IN21B-1336: Coupling urban growth scenarios with nearshore biophysical change models to inform coastal planning in Puget Sound, Washington

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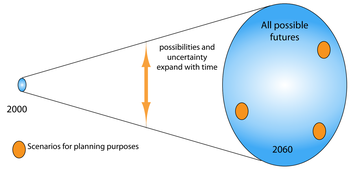
I. Abstract

A scenario represents an account of a plausible future given logical assumptions about how conditions change over discrete bounds of space and time. Development of multiple scenarios provides a means to identify alternative directions of urban growth that account for a range of uncertainty in human behavior. Interactions between human and natural processes may be studied by coupling urban growth scenario outputs with biophysical change models; if growth scenarios encompass a sufficient range of alternative futures, scenario assumptions serve to constrain the uncertainty of biophysical models. Spatially explicit urban growth models (map-based) produce output such as distributions and densities of residential or commercial development in a GIS format that can serve as input to other models. Successful fusion of growth model outputs with other model inputs requires that both models strategically address questions of interest, incorporate ecological feedbacks, and minimize error. The U.S. Geological Survey (USGS) Puget Sound Ecosystem Portfolio Model (PSEPM) is a decision-support tool that supports land use and restoration planning in Puget Sound, Washington, a region that comprises 35,500 sq. km. The PSEPM couples future scenarios of urban growth with statistical, process-based and rule-based models of nearshore biophysical changes and ecosystem services. By using a multi-criteria approach, the PSEPM identifies cross-system and cumulative threats to the nearshore environment plus opportunities for conservation and restoration. Sub-models that predict changes in nearshore biophysical condition were developed and existing disciplinary models were integrated to evaluate three growth scenarios: 1) Status Quo, 2) Managed Growth, and 3) Unconstrained Growth. These decadal scenarios were developed and projected out to 2060 at Oregon State University using the GIS-based ENVISION model. Given land management decisions and policies under each growth scenario, the sub-models predicted changes in 1) fecal coliform in shellfish growing areas, 2) sediment supply to beaches, 3) State beach recreational visits, and 4) forage fish habitat suitability. In some cases thousands of shoreline units were evaluated with multiple predictive models, creating a need for streamlined and consistent database development and data processing. Model development over multiple disciplines demonstrated the challenge of merging data types from multiple sources that were inconsistent in spatial and temporal resolution, classification schemes, and topology. Misalignment of data in space and time created potential for error and misinterpretation of results. This effort revealed that the fusion of growth scenarios and biophysical models requires an up-front iterative adjustment of both scenarios and models so that growth model outputs provide the needed input data in the correct format. Successful design of data flow across models that includes feedbacks between human and ecological systems was found to enhance the use of the final data product for decision making.

Figure 1. Uncertainty in Scenario Planning

A.



B.

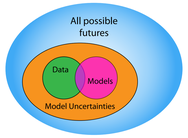


Figure 1A. The number of possible futures and the uncertainty around these futures expand with increasing time horizons. Scenarios represent a set of plausible futures given logical assumptions about how conditions change over discrete bounds of space and time (adapted from http://www.new.dpi.vic.gov.au/energy/policy/june-2010).

Figure 1B. The overlap of existing data and models represent available information to assess and project the future of ecosystem services within a given scenario. The orange ellipse represents the "known unknowns," or uncertainty, that can be inferred from existing information. The blue ellipse beyond the orange ellipse represents the "unknown unknowns," or the full set of all possible futures. (Carpenter, S. R., E. M. Bennett, and G. D. Peterson. 2006. Scenarios for ecosystem services: an overview. Ecology and Society 11(1): 29. [online] URL: http://www.ecologyandsociety.org/vol11/iss1/art29/. Copied with author permission.)

The Puget Sound Region

II. Scenarios

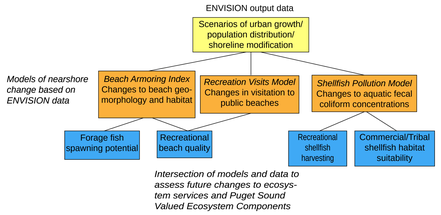
ENVISION is an agent-based growth model developed and run by Dr. John Bolte at Oregon State University. Three growth scenarios were developed for the Puget Sound region out to 2060. Map-based scenarios attributed over 450,000 polygons with information on *population*, *land use*, and in coastal areas, *shoreline modifications*. The three scenarios were:

Status quo: Continuation of current trends. Development pattern emphasizes medium density use.

