable

insight into probable future changes in temperature rather than one single possible future (Timpe & Scheepers, 2003). If we observe the changes from today's standpoint gazing into the future, the range of possible changes in temperature is large. Ranges in change values for climate variables (spread of the funnel mouth) were arbitrarily divided into change values in the funnels (Figure 3a). Incremental scenarios were developed using 10% increments of change for precipitation and 1°C increments for temperature.

Climate scenarios developed from meta-analysis can be adopted for impact studies for developing synthesized scenarios from multiple studies. The likelihood is high that they have combined multiple scenarios and development methods. There are several limitations that may restrict the usefulness of these studies for impact assessment: (a) the mismatch between spatial resolution of studies in meta-analysis and the resolution required for impact assessments; (b) the difficulty in distinguishing an anthropogenic signal from the

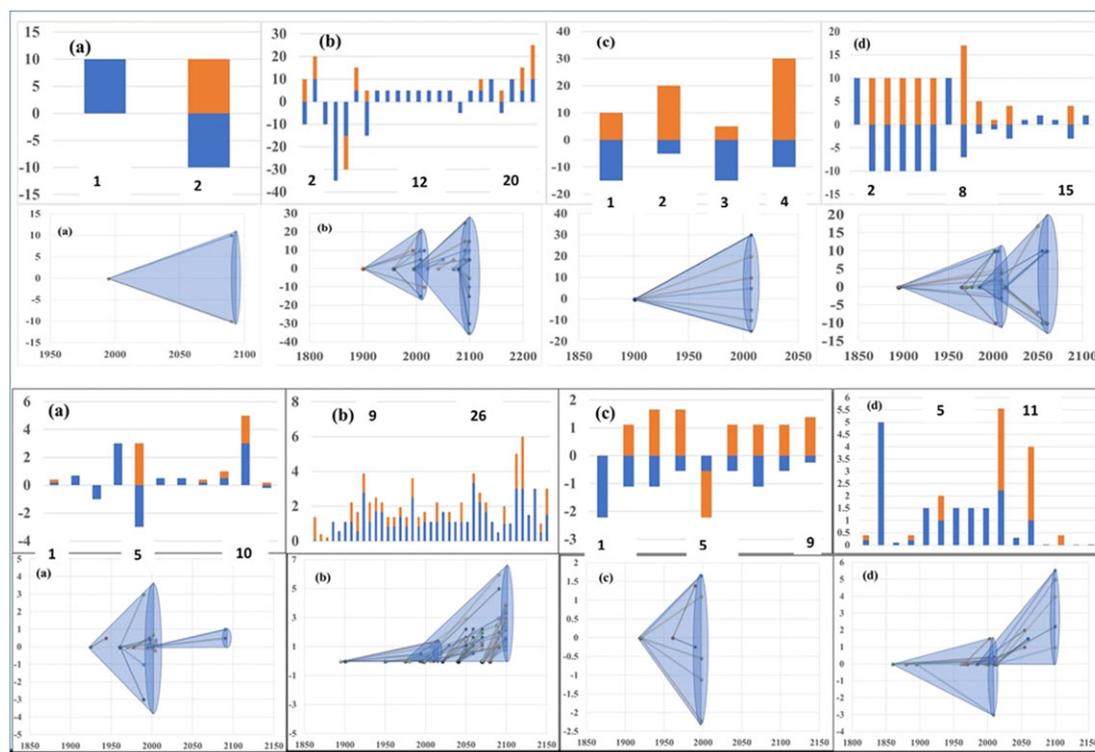


FIGURE 6 Spatial distribution of individual studies using bar plots (Rows 1 and 3) and distribution of the studies using funnel plots (Rows 2 and 4). Rows 1 and 3 represent temperature change, and Rows 2 and 4 represent precipitation change observed from meta-analysis in Florida region, respectively. The columns show the changes in temperature and precipitation obtained from studies at (a) global, (b) USA, (c) south-eastern United States, and (d) Florida spatial scales. The x-axis in bar plots (Rows 1 and 3) are serial numbers

