Appendix 8

Habitat Time Series Analysis

The purpose of this task was to develop habitat augmentation rules to avoid or mitigate both pulse and press disturbances (Niemi et al. 1990). The key criteria for these rules were developed by the determination of habitat stressor thresholds (HST) from their frequency of occurrence. Intra-annual rules should specify the magnitude of extreme habitat that should always be exceeded, as well as the magnitude and the duration of low-habitat events that are common in an average year. Inter-annual rules should define how frequently uncommonly low and long events could occur. We distinguished two duration types for rare events: persistent lows that can happen two or three years in a row (equivalent to a press disturbance); and catastrophic events that occur on the decadal scale (pulse stressors). All of these rules are organized by annual bio-periods.

To identify HST, habitat time series were developed and the habitat duration curves analyzed. Then we created uniform continuous under-threshold habitat-duration curves (UCUT-curves) modified from Capra et al. (1995). The curves evaluate durations and frequency of continuous events with habitat lower than a specified threshold. This is as a proportion of the entire study period, which is a sum of all days within one bioperiod in the hydrological record. As documented by Capra et al. (1995) the curves are good predictor of biological conditions.

Approximations of the threshold within the habitat template of the Pomperaug River were developed from the simulated hydrograph and habitat rating functions (see Appendices7). To create our UCUT curves (uniform continuous under-threshold habitat-duration curves), we first ‘translated’ the simulated hydrological time series (mean daily flows from 1947 – 1977) into a habitat time series (habitograph). Each incremental flow value was converted into a habitat value using a flow-habitat rating curve (representing habitat as a function of flow) for a bioperiod under the present habitat conditions.

Following Capra’s procedure, a habitat event is defined as a continuous period in which the quantity of habitat (WUA, wetted usable area) stays under a predefined threshold. In our adaptation the UCUT curves describe the duration and frequency of events for a given bioperiod. Therefore the first step is to extract bioperiod data for each year from the habitographs (Figure 1).

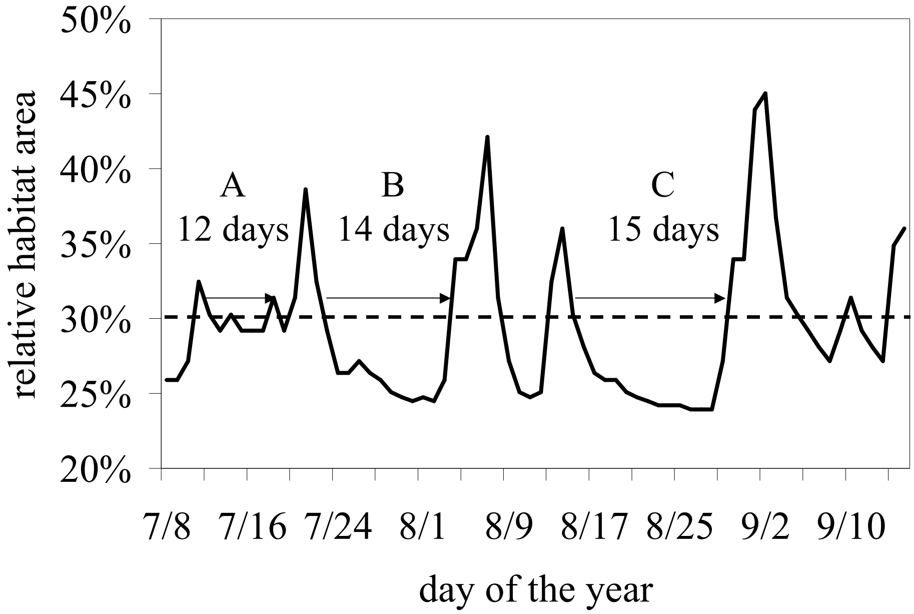

Figure 1: Schematic of UCUT curve computation for hypothetical suitable habitat time series.

In the second step, the sum-length of all events of the same duration within each bioperiods is computed as a ratio of the total duration of all bioperiods in the record (on the x-axis of the graph). The proportions are plotted as a cumulative frequency, i.e., the proportion of shorter periods is added to the proportions of all longer periods (Figure 2).