Managed growth: Adoption of an aggressive set of land use management policies and concentrating growth within Urban Growth Areas. No new development allowed within 200 feet of shoreline.

Unconstrained growth: Relaxation of land use restrictions and more growth occurring outside Urban Growth Areas. Significant new development in the nearshore.

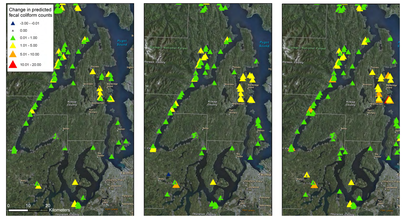
Figure 2. Fusion of a growth model with nearshore biophysical models



III. The Shellfish Pollution Model

The Shellfish Pollution Model evaluates the ENVISION scenarios to determine which Puget Sound commercial shellfish growing areas are at greater risk of increased fecal coliform contamination within the next 50 years, given expected development patterns in watersheds draining to the nearshore. A negative binomial regression method was applied to relate watershed variables and water temperature and salinity data to fecal coliform count data collected by the WA State Dept. of Health. A watershed-scale four variable model was found to have the best model fit (Wald $chi^2 = 98.02$, p=0.00, n=335) Fecal coliform bacteria counts increased with lower percent cover evergreen forest (Figure 4A.) and higher water temperatures, and higher percent cover impervious surfaces (Figure 4B.) and lower water salinity. While model results are significant, much of the variance in the data is unexplained (pseudo $R^2 = 0.12$). Based on ENVISION model scenario projections for evergreen forest cover and impervious surfaces, predicted pathogen counts across all subbasins and years tend to be higher in the Unconstrained Growth scenario.

Figure 3. Change in predicted fecal coliform counts from 2000-2060 across scenarios



Managed Growth | Status Quo | Unconstrained Growth

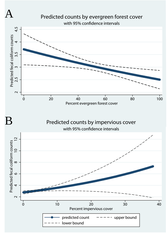


Figure 4. Predicted bacteria counts by A. evergreen forest cover and B. impervious surface, holding other variables constant.

IV. The Beach Armoring Index

Coastal bluff erosion is the primary source of beach sediment in Puget Sound, and this sediment source is essential for maintaining the quality of beaches and their associated habitats. Bulkheads or other shore armoring limit bluff erosion and reduce coastal sediment transport and supply to down drift beaches, resulting in changes to beach condition and habitat quality (Figure 5). The Beach Armoring Index model provides a method for quantifying the cumulative effects of updrift and on-site armoring on Puget Sound beaches. The index classifies beaches based on their potential for beach geomorphological and ecological changes, such as erosion and loss of eelgrass or forage fish spawning habitat, due to loss of sediment supply. The Index evaluates ENVISION scenarios of future shoreline armoring to assess which shorelines are at greater risk of shoreline change and habitat loss.

Currently three variables are included in the index:

- Fetch distance measured from the South (180°) (SFetch),
- Percent length of updrift bluffs that are armored (P_Up_Armor)
- Percent length on-site bluffs that are armored (P_Armor)

The three variables were assigned scores based on their data distribution. Scores were combined to create an index with values ranging 1 to 5, with 5 being greatest potential for beach impacts.

The index is calculated as:
2*(P_Up_Armor score) + 2*(SFetch score) + [(P_Armor score) if Beach type = BLB]

In scenario development, future shoreline armoring rates were based on current ratios between armoring density and shoreline development densities by zoning class. The use of these ratios led to very low prediction rates for future shoreline armoring for both scenarios out to 2060. As a result, there are very few differences in index scores across scenarios and years. The greatest projected increase in armoring occurred in the 2060 Unconstrained Growth scenario for the South Central Puget Sound Subbasin – a 4.6% increase in the length of armored shoreline, with notable increases on Bainbridge Island (Figure 6).