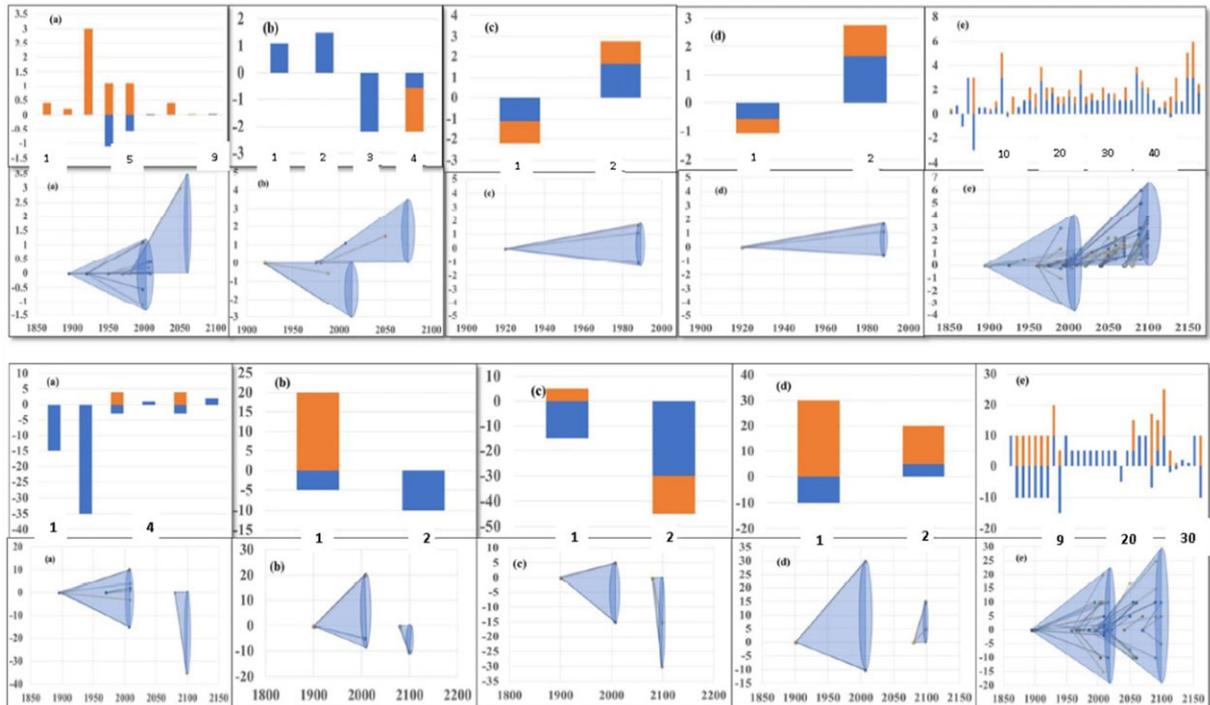


FIGURE 7 Temporal distribution of temperature and precipitation change bar plots (Rows 1 and 3) and funnel plots (Rows 2 and 4) observed from meta-analysis for Florida region. The studies were separated temporally for four seasons (a) summer, (b) winter, (c) spring, (d) fall, and (e) the rest (e.g., annual/diurnal/daily) for Florida. The x-axis in bar plots (Rows 1 and 3) are serial numbers for the studies in Tables 1a and 1b

noise generated by inherent internal model variability; and (c) the difference in climate sensitivity for various models. In spite of these limitations, the scenarios developed using meta-analysis can be widely used for developing climate scenarios for quantitative impact assessments.

3.3 | Methodology followed for Component 3: Causal chains and loops development

In Component 3, causal chain and loop diagrams were developed. Causal chain is an ordered sequence of events in which any one event in the chain causes the next. Causal loop is when an event in the chain causes an earlier event in the chain then the loop developed is referred to as causal loop. Describing the causal chain from driving forces to impacts and response is a complex task and needs to be broken down into sub-tasks (Kristensen, 2004). These diagrams explain the cause and effect behaviour from the systems (e.g., ecosystems) standpoint to assess the impacts of climate change on multiple ecosystems. There are a number of frameworks available for the development of causal chains. One is the Driving Forces Pressure State Impacts Response (DPSIR) framework, in which there is a chain of causal links (or components) starting with “driving forces” (e.g., climate, temperature, and precipitation change) through “pressures” (e.g., changes in freeze and rain) to “states” (physical, chemical, and biological states) and “impacts” on ecosystems health and functions, eventually leading to “responses” (prioritization, target setting,). The other is the Global International Waters Assessment where the causal chain is an assessment of the linkages between problems and their underlying (root) causes (includes immediate and intermediate causes, and the

root causes that lead to the creation of the problem, Kristensen, 2004).