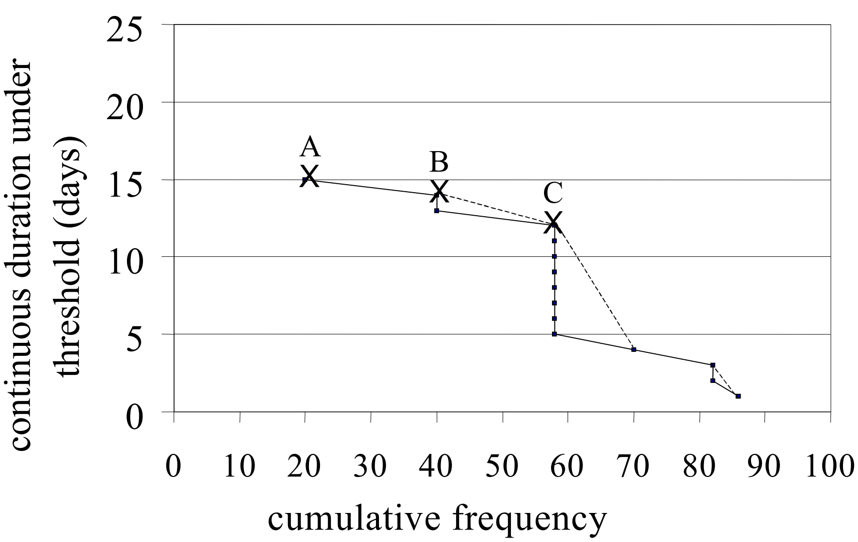

Figure 2: Differences between the CUT curves defined by Capra et al. 1995 (dashed line) and UCUTs (solid line).

For easier interpretation and calculation, we further modified Capra's technique by including in the plot the continuous durations with 0% of cumulative increase (i.e., events that did not occur in the time series). For example, if the time series including the continuous durations of 14 and then 12 days, the CUT curve method will plot only those two points. In our method, we also plot the points for a cumulative duration of 13 days (equal to the one of 14 days), dropping the line first vertically and then joining it with the plot for 12 days (see Figure 2). To distinguish between the two approaches, we called this adaptation uniform continuous under-threshold (UCUT).

This procedure is repeated for the entire set of thresholds with constant increments. The magnitude of the habitat increments between the thresholds is selected on an iterative basis, i.e., changing the increments until a clear pattern can be recognized. We look here for specific regions with a higher or lower concentration of the curves on the plot that would correspond with *rare, critical, and common* events. When many curves are plotted these three regions are easily identifiable.

We can identify common and less common habitat events based on the cumulative durations, and the shape of, and distances between the curves. The procedure has two steps: 1) determination of habitat threshold levels by selecting curves on the graphs, and 2) identification of critical durations by locating inflection points. Interpretation of these patterns is based on following observations:

- The curves in the lower left portion of the graph depict rare events (i.e., with low cumulative durations).
- The horizontal distance between curves indicates the change in frequency of events associated with a habitat increase to the next level (e.g., the larger the distance between two curves at the same continuous duration, the larger the change in the frequency of the events).
- Steep curves represent low change in event frequency.
- Inflection points reflect rapid change in frequency of continuous durations.

The relative position of a curve defines the magnitude of habitat and the ecologically relevant threshold demarcating pulse stressors. We look for extreme, rare, critical, and common habitat stressor thresholds (HST) for the low-flow conditions. Rare habitat events happen infrequently and for only a short period of time (e.g., 95% of pulse stressor). The critical level defines a more frequent event than rare, below, which the habitat circumstances rapidly decrease to the rare level (e.g., 75% pulse stress). Common habitat levels are the highest defined and should demarcate the beginning of normal circumstances from the less common events (= no stress).

Typically, the UCUTs for rarely low habitat availability are located in the left corner, and are steep and very close to each other. Apparently, in this range small increases in habitat level have barely any effect on cumulative duration. As the habitat level increases this pattern rapidly changes. We selected the highest in this lower-habitat group (before the rapid change of cumulative duration) of curves as a *rare* habitat level threshold. Not surprisingly, this value usually corresponds with the lowest inflection point on the habitat duration curve. In our framework the *rare* habitat should be exceeded most of the time and calls for the most immediate augmentation. We identified the next highest UCUT line (the first that stands out) as a *critical* level. The distance between the lines after exceeding the *critical* level are usually greater than in the previous group, but still close to each other. The next outstanding curve demarcating rapid changes in the frequency of events is assumed to mark the stage at which more *common* habitat levels begin.

Once the three threshold levels were identified we located the longest common or allowable durations from inflection points on the UCUT curves. These durations demarcated the beginning of persistent low habitat. The shortest of uniquely long durations appearing on the decadal scale are defined as catastrophic durations and are accompanied by their frequency of occurrence.

To develop habitat time series, the habitat rating curves described above are applied to simulated flow time series as developed for specific reaches. During the R&G and resident-species spawning seasons the preference was to choose the resident adult fish as the indicator otherwise we used individual indicator species such as Atlantic salmon and American shad. The UCUT curves were computed for selected indicator species in every reach using a time series from associated flow gauges (see USGS report).

Habitat UCUTs were not developed for the seasons in which habitat information was sparse or nonexistent for the fauna of interest (e.g., over-winter). Instead, for the over-winter bioperiod we evaluated negative run length (i.e., flow-based UCUTs) and derived criteria solely on these data, presuming again that the fauna have adjusted to the most common natural flow conditions.

