A Watershed Planning Guide for the Reedy River, South Carolina

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Abstract

The Reedy River represents a case study in watershed development and its associated ramifications on the biological integrity of fish communities. The Reedy watershed harbors land use activities ranging from intensive urban/suburban development and associated population growth in the Greenville metropolitan area to extensive agricultural and relatively undisturbed forested areas. Such heterogeneity provides a spatial framework for characterizing the gradient of disturbance and the associated effects on fish assemblage integrity.

A recent SCDNR study examined the current status of 15 Reedy tributaries by ‘ranking’ sites based on their relative biological integrity, and examined the spatial distribution of site ranks across a gradient of urban land use intensities (Marion 2008). A threshold in land use level/type where fish community integrity exhibited significant decline in rank (ie. biological integrity) was identified at approximately > 20% urban watershed land use.

Of greatest concern is future predicted urban expansion in upstate SC. Clemson University’s Strom Thurmond Institute recently estimated that from 1990-2000 the amount of developed land in upstate SC grew from approximately 223,000 to 576,000 acres. Under a predicted 5:1 growth ratio (5 developed acres to each 1 additional person), the amount of developed land is anticipated to grow to over 1,500,000 acres by the year 2030 (Campbell 2007). It is vital, at this juncture, to identify Reedy sub-watersheds most and least at risk for future urban expansion, and to select areas suitable for conservation efforts.

Using information regarding the urban land use threshold (SCDNR), current conservation lands, and predicted future development (Upstate Growth Model, STI), we conducted a threat analysis on Reedy River subwatersheds to identify specific geographic localities where the condition of fish assemblages are most threatened by future predicted land development. Additionally, we prioritized specific watersheds for conservation/restoration action based on their given threat level. Threats were defined as low to high, and specific conservation actions were prescribed for each. Subwatersheds representing low threats were prescribed passive conservation, high threat sites were prescribed active conservation, and sites which had previously exceeded the 20% development threshold were prescribed restoration and public development activities.

This type of proactive conservation approach will assist land managers, local governments, private citizens, and special interest groups to make sound ecological decisions based on relevant information.

Introduction

The Reedy River watershed represents a case study in watershed development and its associated ramifications on the biological condition of fish communities. The Reedy watershed harbors land use activities ranging from intensive urban/suburban development and associated population growth near the River's headwaters in the Greenville metropolitan area to extensive agricultural and relatively undisturbed forested areas in the lower portion of the watershed. Such heterogeneity provides a spatial framework for characterizing a gradient of urban disturbance and the associated effects on fish assemblage condition.

A recent South Carolina Department of Natural Resources (SCDNR) study examined the biological (fish) status of 15 Reedy tributaries by 'ranking' sites based on their relative biological condition, and examined the spatial distribution of site ranks across a gradient of urban land use intensities (Marion 2008). A threshold in land use level/type where fish community condition exhibited significant decline in rank (i.e. biological condition) was identified at > 20% urban watershed land use. Tributaries within watersheds that had exceeded a 20% urban threshold were characterized by fish assemblages with simplified taxonomic and functional composition, and reductions/eliminations of sensitive species.

Of greatest concern for Reedy River watershed fish communities is the potential threat of predicted future urban expansion in upstate South Carolina. Clemson University's Strom Thurmond Institute recently estimated that from 1990-2000 the amount of developed land in upstate SC grew from approximately 223,000 to 576,000 acres. Under a predicted 5:1 growth ratio (5 developed acres to each 1 additional person), the amount of developed land is anticipated to grow to over 1,500,000 acres by the year 2030 (Campbell 2007). It is highly likely that as the Reedy watershed develops, many if not all Reedy tributaries will surpass a threshold where biological condition declines irrevocably. Future observed changes may mimic what the SCDNR observed in the lower ranked upper Reedy watershed tributaries; losses of sensitive species and community simplification. Therefore, it is vital, at this juncture, to identify Reedy sub-watersheds most and least at risk for future urban expansion, and to select and prioritize areas suitable for conservation and/or restoration efforts.