In this study, the DPSIR framework was used to develop the causal chain diagram for selected ecosystems in Florida. The components in the DPSIR network are easily described using indicators in most ecosystems. Indicators are powerful tools used to communicate technical data in relatively simple terms which portray the interrelationships among climate and other physical and biological elements of the environment. In this study, they are used to facilitate identification of discernible impacts from climate change (Anandhi, Steiner, & Bailey, 2016). Causal chain and loop diagrams were developed using one or more studies in the meta-analysis, incremental scenarios developed in this study, studies on altered climate impact assessments, and author expertise on the topic. Essentially, the diagrams convert the complexity of the ecosystem into relatively simple, easily understood cause and effect diagram. These diagrams can be subsequently used to develop further experiments to help understand cause and effect in more detail.

4 | RESULTS AND DISCUSSION

The results of the meta-analysis (Component 1 of the decision support tool) were discussed using yearly distribution plots, bar plots, scenario line plots, and funnel plots (Figures 5–7) and tables (Tables 1a and 1b). Incremental scenarios (Tables 2a and 2b, Figure 3) were developed by summarizing ranges of change values in scenario funnels. Subsequently, causal chain diagrams (Component 3) were used to explain the cause and effect (Figure 8) for multiple stakeholders.

TABLE 2a Incremental scenarios developed for temperature based on scenario funnels (Figures 6 and 7)

	Time period	Ranges	Incremental scenarios	No. of studies (change value)
Spatial scale				
Global	1925–2005	–0.2 to 3	–1, 0, 1, 2, 3	7
	1995–2090	0 to 5	0, 1, 2, 3, 4, 5	2
USA	1895–2008	0 to 1.11	0, 1, 2	5
	1996–2099	0 to 6	0, 1, 2, 3, 4, 5, 6	33
SEUS	1920–1990	–2.22 to 1.66	–3, –2, –1, 0, 1, 2	9
Florida	1860–2003	0 to 1.5	0, 1, 2	2
	1985–2100	0 to 5.55	0, 1, 2, 3, 4, 5, 6	14
Temporal scale				
Summer	1895–1998	–1.11 to 1.11	–2, –1, 0, 1, 2	2
	1980–2050	0 to 3	0, 1, 2, 3	7
Winter	1920–1998	–2.22 to 0	–3, –2, –1, 0	2
	1975–2050	0 to 1.5	0, 1, 2	2
Spring	1920–1988	–1.11 to 1.66	–2, –1, 0, 1, 2	2
Fall	1920–1988	–1.11 to 1.66	–2, –1, 0, 1, 2	2
Annual/diurnal	1895–2008	–0.24 to 3	0, 1, 2	7
	1996–2099	0 to 6	0, 1, 2, 3, 4, 5, 6	27

Note. SEUS: south-eastern United States.

TABLE 2b Incremental scenarios developed for precipitation based on scenario funnels (Figures 6 and 7)

	Time period	Ranges	Incremental scenarios	No. of studies (change value)
Spatial scale				
Global	1995–2090	±10%	–10, 0, 10	2
USA	1900–2015	–15% to 20%	–20, –10, 0, 10, 20	4
	1996–2099	–35% to 25%	–40, –30, –20, –10, 0, 10, 20	19
SEUS	1901–2007	–15% to 30%	–20, –10, 0, 10, 20, 30	4
Florida	1895–2009	±10%	–10, 0, 10	11
	2006–2060	–10% to 17%	–10, 0, 10, 20	5
Temporal scale				
Summer	1895–2009	–15% to 10%	–20, –10, 0, 10	5
	2080–2099	–35% to 0%	–40, –30, –20, –10, 0	1
Winter	1901–2007	–5% to 20%	–10, 0, 10, 20	1
	2080–2099	–10 to 0	–10, 0	1
Spring	1901–2007	–15% to +5%	–20, –10, 0, 10	1
	2080–2099	–30% to 0%	–30, –20, –10, 0	1
Fall	1901–2007	–10% to 30%	–10, 0, 10, 20, 30	1
	2080–2099	5% to 15%	0, 10, 20	1
Annual/diurnal	1895–2008	–15% to 20%	–20, –10, 0, 10, 20	6
	1996–2099	–10% to 25%	–10, 0, 10, 20, 30	26

Note. SEUS: south-eastern United States.