Figure 5. Shoreline armoring (photo credit: Hugh Shipman)

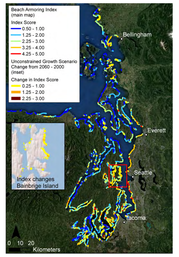
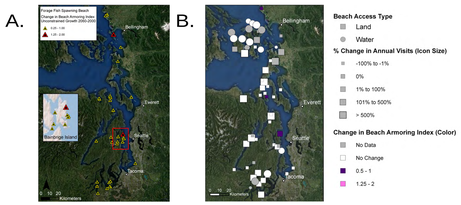


Figure 6. The Beach Armoring Index

Year 2000 Index Scores. Inset: Some of the greatest Index changes were found on Bainbridge Island in the 2060 Unconstrained Growth Scenario.

Figure 7. Intersection of the Beach Armoring Index with Forage Fish Spawning Beaches and the Recreation Visits Model



7A. Increase in Index scores at forage fish spawning beaches (WA Dept of Fish and Wildlife 2009) from 2000 - 2060 in the Unconstrained Growth scenario. Due to the low armoring rates in the scenarios, only 40 beaches out of a known 1000 show change. 7B. Increase in Index scores at State beaches and percent change in annual visits from 2000 - 2060 in the Unconstrained Growth scenario, by beach access type. In both cases resource impacts occur at higher magnitudes on Bainbridge Island.

V. The Recreation Visits Model

Recreational opportunities are a major contributor to human well-being in Puget Sound. Future increased population and land use change may stress recreation resources, but allow more people access, effectively increasing net visitation. We modeled current recreational use of 57 coastal State Parks in Puget Sound using a dataset of observed park attendance from 2001 - 2008. We then used our model and ENVISION scenarios of population growth to estimate likely future recreational use at each park across scenarios. We modeled recreational visitation as a function of environmental condition, park characteristics, and recreational demand using a negative binomial regression. Environmental condition was described by e. coli counts, which may act as a proxy for perceived environmental quality. With data on the origins and destinations of travelers we constructed a demand function that relates the visitation rate (# visits/zip code population) to the distance traveled ($p < 0.001$, $R^2 = .67$). The final regression model explains nearly 70% of the null deviance. The variables that increased visitation include the number of campsites at a park, the park size, and the number of possible activities at the park. Variables that negatively affected visitation include access only through personal watercraft, the weighted population, the travel time to a park from Seattle, and the water quality (e. coli counts). Results show that over time, park visitation becomes increasingly distributed across the Sound, with increases in the San Juan Islands and in South Puget Sound (Figure 8).

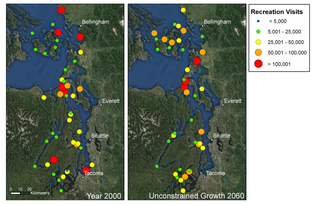


Figure 8. Comparison of park visitation between 2000 and 2060 in the Unconstrained Growth Scenario

VI. Scenario Analysis Visualization Tool

View and compare model results across scenarios and years at http://geography.wr.usgs.gov/pugetSound/index.html

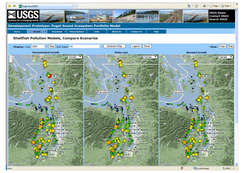


Figure 9. The Puget Sound Ecosystem Portfolio Model Website

VII. Conclusions and Next Steps

- Model uncertainty and limited data lower capacity for quantitative assessment of nearshore change, but allow for relative comparisons among sites and regions across decades.
- Despite challenges in merging multiple data types, analysis highlights resource-rich areas that may be potentially impacted by multiple stressors.
- Iterative adjustment of scenarios and models is needed to better discern differences among alternative futures.
- Evaluation of multiple environmental criteria targets a short list of sites for further study and higher level conservation and restoration planning.
- The Washington Climate Change Impacts Assessment (2009) identifies potential climate change impacts to Puget Sound beaches and bluffs and shellfish aquaculture. This research lays the foundation for future work on the development of integrated climate change and land use change scenarios to evaluate potential changes to these resources.

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