We conducted a threat analysis on Reedy River subwatersheds using information regarding the identified 20% urban land use threshold (SCDNR), current conservation lands (The Nature Conservancy), and predicted future development (Upstate Growth Model, STI), we predict areas within the Reedy River watershed that are most (and least) vulnerable to future declines in biological condition, and prioritize subwatersheds for conservation/restoration efforts based on those predictions. This type of proactive conservation approach will greatly enhance our ability to communicate predicted trends in aquatic resources and to recommend resource conservation strategies to land managers, local governments, private citizens, special interest groups, and other stakeholders. Our primary objectives were to: 1) perform a threat assessment to identify Reedy River subwatersheds most and least at-risk for future declines in biological condition, 2) prioritize subwatershed areas for conservation/restoration efforts, and 3) explore alternative biological threshold values and assess their potential impacts on conservation/restoration scenarios.

Methods

Study Area

The Reedy River drains a watershed of approximately 700 km^2 within the Southern Inner and Outer Piedmont ecoregions (Griffith et al. 2002) of the upper Santee River basin in northwestern South Carolina (Fig. 1). The watershed is situated in one of the most vigorously developing areas of South Carolina; developed land an eight-county region of Upstate South

Carolina is projected to increase by almost 40% by the year 2030 (Campbell 2007). The upper portion of the watershed includes a rapidly growing urban area centered around the city of Greenville and Interstates I-85 and I-385 corridors, while lower parts of the watershed are moderately forested or in various forms of agrarian use. The Reedy watershed is relatively narrow, draining 15 major tributaries and numerous smaller tributary streams. The tributaries of the Reedy River are characterized primarily by sandy runs interspersed with bedrock and cobble/gravel riffles.

Biological Data

A recent SCDNR study examined the status of fifteen Reedy River tributaries by 'ranking' sites based on their relative biological condition, and examined the spatial distribution of site ranks across a gradient of urban land use intensities (Marion 2008). A threshold in land use level/type where fish community condition exhibited significant decline in rank (i.e. biological condition) was identified at approximately > 20% urban/developed watershed land use. Fish communities in watersheds that had surpassed a 20% threshold in developed land cover were characterized by reductions/eliminations in sensitive taxa, and general simplification of the structural (taxonomic) and functional composition of assemblages. For the purpose of this project, we used the 20% watershed development level as a benchmark, or threshold, upon which to judge our threat levels among three years of predicted development. We considered subwatersheds with current or predicted development levels of greater than the 20% threshold to reflect a landscape environment conducive to biological decline.

Growth Model

Clemson University's Strom Thurmond Institute (STI) modeled future predicted growth in developed land for an 8-county region of upstate South Carolina that makes up the Saluda

River – Reedy River watershed (Campbell 2007). A geographic information system-based model was developed which combined a binomial logistic regression approach with expert information provided by informed participants throughout the region. The STI model predicted the amount of developed land for every 5 years, beginning in 2005. Twenty-one parameters affecting growth were included as predictive variables in the model. The growth of developed land was modeled based on several potential growth ratios, each indicating differing intensities of development. For the purpose of our project, we chose to use spatial data for the years 2010, 2020, and 2030, based on the assumption of a 5:1 growth ratio, indicating a 5:1 ratio of developed area growth to population growth. This ratio is considered conservative, and is recommended by the STI for use in practical applications of the STI growth model.

Protected Lands

Protected land spatial layers were obtained from the South Carolina Chapter of The Nature Conservancy. Layers included federal, state, and private protected lands updated for 2009. The Reedy River watershed contained only private and state protected lands, both in negligible quantities. There was a total of 2.26 km^2 of private protected lands, and a total of 0.26 km^2 of state protected lands within the Reedy watershed. The STI growth model accounted for 2006 Nature Conservancy documented protected lands, therefore we simply updated the STI growth model with the 2009 state and private protected lands records. Protected lands were accounted in our threat analysis by treating individual protected areas (individual 30 m^2 raster cells) as unable to develop over time.