4.1 | Meta-analyses: Distribution plots, bar plots, scenario line plots, and funnel plots

The yearly distributions of the 32 studies (Step 1 in Section 3.1) and the total number of studies observed during systematic literature search were plotted (Figure 4). Around 2005, the total number of studies on climate change (precipitation and temperature) in Florida increased exponentially (nearly 10-fold). Temperature and precipitation changes documented among the studies used in meta-analysis over Florida could be observed from bars in Figure 5a and 5d, lines in Figure 5b and 5e. The spread of the changes can be observed from

funnel in Figure 5c and 5f. The temperature change ranged between 6°C and –3.5°C among individual studies, whereas precipitation change ranged between –30% and 35%. From Figure 5b, it is observed that temperature ranged between 3°C (Easterling et al., 1997) and –4°C during the 20th century but the range was higher up to 6°C during the 21st century. Figure 5e shows a –15% to 30% precipitation change during 20th century but a 25% to 35% increase during 21st century (Obeysekera et al., 2011; Orem, Newman, Osborne, & Reddy, 2015). Most studies suggest a gradual increase in temperature for the historical analysis, whereas future emission scenarios predict rapid increases. Temperature and precipitation

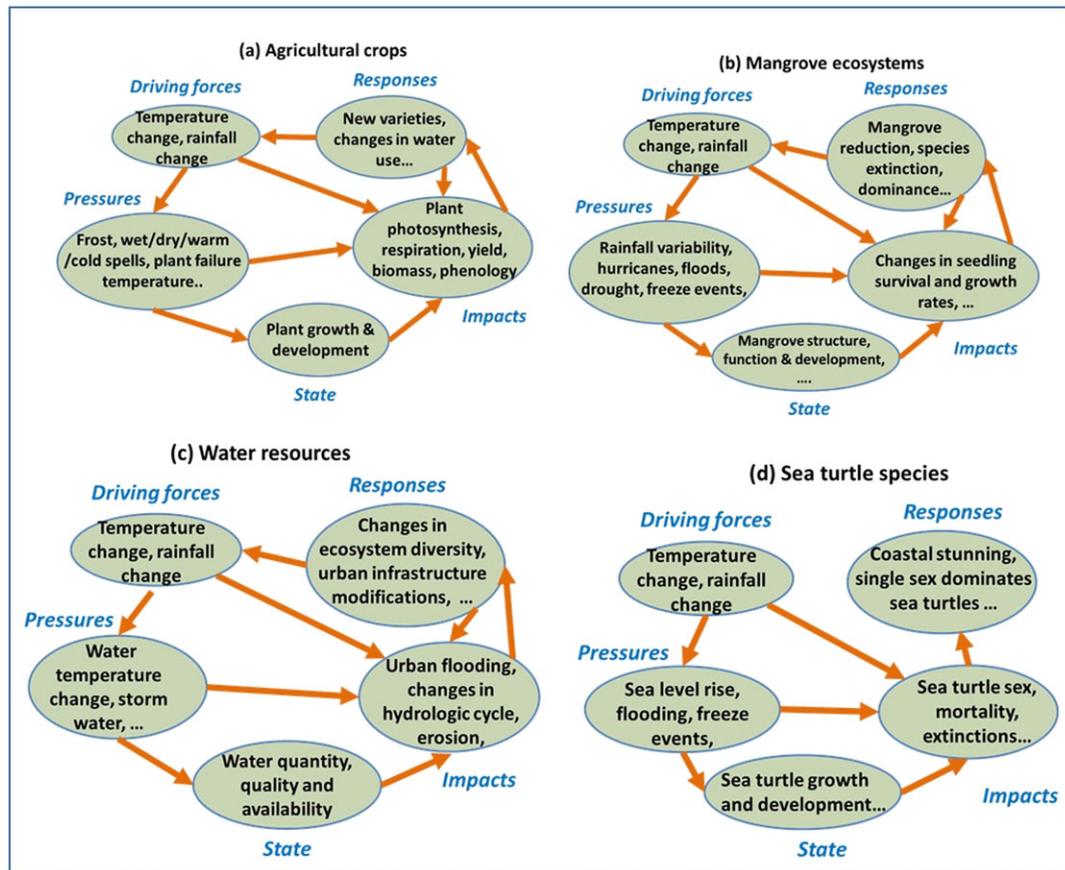


FIGURE 8 Potential causal chain and loop diagram for (a) agroecosystems, (b) mangrove ecosystems, (c) water resources, and (d) sea turtles. Agroecosystems is an example for man-made systems whereas mangrove ecosystems are an example for natural systems. Sea turtles are an example for an individual species, and water resources are representative of a natural resource. The ovals are made different sizes just to accommodate the text

changes observed using these scenario funnels could be subjective to the time period and spatial scales used.