Results

R& G bioperiod

Figures 3-5 present UCUT curves for the Nonnewaug, Weekeepeemee and Pomperaug Rivers. For the Nonnewaug River (Figure 3) 12 % CA of habitat is selected as a *rare* threshold. The UCUT curves show dramatic increase of frequency when the threshold moves to 14 % CA. The *common* threshold is identified with 34 % CA.

For the determination of the longest common duration for *rare* habitat events, the lowest of the two inflection points corresponding with 8 days was selected. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 13 days. The UCUT for the *critical* event has an inflection point at 10 days and catastrophic duration of 17 days. For the *common* level the inflection points were estimated with 49 days for common durations and 58 days for a catastrophic duration.

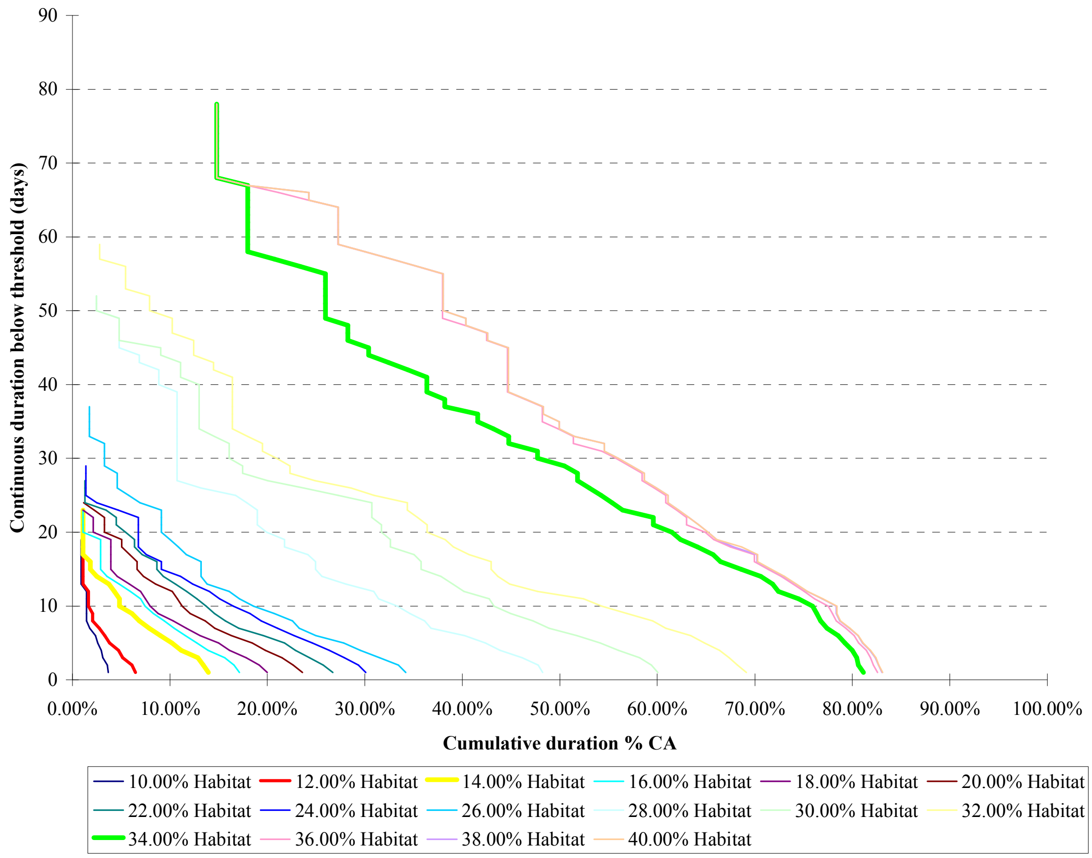

Figure 3: UCUT curves for the Nonnewaug R&G bioperiod.

For the Weekeepeemee River (Figure 4) 29 % CA of habitat is selected as *rare* threshold. The UCUT curves show dramatic increase of frequency when the threshold moves to 30 % CA. The *common* threshold is identified with 37 % CA.

For the determination of longest common duration for *rare* habitat events, the lowest of the two inflection points corresponding with 7 days was selected. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 15 days. The UCUT for the *critical* event has an inflection point at 15 days and catastrophic duration of 24 days. For the *common* level the inflection points were estimated with 37 days for common durations and 59 days for a catastrophic duration.