Watershed Framework

The digital elevation model (DEM) used for watershed delineation was obtained from the U.S. Geological Survey National Map Seamless Server (http://seamless.usgs.gov). This layer was imported into ArcGIS 9.3 and projected into an appropriate coordinate system and cell size with ‘raster projection’ under Data Management Tools in the Arc Toolbox. ArcHydro was used for further layer manipulation to ‘fill sinks’ in the DEM, create “flow direction’, ‘flow accumulation’, and ‘stream definition’ layers. The Reedy watershed was created using existing coordinates obtained from a field GPS unit and saved as a .csv file extension. A personal geodatabase was created in Arc Catalog and the .csv file was imported as a single table. Once the personal geodatabase table was added into Arc Map, the point was displayed by selecting ‘display XY data’. Arc Hydro’s ‘catchment grid delineation’ tool was used to define the Reedy watershed. The Reedy watershed layer was further used to define all subwatersheds using ‘catchment grid delineation’ with a stream link area definition threshold of 1 km^2. There were over 300 subwatersheds created for the Reedy River watershed, of average size 1.7 km^2.

Threat Assessment

Threat assessment methodology was modified from the recommendations of Margules and Pressey (2000), who proposed a strategy for conservation prioritization based on a bivariate scatter plot of irreplaceability versus vulnerability. Site irreplaceability is defined as the extent to which the loss of the area will compromise regional conservation targets, and vulnerability as the risk of landscape transformation. Areas of both high irreplaceability and high vulnerability should receive priority conservation action, because they are most likely to be lost and their loss will have the most serious impact on the achievement of conservation targets.

For our analysis, ‘vulnerability’ as defined by the latter example is analogous with the future predicted level of percent developed land within subwatersheds. Using the STI growth model, the predicted level (%) of developed land in all individual subwatersheds was projected for three separate time periods – 2010, 2020, and 2030. We did not have information directly equivalent to Margules and Pressey's (2000) irreplaceability variate, however for the purpose of this analysis, we defined a given subwatershed as irreplaceable if it contained less than 20% developed land cover at year 2000. The Reedy River tributary ranking analysis conducted by the SCDNR concluded that sites with watershed development levels of less than 20% were in better biological condition than watersheds with development levels of greater than 20%, the latter of which displayed losses of sensitive taxa and increased assemblage simplification (Marion 2008).

Figure 2 shows a generalized example of the threat analysis strategy. Subwatershed percentage levels of developed land at year 2000 (irreplaceability value) are plotted on the Y-axis, and predicted percentage levels of developed land for three separate time periods, 2010, 2020, and 2030, are plotted on the X- axis (vulnerability value). Threat classification quadrants were established by drawing both X- and Y- reference lines set at 20%, our established developed land threshold. Quadrant I represents subwatersheds that have low current development (<20%), and that are not predicted to exceed 20% development at time X_n. These subwatersheds were deemed to contain low threat, since they were not expected to surpass the 20% threshold over time. Quadrant II represents subwatersheds that have low current development (<20%), but are predicted to exceed 20% development at time X_n. Quadrant II subwatersheds contain high threat levels, and are of most concern because they are most likely to foster environments conducive to biological decline. Quadrant III represents subwatersheds that have high current development (>20%), and are predicted to decrease in development to less than 20% at time X_n – an improbable circumstance. Our analysis contained no quadrant III sites for any time period X_n. Quadrant IV represents subwatersheds that have high current development (>20%), and are predicted to remain above and/or exceed beyond the 20% developed land level over time. Quadrant IV subwatersheds have exceeded the 20%

development threshold at some point in time prior to our base year 2000, so we assume that these sites are already degraded and therefore are considered to contain the lowest threat. This assumption is reinforced by the fact that sites with >20% watershed developed land at year 2000 ranked low in biological condition (Marion 2008).

Alternative Threshold Analysis

Previous research has indicated that landscape urbanization can affect stream habitats and biota at even relatively low levels (≤ 10%) of watershed development (Wheeler et al. 2005, Wang et al. 2001). Other studies indicate urban land cover ranging from 7-20% to impair biological communities, and above 20% to cause irreparable damage (Paul and Meyer 2001, Morgan and Cushman 2005). Although our data indicate that the watershed landscape development threshold is approximately 20%, we deemed it prudent to explore both more conservative and liberal scenarios. In order to account for potential alternative watershed development threshold values, we introduced alternative threshold scenarios of 10% and 30% development for model comparison. Differing trends over time were evaluated, as well as potential impacts to conservation scenarios.