4.2 | Meta-analysis: Spatio-temporal variability in temperature and precipitation changes

To observe if the changes in temperature and precipitation vary across spatial and temporal scales, the studies from Tables 1a and 1b were subset using two criteria. The first criteria were based on the spatial coverage of the original study into four classes, namely, whether the change values for Florida were obtained from (a) global studies, (b) entire United States, (c) south-eastern United States (SEUS), and (d) focused over entire or parts of Florida (Figure 6). From the bar plots, scenario lines, and funnels (Columns a to d in Figure 6), it was observed that the changes in temperature and precipitation were different across the classes. More information on spatio-temporal variability in temperature and precipitation changes in SEUS can be obtained from Anandhi and Bentley (2018).

The precipitation change in Florida (Rows 1 and 2 in Figure 6) ranged between $\pm 10\%$ in global studies for historical time period. The change was different for Florida in the second class (entire United States). The precipitation change ranged between $\sim(\pm 20\%)$ and $\sim 25\%$ to $\sim(-35\%)$ during historical and future time periods, respectively. For the third class (SEUS), the precipitation change in Florida ranged

between 30% and -10% for the historical period. Finally, in the fourth class (studies in entire or parts of Florida), the precipitation range was $\pm 10\%$ and 20% to about -12% during historical and future time periods. The temperature change in Florida (Rows 3 and 4 in Figure 6) ranged between $\sim 3^\circ\text{C}$ to -4°C and 0°C to 1°C in global studies for historical and future time periods, respectively. The change was different for Florida in the second class (entire United States). The temperature change ranged between 0°C to 1.38°C (Misra, Carlson, Craig, & Enfield, 2011) and $\sim 0^\circ\text{C}$ to $\sim 6^\circ\text{C}$ during historical and future time periods, respectively. For the third class (SEUS), the temperature change in Florida ranged between 1.39°C (Soule, 2005) and -3.5°C (Williams, 2010) for the historical period. Finally, in the fourth class (studies in entire or parts of Florida), the temperature range was $\sim 1.5^\circ\text{C}$ to -3°C and 0°C to 5.5°C during historical and future time periods.

The second criteria for classification were based on the seasonal/annual coverage of the original study. The five classes were, namely, four seasons (a) summer, (b) winter, (c) spring, (d) fall, and (e) the non-seasonal (e.g., annual/diurnal/daily; Figure 7). The precipitation change (Rows 1 and 2 in Figure 7) of -15% to 10% and 0 to -35% was observed for summer season during historical and future time periods, respectively. The change during winter season was $\sim(-15\%)$ to 10% and 0% to 10% during historical and future time periods, respectively. During autumn season, the changes in precipitation were in the ranges -15% to 5% and -30% to 0% in historical and future time periods,

respectively. The ranges observed were -10% to 30% and 0 to 30% during historical and future time periods, respectively, for spring season. Higher range of precipitation change of $\sim(\pm 20\%)$ and $\sim(-20\%)$ to $\sim 30\%$ during historical and future time periods, respectively, was observed in the fifth class (nonseasonal).

From Figure 7 (Rows 3 and 4), the temperature change of $\sim(-1.5^\circ\text{C})$ to 1.25°C and 0°C to 3.3°C during historical and future time periods, respectively, was observed for summer season. The change ranged from $\sim(-3^\circ\text{C})$ to 0°C and 0°C to $\sim 3.5^\circ\text{C}$ during historical and future time periods, respectively, during winter season. During autumn and spring seasons, the temperature change ranged $\sim(-1.5^\circ\text{C})$ to 2°C and $\sim(-0.5^\circ\text{C})$ to $\sim 0.5^\circ\text{C}$, respectively. Higher range of temperature change of $\sim(\pm 4^\circ\text{C})$ and 0 to $\sim 6^\circ\text{C}$ during historical and future time periods, respectively, was observed in the fifth class (nonseasonal).