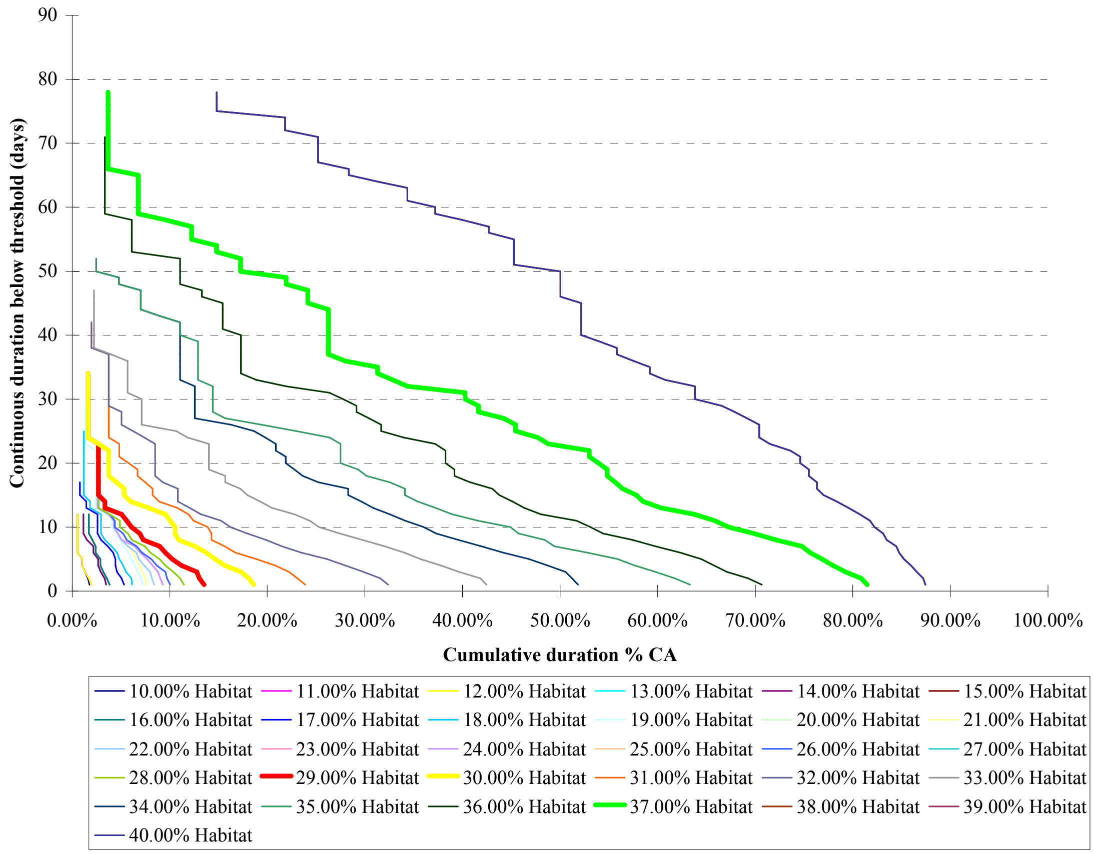

Figure 4: UCUT curves for the Weekeepeemee R&G bioperiod.

For the Pomperaug River (Figure 5) 13 % CA of habitat is selected as a *rare* threshold. The UCUT curves show dramatic increase of frequency when the threshold moves to 16 % CA. The *common* threshold is identified with 28 % CA.

For the determination of longest common duration for *rare* habitat events, the lowest of the two inflection points corresponding with 9 days was selected. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 12 days. The UCUT for the *critical* event has an inflection point at 15 days and catastrophic duration of 23 days. For the *common* level the inflection points were estimated with 27 days for common durations and 43 days for a catastrophic duration.