Results

Threat Assessment

Three unique threat assessments were produced for the years 2010, 2020, and 2030. Figure 3 shows plots of the sequential shifts in threat categories through time. Of greatest concern is the mass of subwatershed sites that are predicted to shift into quadrant II over time. Quadrant II represents subwatersheds of highest threat - they are predicted to shift from less than 20% watershed development to greater than 20% watershed development, a known threshold associated with local biological decline. The sequential increase of plots in both breadth of scatter and left to right movement over time is indicative of an overall trend of increasing levels of development within the entire Reedy watershed. Maps depicting shifts in threat categorization from base year 2000 (48.2 % developed) to years 2010, 2020, and 2030, respectively are displayed in figure 4. At year 2010, there is predicted to be a 5.2 % increase in high threat (quadrant II) sites. At year 2020, there is predicted to be a 15.3% increase in high threat sites. By the year 2030, there is predicted to be a 25.9% increase in high threat sites. In other terms, the percent of the Reedy watershed as a whole that contains subwatersheds greater than 20% developed is 53.2 % in 2010, 63.5% in 2020, and 74.1% in 2030. The general trend of development shows a southern progression over time, with largest aggregated areas of development occurring along the I-385 corridor, and along the outskirts of the cities of Laurens and Honea Path.

Conservation Prioritization

Three conservation prioritization categories were defined for each of the three threat assessments, however we used the analysis for year 2030 in the following interpretation. For each time period, Quadrant I sites (low threat – level I) are targeted for passive conservation efforts, quadrant II sites (high threat – level II) are targeted for active conservation efforts, and quadrant IV sites (exceeded 20% development threshold prior to 2000 – level IV) are targeted for stream/landscape restoration projects (Fig. 5a). Potential approaches to conservation prioritization may include a subwatershed approach, or an aggregate watershed approach (Fig. 5a,b). A subwatershed approach treats individual subwatershed units separately, and while greatly informative when viewed at an entire Reedy watershed scale, may not be pertinent individually (i.e. development in one subwatershed may negate the benefits of non-development another subwatershed within the same dendritic stream network). An aggregate watershed approach treats subwatersheds as part of a greater stream network, and may provide a more intuitive and logical way to prioritize conservation efforts. Figure 5c shows 15 major tributaries to the reedy river and depicts areas of ‘good’ and ‘poor’ biological condition (Marion 2008). An aggregate watershed map for projected development in 2030 shows that the majority of sites deemed to be in ‘good’ current biological condition (Fig. 5c) are largely predicted to fall into categories of high threat (Fig.5b). Potential expected biological declines in high threat areas may include the loss/elimination of sensitive taxa and a simplification of the taxonomic and functional structure of fish assemblages.

Alternative Threshold Analysis

In order to account for potential alternative watershed development threshold values, we introduced alternative threshold scenarios of 10% and 30% development for model comparison (Table 1). Each shows a general trend of development moving in a southern progression over time, similar to the trend for our threat analysis using a 20% threshold. The total percentage of Reedy subwatersheds containing greater than 20% developed for the year 2030 ranges from 65.2% at the 30% threshold level to 84.8 % at the 10% threshold level. This analysis acts as a confidence interval for the potential biological threats and related consequences of watershed development, for exact thresholds are difficult to define definitively with a single, hard number. It is expected that the ‘real’ threat to biological condition will fall somewhere between predictions for 10% and 30%.

The Reedy River represents a case study in watershed development and its associated ramifications on the biological integrity of fish communities. The Reedy watershed harbors land use activities ranging from intensive urban-/suburban development and associated population growth in the Greenville metropolitan area to extensive agricultural and relatively undisturbed forested areas. Although certain stressors are locally dominant and relatively contiguous where so (e.g., urban/suburban development near the city of Greenville), at the scale of the entire watershed system, a wide range of land cover/uses and intensities (i.e., degrees of disturbance) exists among and within sub-watersheds as well as longitudinally along individual streams, including areas of little or no disturbance. Such heterogeneity provides a spatial framework for characterizing the gradient of disturbance and the associated effects on fish assemblage integrity.