4.3 | Incremental scenario development

Incremental temperature and precipitation change scenarios were developed in this study (Tables 2a and 2b, respectively), from precipitation changes ranging between $+30\%$ and -40% and temperature changes ranging from $+6^\circ\text{C}$ to -3°C for Florida. Incremental scenarios were developed at 10% increments in the precipitation change range and 1°C increments in the temperature change range. Incremental scenarios for Florida include $+30\%$, $+20\%$, $+10\%$, -10% , -20% , -30% , -40% precipitation changes, $+6^\circ\text{C}$, $+5^\circ\text{C}$, $+4^\circ\text{C}$, $+3^\circ\text{C}$, $+2^\circ\text{C}$, $+1^\circ\text{C}$, -1°C , -2°C , -3°C for temperature changes. Similarly, incremental scenarios for the two criteria of classification (discussed in previous section), namely, spatial (e.g., global studies, studies over United States, SEUS, and studies limited to Florida) and temporal scales (e.g., summer, winter, spring, fall, the rest), are listed in Tables 2a and 2b.

4.4 | Causal chains and loops for incremental scenarios

This section briefly describes the causal chains developed in this study using the DPSIR framework for multiple ecosystems in Florida, scenarios changes, and author expertise (Figure 8). The driving forces for every causal chain developed in this study were the temperature and precipitation changes. Incremental precipitation changes scenarios ranged between -40% and $+30\%$ in 10% increments whereas the temperature change scenarios ranged between -3°C and $+6^\circ\text{C}$ in 1°C increments. A no-change scenarios was not assessed. Adaptive responses were classified into three types depending on the degree of climate change and the level of adaptation as incremental, systems, and transformational adaptation—which varied from a minimal change to a more radical change in land use and management (Anandhi, 2017).

In the previous section, spatio-temporal changes in temperature and precipitation from 1850 to 2100 observed in the meta-analysis show the impacts of changes in these climate variables on Florida with its low topography, extensive coastline, large storm events, hotspots for biodiversity, and economic dependence on agriculture. Some potential causal chains and loops are briefly discussed from the perspective of (a) agricultural crops, (b) mangroves, (c) water resources, and (d) sea turtles. These are just examples of developing causal chains and loops on man-made and natural ecosystems, individual species,

and natural resources. This methodology can be applied to develop other causal chains/loops and so forth.

In the causal chains in agroecosystems (Figure 8a), the state of the system can be represented using indicators like growing degree days to estimate the plant's growth and development. The pressures were represented using indicators such as plant failure temperature, frost, spells (warm/cold/wet/dry), drought, and floods and increasing temperature change scenarios (e.g., $+6^\circ\text{C}$, $+5^\circ\text{C}$, $+4^\circ\text{C}$, $+3^\circ\text{C}$, $+2^\circ\text{C}$, $+1^\circ\text{C}$). The plant failure temperature are critical temperature thresholds beyond which plants and plant tissue has a high potential of being damaged, impacting both crop yield, quality as well as causing plant failure (Anandhi & Blocksome, 2017), increases in warm spells impact plant water use, evapotranspiration, the growing season, plant growth, and development (Anandhi, Hutchinson, et al., 2016). Change scenarios with decreasing temperature (e.g., -1°C , -2°C , -3°C) could increase the number and duration of frost days. This in turn could change the timing of the last spring freeze, first fall freeze of each year, growing season length, increase the cold spells. The frost and cold spells in turn impact plant phenological events in the region such as bud break in spring and senescence and dormancy in the fall (Anandhi, Perumal, et al., 2013; Anandhi, Zion, et al., 2013). Change scenarios with decreasing precipitation (e.g., -10% , -20% , -30% , -40%) increase the dry spells and drought (Anandhi, Hutchinson, et al., 2016; Anandhi & Knapp, 2016). The direct effects of drought and dry spells are reduced cropland, increased wildfire occurrence, diminished water availability, and increased plant failure and water demand. On the other hand, change scenarios with increasing precipitation (e.g., $+30\%$, $+20\%$, $+10\%$) increase the wet spells and flooding (Anandhi, Hutchinson, et al., 2016). The response to these changes could be an incremental change in cultivation practices (e.g., changes in planting and/or harvest dates), systems change (e.g., change in crop variety and crops grown), or a more transformational change (e.g., a change to a different land use). The response can alter the climate (e.g., due to changed albedo).