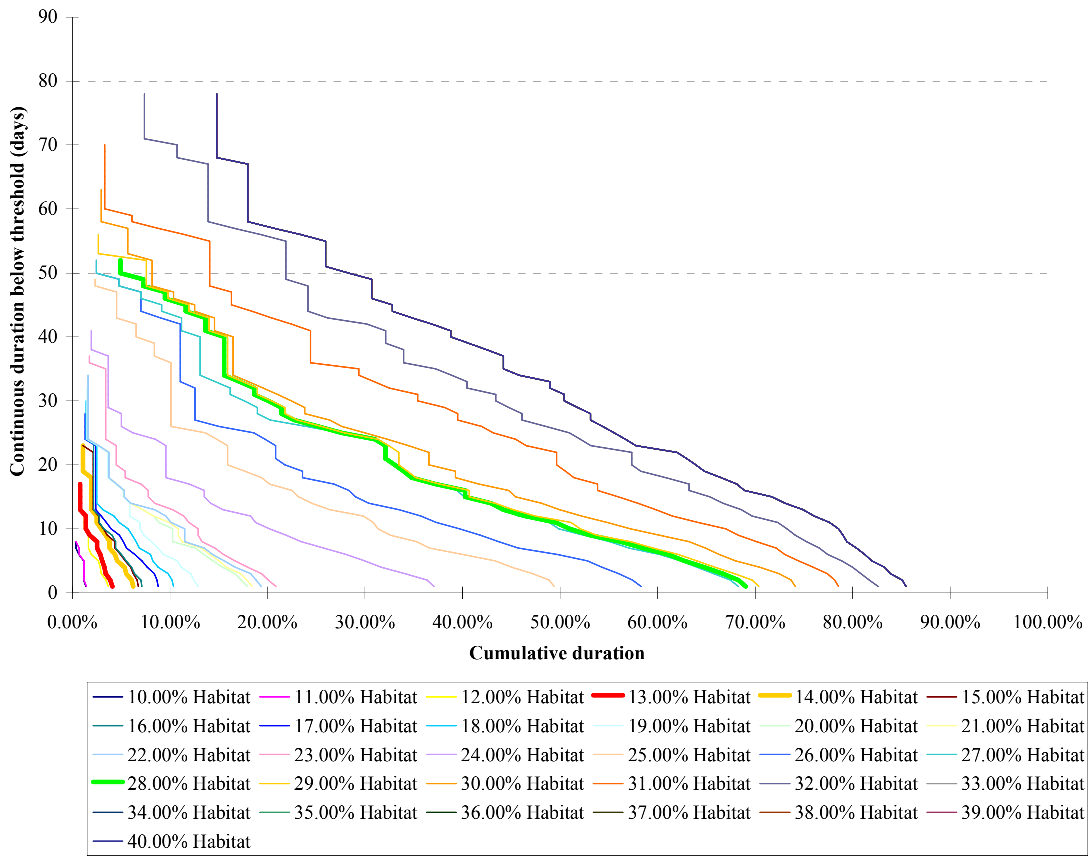

Figure 5: UCUT curves for the Pomperaug R&G bioperiod.

Atlantic salmon spawning

Figure 6 presents UCUT curves for Atlantic salmon spawning habitat in the Nonnewaug River. The determination of the thresholds was difficult because of very little habitat available for salmon spawning. 1% CA of habitat is selected as a *rare* threshold. The UCUT curves show dramatic increase of frequency when the threshold moves to 2 % CA. The *common* threshold is identified with 3 % CA.

For the determination of longest common duration for *rare* habitat events, the lowest of the two inflection points corresponding with 6 days was selected. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 10 days. The UCUT for the *critical* event has an inflection point at 11 days and catastrophic duration of 13 days. For the *common* level the inflection points were estimated with 14 days for common durations and 26 days for a catastrophic duration.