The primary focus of this study was to 'rank' fifteen Reedy River tributary sites based on their relative 'biological integrity', and examine potential relationships among land use and fish community integrity (rank) across an environmental gradient of urban and forest land cover intensities within the Reedy River watershed. Secondly, the analysis was intended to identify rough thresholds in land use level/type at which fish community integrity exhibits significant decline. Third, the ranking scheme should provide initial input/identification of sites and watersheds which may represent 'best candidates' for conservation and restoration efforts. Likewise, such analysis should also identify those sites and components on the other end of the spectrum of conservation potential, or those which are functionally (ecologically) irreparable or otherwise not expected to yield efficient return.

Conclusions

Conservation prioritization and regulated development within the Reedy River watershed are essential for the maintenance and continuance of its biological viability. The Reedy river has suffered thorough at least 200 hundred years of anthropogenic impacts; historically deriving from point-source pollutants from local industry, to a modern onslaught of landscape-derived non-point source pollutants and anthropogenically induced habitat / hydraulic alterations (O'Neil 2005, Allen et al. 2007). Despite this ragged history of degradation, the Reedy River is also a testament to the inherent resiliency of natural systems. Current research has shown that tributary sites in the lower portion of the Reedy watershed remain in 'good' biological condition (Marion 2008). Unfortunately, our threat analysis shows that it is precisely these subwatersheds that are at most risk of future development over the next 20 years. In order to mitigate the potential deleterious effects of predicted future development, we suggest the following conservation actions. We suggest acknowledging the general development trends portrayed in all three threat maps (2010, 2020, 2030), but to plan conservation strategies based on threats portrayed by the 2030 threat analysis map (Fig. 4). We recommend passive conservation efforts be applied to low threat sites. We define passive conservation as concentrating more on damage prevention than on active physical intervention. Conservation recommendations for low threat sites may include: routine biological monitoring, development regulation (e.g. zoning regulation), strict adherence to and monitoring of best management practices for all construction efforts, landowner environmental education programs, and the creation of a watershed development 'master plan' advocating development by choice, rather than chance. We recommend active conservation be applied to high threat sites. We define active conservation as a concentration of effort focusing on ecologically defensive actions to mitigate the effects of landscape development. Recommendations for high threat sites include all recommendations cited for low threat sites as well as aggressively advocating conservation easements and other landowner conservation agreements, active purchases of land tracks by private and government institutions, and active riparian protection and enhancement zones. We recommend restoration efforts be applied to our subwatershed sites that have already exceeded the 20% threshold (threat level IV). Because these are mostly established urban sites, we feel that a focus on restoration of stream channels to mitigate flood events and to enhance aesthetic qualities is appropriate. These areas are also appropriate for the construction of publicly accessible parks, walkways, and other public gathering sites that may generate and increase public interest in the natural world and the ecological system in which they reside.

The Reedy River watershed is only one of many watersheds residing in upstate South Carolina. Of greatest concern is future predicted urban expansion in the entirety of Upstate South Carolina. Future research should be expanded to focus on evaluating the threat of predicted development on the aquatic biotic community of upstate South Carolina as a whole.