In Florida, mangrove communities are most extensive on the southern tip of the peninsula, where they occur in an assortment of geomorphologic settings (Ross et al., 2006). Mangroves control the health and sustainability of coastal ecosystems and the future of the Florida's recreational and commercial fisheries, recreational boating, diving, beach-related recreation including tourism, nature observation, and other ecosystem-dependent activities, collectively worth hundreds of billions of dollars a year to the state's economy (Geselbracht, Freeman, Birch, Brenner, & Gordon, 2015). Mangroves are tropical species and well develop within an optimum temperature range (Odum, McIvor, & Smith III, 1982). The changes in temperature (incremental scenarios) may result in the temperatures in the ecosystem to go above/below the optimum range and impact them. Pollution, harvesting, habitat destruction, invasive species, land and resource use, and extreme natural events are some of the stressors that, when superimposed with the potential impacts of climate change, may lead to more significant consequences (Scavia et al., 2002). The state of the mangroves (Figure 8b) can be represented using its structure, function, development, salinity rates, species diversity, and so forth. Temperature change, food availability, or other physical factors stress the physiology of marine animals and can be represented using biochemical indicators of growth rate, metabolic condition, and

physiological stress (Dahlhoff, 2004). Some potential impacts of these temperature/precipitation scenarios over South Florida mangrove forests state are (a) hurricanes or tropical storms in which the principal damaging agent is wind, (b) hurricanes accompanied by a storm surge that deposits massive volumes of marine sediment, and (c) freeze/dry events impact seedling survival and growth rates, which in turn causes fluctuations in freshwater-seawater exchanges. These disturbance types differ in severity and spatial scale, and possibly in the communities, they are most likely to affect along the coastal gradient (Hawkes, Broderick, Godfrey, & Godley, 2009). Some of the mangroves response to impacts can be through expansion/reduction, species extinction and/or dominance of a species, and so forth.

Water resources system's state in the causal chain/loop can be represented using indicators such as water quantity (streamflow)/quality or availability. Water resources in Florida are impacted by changing temperature and precipitation (Figure 8c). For example, evapotranspiration represents a large fraction of precipitation in most regions of Florida and is an important for water resources (Obeysekera, 2013). Under increasing temperature change scenarios (e.g., +6°C, +5°C, +4°C, +3°C, +2°C, +1°C), the pressure on the ecosystems increases. Water and land temperatures would increase causing an increase in water uptake by plants and animals, changing water availability. Increases in connective precipitation may impact extreme events—increasing the risk of flood and drought. Additionally, there will be increased competition for water, affecting water quality, supply, and demand. Components of the hydrologic cycle would also be impacted, such as increased evaporation, evapotranspiration, and streamflow. Under increased precipitation scenarios (e.g., +30%, +20%, +10%), Florida would experience increased wet spells and flooding. Change scenarios with decreasing precipitation (e.g., -10%, -20%, -30%, -40%) would see an increase in dry spells, drought, reduced streamflow, and increased salinity. Increasing/decreasing change scenario impacts on natural and man-made ecosystems (e.g., natural species and their habitats, urban infrastructure) demonstrate how species may respond to ecosystem changes through shifts in species ranges, and phenology. In man-made systems, response may include improved urban infrastructure to manage the excess water during flooding, managing water supply and demand as well as changes in water and nutrient cycling (e.g., run-off carrying fertilizers from agricultural lands).

Climatic effects on one or a few key species may drive community-level change in a variety of nearshore assemblages, for example, invertebrate responses to elevated sea surface temperatures (Harley et al., 2006). In Florida, sustainable coastal habitats are critical drivers of both the economy and quality of life (Geselbracht et al., 2015). The biological importance of rising temperature varies within and among species with unexpected differences observed in climate change vulnerability among species (Harley et al., 2006). Sea turtles show temperature-dependent sex determination (Hays, Broderick, Glen, & Godley, 2003). Egg incubation period especially during middle third of the embryonic period are sensitive to nest temperatures, which impact the sex of turtles. Decreasing temperature scenarios during egg incubation period could yield males whereas increasing temperature scenarios could yield female turtles (Hays et al., 2003). Low and high temperatures impact sea turtle (e.g., loggerheads) mortality during