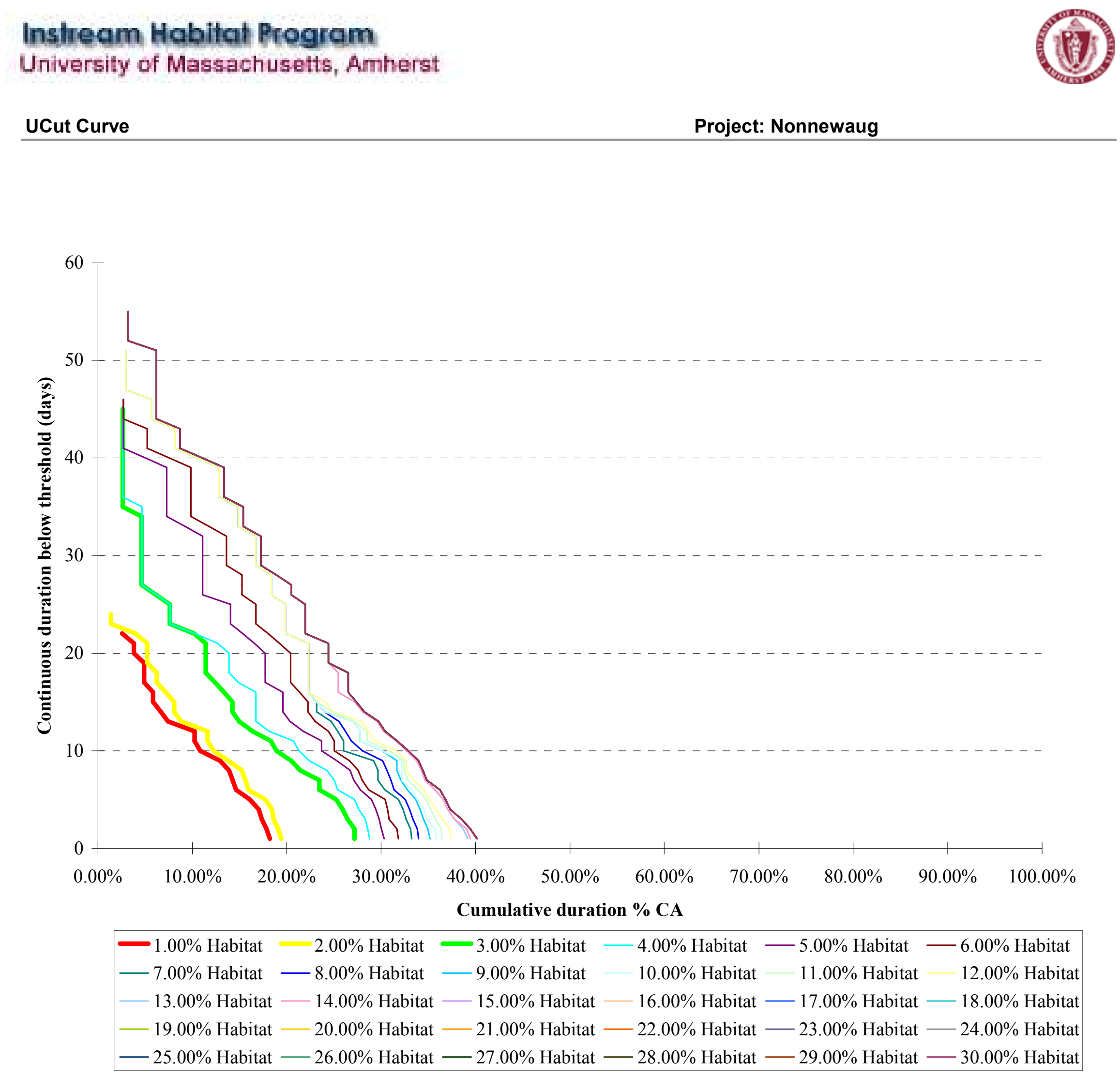

Figure 6: UCUT curves for Nonnewaug Atlantic salmon spawning.

Figure 7 presents HDC and UCUT curves for Atlantic salmon spawning habitat in the Weekeepeemee River. 1% CA of habitat is selected as a *rare* threshold. The UCUT curves show dramatic increase of frequency when the threshold moves to 6 % CA. The *common* threshold is identified with 21 % CA. The threshold for rare conditions is very conservative because of very low amounts of spawning habitat that occur.

For the determination of longest common duration for *rare* habitat events, the lowest of the two inflection points corresponding with 27 days was selected. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 32 days. The UCUT for the *critical* event has an inflection point at 32 days and catastrophic duration of 47 days. For the *common* level the inflection points were estimated with 35 days for common durations and 56 days for a catastrophic duration.