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Tables and Figures

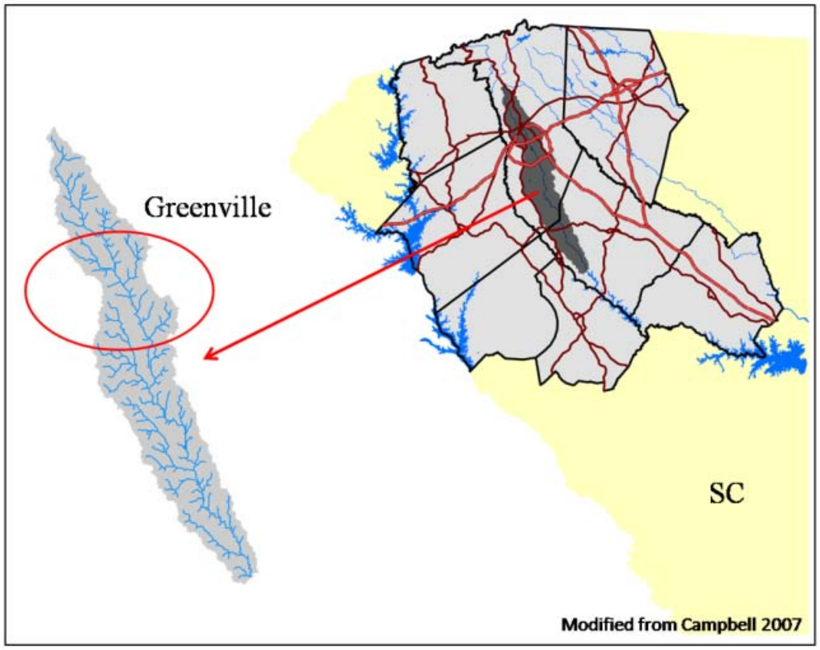

Figure 1. Map of study watershed and location in the upstate of South Carolina with major roads, county boundaries, rivers, and reservoirs.

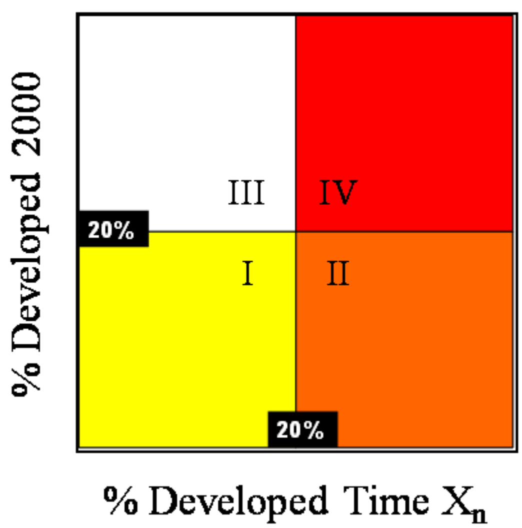

Figure 2. General example of threat analysis strategy with threshold values of 20% urban development. Quadrants I-IV represents threat levels relating current conditions to projected urban development. Quadrant I = low threat, Quadrant II = high threat, Quadrant IV = previously exceeded 20% threshold – low threat.

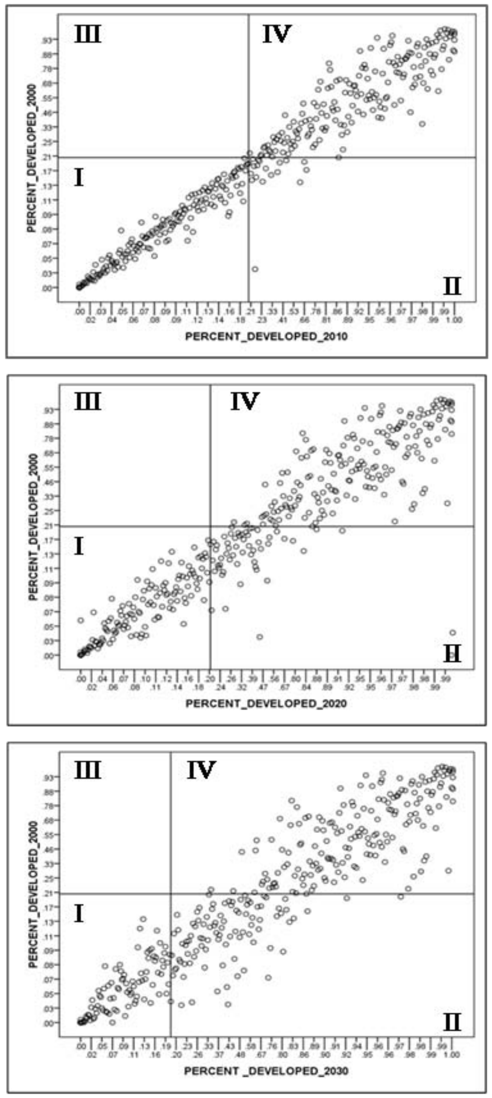

Figure 3. Threat assessment scatter plots for the years 2010, 2020, and 2030. Reference lines indicate 20% development threshold values, resulting quadrants reflect threat levels I-IV.

