

Evaluation of Resilience Thresholds in Stream Ecosystems

Key Words: aquatic ecology; geomorphology; Mediterranean climate; flow regime; salmonids

Background: Ecological resilience has been described as the ability of an ecosystem to withstand disturbance and maintain the processes that control its structures[4]. When a disturbance exceeds the resilience threshold of an ecosystem, organizing processes can shift to an alternative stable state, resulting in changes to community composition and function[1]. Anthropomorphic alterations to the environment can reduce the resilience of natural ecosystems, resulting in losses of ecological services which in turn can stress human systems[7,8].

The increasing demand on freshwater resources to meet human water needs has altered the flow of rivers around the world and exemplifies the tension between human and natural systems[5,7,8]. Where freshwater is limited, increased human demand is coupled with a reduction of flow available to sustain ecological processes, potentially crossing a resilience threshold for the system. This is particularly true of Mediterranean-climate watersheds which experience natural prolonged low flows each year.

One indicator of reduced resilience of aquatic ecosystems is the dramatic decline of anadromous fish populations in Pacific Coast streams over the past 150 years. Substantial research effort has been directed toward salmon population recovery, but has largely been focused on reducing fine sediment and improving in-stream habitat structure[2]. Relatively little attention has been paid to the issue of water *quantity* as a limiting factor to salmon recovery due to the fact that most salmon research has been conducted in the Pacific Northwest. Rivers of this region are characterized by less seasonal flow variability than in coastal California, due to more mesic climate conditions[9] and flow management from dams.

Recently developed flow models for tributary streams in California's Mediterranean climate indicate that dispersed human water extraction has detectably reduced summer flows, resulting in an accelerated and prolonged dry season period[3]. However, quantitative biophysical data relating changes to the stream hydrograph with decreased habitat suitability and salmon mortality are currently not available. Furthermore, monitoring programs typically fail to capture fine-scale variability in stream flows, including pool characteristics, which act as important refugia for fish in the late summer.

Hypotheses: This study will investigate how human-induced modifications to natural flow regimes of northern California streams have affected the resilience of stream ecosystems. Specifically, my research shall test the following two hypotheses: (1) there is a quantifiable resilience threshold for aquatic ecosystems resulting from limited summer stream flows and (2) existing flow models do not adequately capture non-linear, small-scale dynamics of altered stream systems during the dry season. My involvement with a University of California Berkeley watershed research group and previous experiences conducting ecological field studies and stream restoration projects provided the motivation for this original research plan.

Research Plan: *(1) Resilience Thresholds Analysis:* As part of an interdisciplinary team, I will investigate the relationship between flow regime alteration and juvenile salmonid (steelhead trout [*Onchorhynchus mykiss*] and Coho salmon [*O. kisutch*]) abundance and survivorship. This research will utilize data from a 10-year study monitoring fish abundance and over-summer survivorship at multiple tributary stream sites within the Russian River watershed, northern California. Stream flow models are currently being developed for these same tributaries to estimate human water demands and determine the availability of water for ecosystem needs. I will integrate the fish survey data with modeled flow over a gradient of flow regime alterations within specific stream reaches to evaluate if flows are a limiting factor for salmonid survivorship. Systematic declines in salmonid abundance associated with low flows will be interpreted as an indication that a resilience threshold necessary for survivorship has been crossed. Sliding regression is an effective method for detecting non-linear threshold responses[6] and will be used in the analysis of salmonid mortality under specific flow regimes. I expect to explore alternative regression methods such as ordinal logistic regression to detect threshold responses once the stream flow model and salmonid data are fully integrated.

(2) Stream Monitoring: In order to evaluate the ecological effects of stream flow on finer spatial and temporal scales, I propose to collect field data on biotic and physical habitat conditions at specific pools within multiple stream reaches. This field work will validate existing stream flow models to determine their predictive power for water availability in north coast tributary streams and provide small-scale, high resolution information on stream flow and pool dynamics during the dry season. Stream gauges will be installed and flow data collected throughout the summer months. Pool depths and water temperature will also be monitored throughout the low-flow period. The monitoring shall include a comprehensive assessment of habitat variables, including riparian vegetation cover, channel morphology, streambed substrate, and habitat structure (large woody debris and boulders). The effects of reduced dry season flows on streambed composition and other geomorphic variables are of particular interest. The accumulation of fine sediments within salmonid spawning habitat can in part be offset by scouring effects of high flow events which mobilize streambed particles. If the filling of riffles and pools is accelerated by lower summer base flows, a focus on the small-scale dynamics of stream flow and sediment transport will provide insight to ecosystem processes that control habitat quality for salmonids. I will be advised on field methods by a team of experts interested in this research, including V. Resh, P. Moyle, M. Kondolf, and W.E. Dietrich.

Anticipated Results and Significance: I expect to find evidence of an ecological resilience threshold (as measured by minimum stream flows) below which juvenile salmonids do not survive. Analyses of stream flow regimes in relation to biotic and geomorphic variables will fill a gap in aquatic systems science by identifying processes that affect ecological integrity of stream ecosystems during low-flow periods[5]. My research will focus on the effects of dispersed water extraction by individual landowners, which has been much less studied than extraction from central infrastructure (e.g., dams and canals). This dispersed water extraction may be an important impact on aquatic ecosystems that has been overlooked and is likely to grow in many parts of the U.S. experiencing exurban expansion. This study will make an important contribution to our understanding of the effects of land use change on the resilience of stream ecosystems and will evaluate if resilience thresholds can be quantified – a necessary step if such measures are to be used for ecosystem management.

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