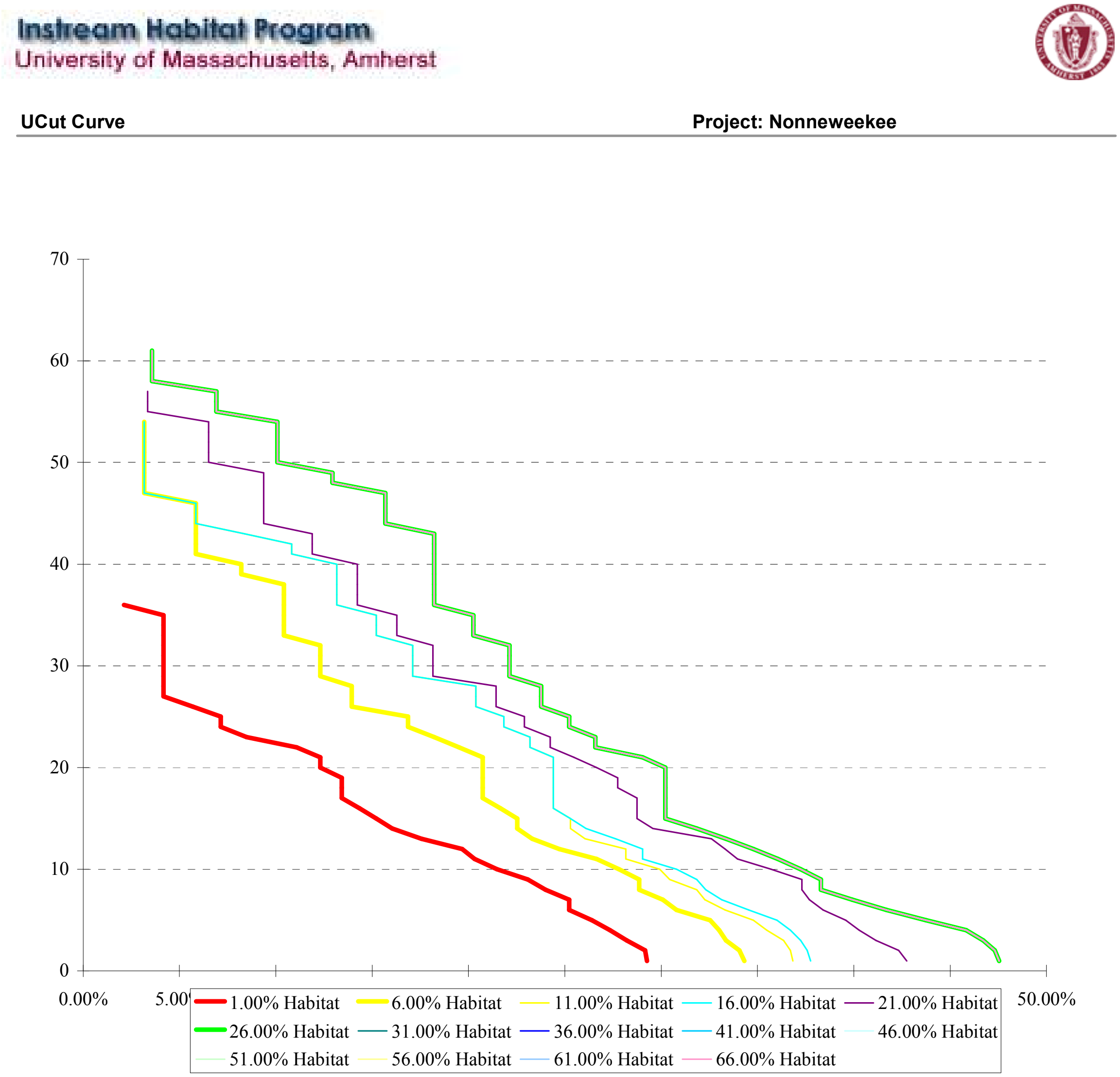

Figure 7: UCUT curves for Weekeepeemee Atlantic salmon spawning.

Figure 8 presents UCUT curves for Atlantic salmon spawning habitat in the Pomperaug River. 2% CA of habitat is selected as a *rare* threshold. The UCUT curves show dramatic increase of frequency when the threshold moves to 4 % CA. The *common* threshold is identified with 16 % CA.

For the determination of longest common duration for *rare* habitat events, the lowest of the two inflection points corresponding with 6 days was selected. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 10 days. The UCUT for the *critical* event has an inflection point at 11 days and catastrophic duration of 13 days. For the *common* level the inflection points were estimated with 14 days for common durations and 26 days for a catastrophic duration.