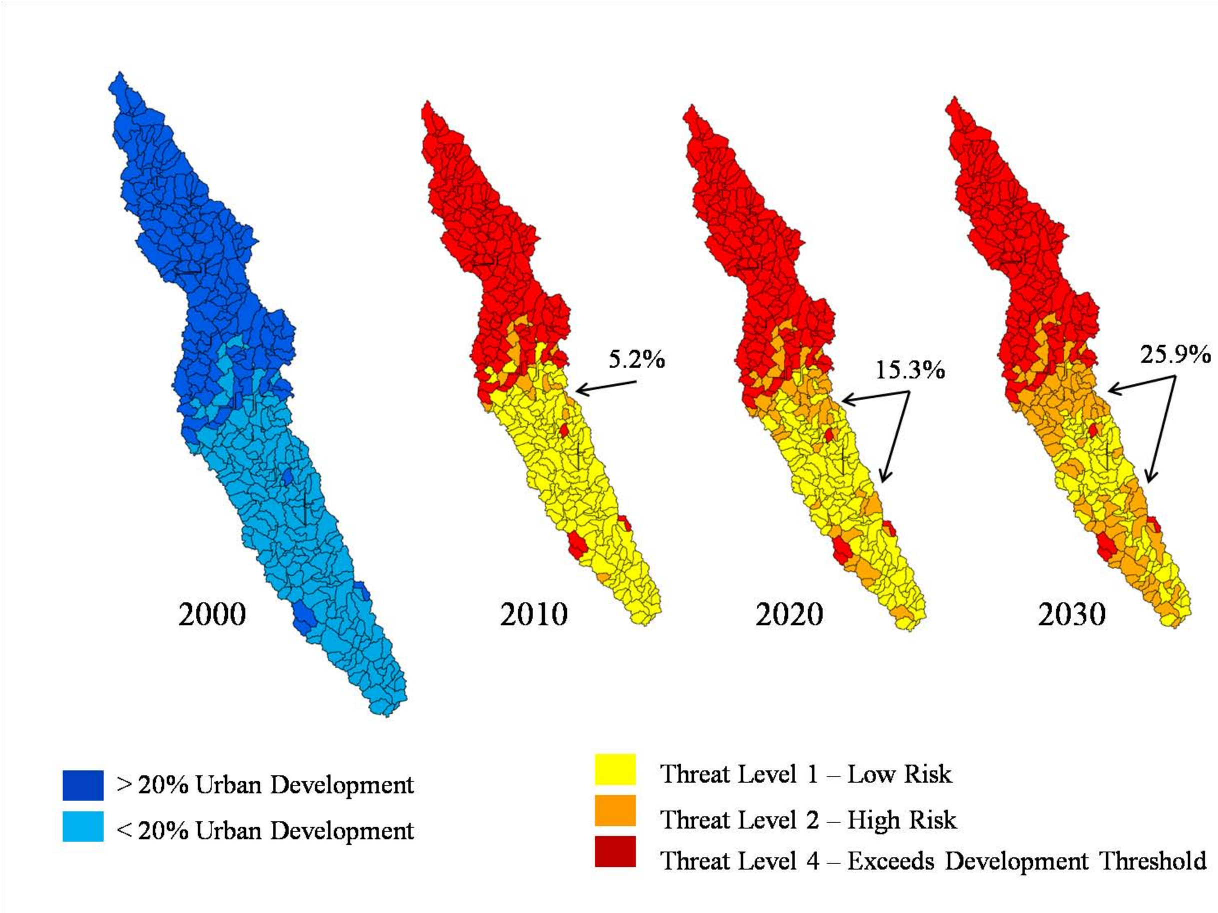

Figure 4. Threat analysis maps for 2010, 2020, and 2030 using base year 2000 for the Reedy watershed. Map for base year 2000 indicates areas above and below development threshold values of 20%. The watershed was 48.2% developed for the year 2000. Threat analysis maps for 2010, 2020, and 2030 show low threat subwatersheds in yellow, high threat subwatersheds in orange, and subwatersheds already exceeding the 20% threshold by 2000 in red. In 2010, there is predicted to be a 5.2% increase in high threat subwatersheds, a 15.3% increase by 2020, and by 2030 there is predicted to be a 25.9% increase.