all stages of its life cycle (e.g., egg, hatchlings, juvenile, and adult). Decreasing temperature scenarios (e.g., -1°C, -2°C, -3°C) directly could cause cold stunning and even colder temperatures could result in coma, whereas increasing temperature scenarios (e.g., +6°C, +5°C, +4°C, +3°C, +2°C, +1°C) potentially causes inefficient terrestrial locomotion, hyperthermia, and desiccation (Davenport, 1997). Coastal ecosystems such as beaches, dunes, barrier islands, and marshes may be able to migrate landward as sea level rises, but if development or other impediments are in the way, these systems will be squeezed and lose spatial extent (Geselbracht et al., 2015). The increasing temperature and precipitation scenarios will impact the vegetation cover, impacting turtle nesting and emergence of hatchlings. Recently, more female turtles have been produced (Davenport, 1997). Increasing temperature and precipitation scenarios could result in coastal squeeze. Sea level rises due to expansion, causing the potential to compromise the availability of nesting beaches, particularly on low-lying narrow coastal and island beaches, while where coastal development prevents landward migration of beaches (Hawkes et al., 2009).

In general, feedback loops are the two-way interaction between climate and ecosystems that accompanies (positive feedback) or reduces (negative feedback) the external climate forcing. Climate and ecosystems interact mutually through both physical and biological feedback. Physical changes involve processes that alter the atmospheric temperature, water temperature, and energy through ocean-atmosphere interaction and precipitation. Biological changes are comprised of phenology, nutrient cycling, evapotranspiration rate, and so forth. These physical and biological changes and processes initiate changes in climate drivers, which sequentially results in climate responses that amplify climate change leading to continue the loop again as shown in Figure 8. Thus, ecosystems and transformed ecosystems influence climate through different processes by altering the energy equilibrium of the atmosphere.

5 | CONCLUSION

Environment and ecosystems are impacted by altered climate and other stressors (e.g., urbanization). Decisions need to be made to adjust as well as to mitigate impacts. The overall goal of the study was to reduce the disconnect between the supply and demand for climate information in making decisions from climate change impacts, assessments of natural and man-made ecosystems. Meta-analysis of previous studies has been used to develop a decision tool for reviewing and synthesizing existing studies for drawing conclusions for the future. Scenarios have been used as powerful tools to communicate how climate may and how the changes may affect vulnerability of resources, species, and ecosystems. Causal chain and loops have been used to understand the interactions between the environment, ecosystems, and altered climate. These tools are often used individually. The objective of this study was to develop and demonstrate the decision support tool that could reduce this disconnect by combining them. The tool developed had three major components: (a) meta-analysis that synthesized and combined recent relevant studies to arrive at conclusions about a body of research on temperature and precipitation changes, (b) developed climate scenario(s) (synthetic or

incremental) from meta-analysis, and (c) development causal chain and loops for selected ecosystems (Figure 1).

In meta-analysis (Component 1 of the decision tool), revealed precipitation changes ranged between +30% and -40%, and temperature changes ranged from +6°C and -3°C for Florida among studies. Incremental scenarios (Component 2 of the decision tool) were developed at 10% increments in the precipitation change range (+30%, +20%, +10%, -10%, -20%, -30%, -40%) and 1°C increments in the temperature change range (+6°C, +5°C, +4°C, +3°C, +2°C, +1°C, -1°C, -2°C, -3°C) for Florida. The causal chains/loops (Component 3 of the decision tool) were developed using Driver-Pressure-State-Impact-Response (DPSIR) framework for selected ecosystems and resources (e.g., agroecosystem, mangroves, water resources, and sea turtles). The driving force for all the causal chain developed in this study were the temperature and precipitation changes which puts pressure on the ecosystem or environment. The state of the selected ecosystems and resources is impacted due to pressure exerted by the changes in temperature and pressure (incremental scenarios), and their response to them (e.g., mitigation and adaptation strategies) was shown in the causal chains/loops. The studies on climate impact assessments (meta-analysis and others) in these ecosystems as well as author expertise on the topic was used to identify the indicators used to represent the components of the framework (pressure, state, impact, response) and develop the chains/loops. The indicators to represent the components of DPSIR framework is subjective to the needs of the stakeholders. Although the developed decision tool is demonstrated by applying it to selected man-made and natural ecosystems and environments in Florida, USA, the tool can be used by multiple stakeholders in other ecosystems and environments throughout the world.

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