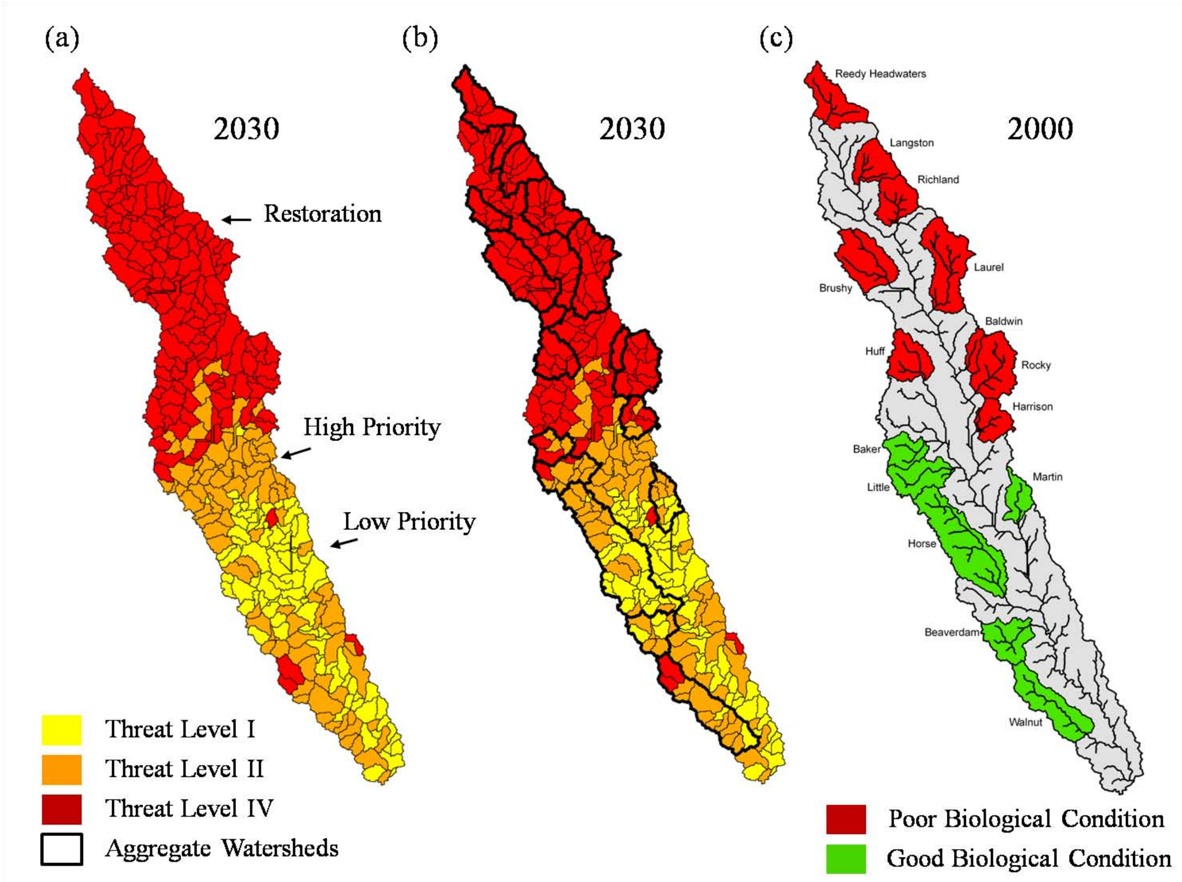

Figure 5. Conservation prioritization maps for the Reedy watershed. 5a represents conservation prioritization map for 2030. 5b represents aggregated conservation prioritization map for 2030. 5c shows South Carolina Department of Natural Resources results 'good' vs 'poor' biological condition sites for 2000. Conservation prioritization for 5b shows that most 'good' condition sites are predicted to fall into a high threat category by 2030.

Table 1. Alternative threshold analysis of 10% and 30% for model comparison to original urban development threshold value of 20% for each threat level and year.

	10% urban development threshold			20% urban development threshold			30% urban development threshold		
	2010	2020	2030	2010	2020	2030	2010	2020	2030
Threat Level	Percent developed	Percent developed	Percent developed	Percent developed	Percent developed	Percent developed	Percent developed	Percent developed	Percent developed
1	29.4	19.3	15.3	46.6	36.5	25.9	51.8	43.9	34.3
2	1.9	12.0	16.1	5.2	15.3	25.9	9.5	17.4	27.0
3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
4	68.4	68.4	68.7	48.2	48.2	48.2	38.7	38.7	38.7