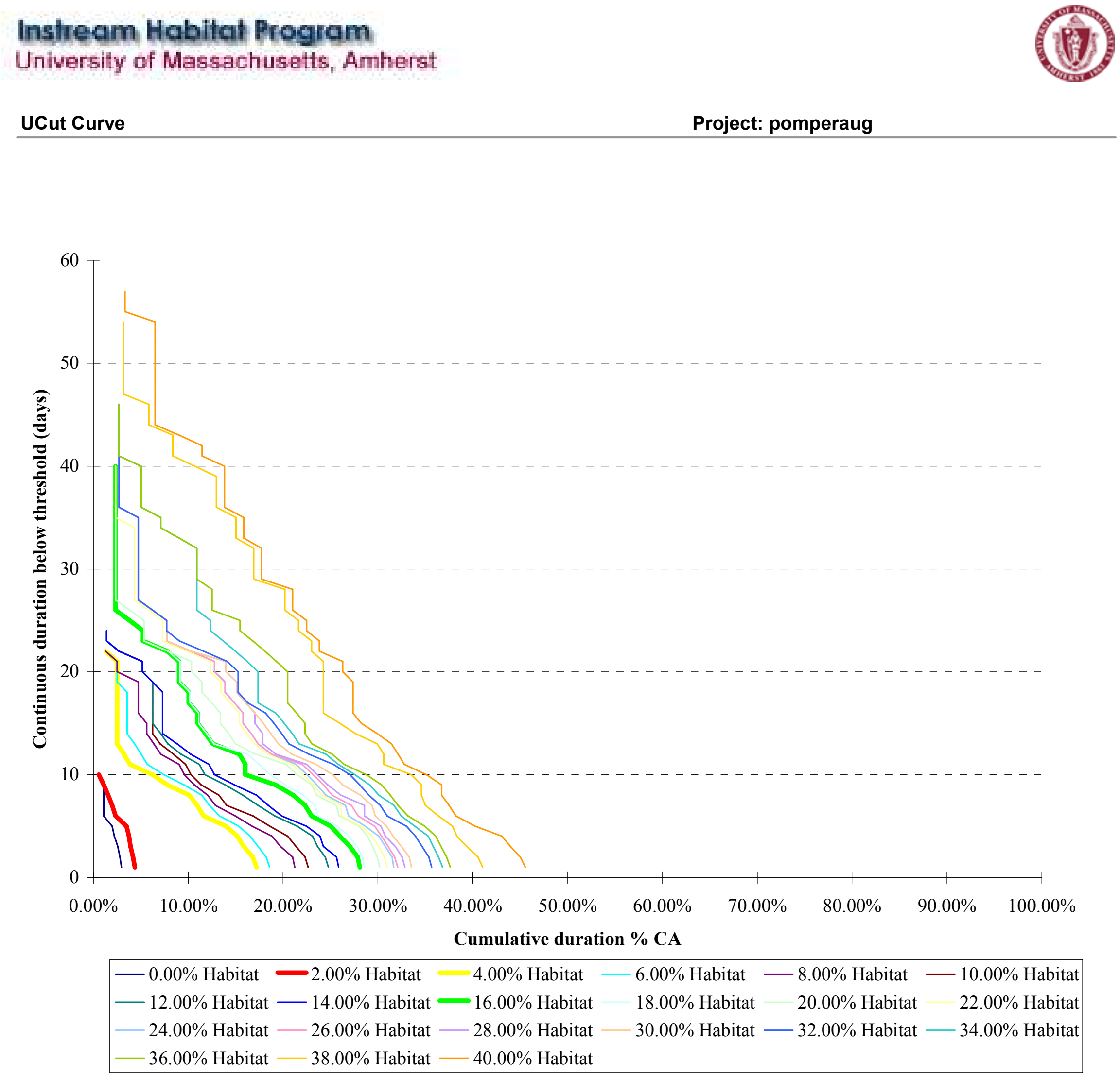

Figure 8: UCUT curves for Pomperaug Atlantic salmon spawning.

Overwintering

Figure 9 presents flow based UCUT curves for USGS gauge in on the Nonnewaug in the overwintering season. Events of flows lower than 0.5 cfsm happened for 2 % of the time. The *critical* level was chosen with 1.5 cfsm and *common* levels with 4.5 cfsm. There are hardly any inflection points visible on the UCUT curves. We attempted to identify common and catastrophic durations at 5 and 10 days for the *rare* threshold, 5 and 10 days respectively for the *critical* and 20 days and 40 days for the *common* threshold.

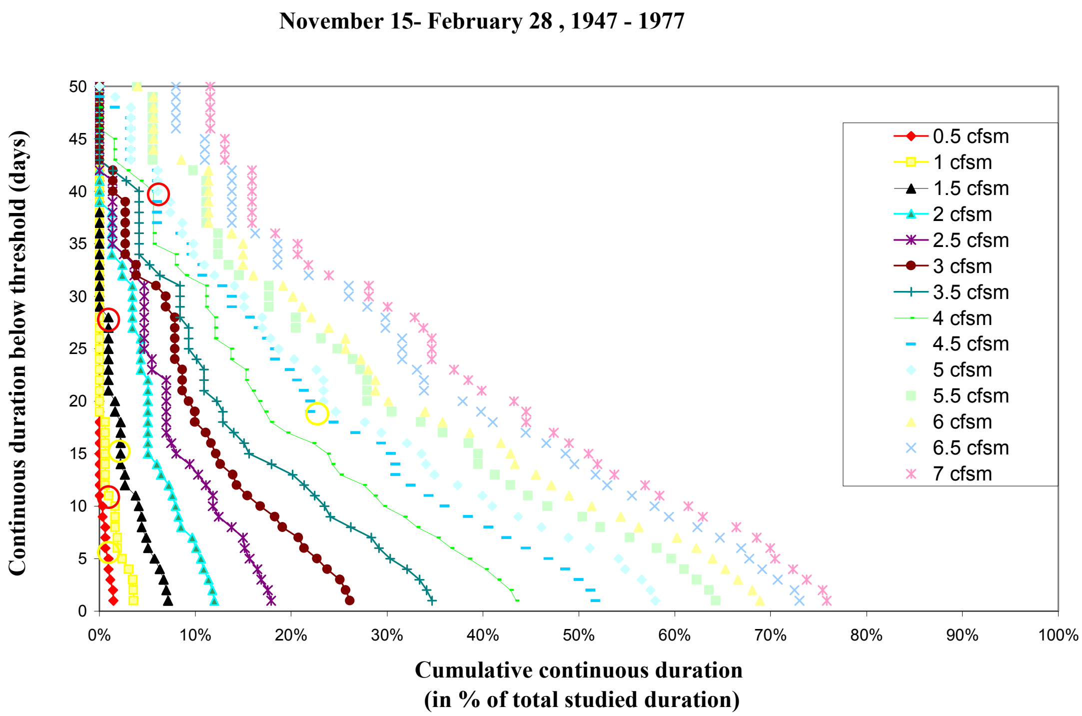

Figure 9: UCUT curves for Nonnewaug overwintering bioperiod.

Figure 10 presents flow based UCUT curves for USGS gauge in on the Weekeepeemee in the overwintering season. Events of flows lower than 0.5 cfsm are chosen as demarcating *rare* levels. The *critical* level was chosen with 0.35 cfsm and *common* levels with 1.85 cfsm. There are hardly any inflection points visible on the UCUT curves. We attempted to identify common and catastrophic durations at 15 days for the *rare* threshold, 20 days and 35 for the *critical* and 37 days and 43 days for the *common* threshold.

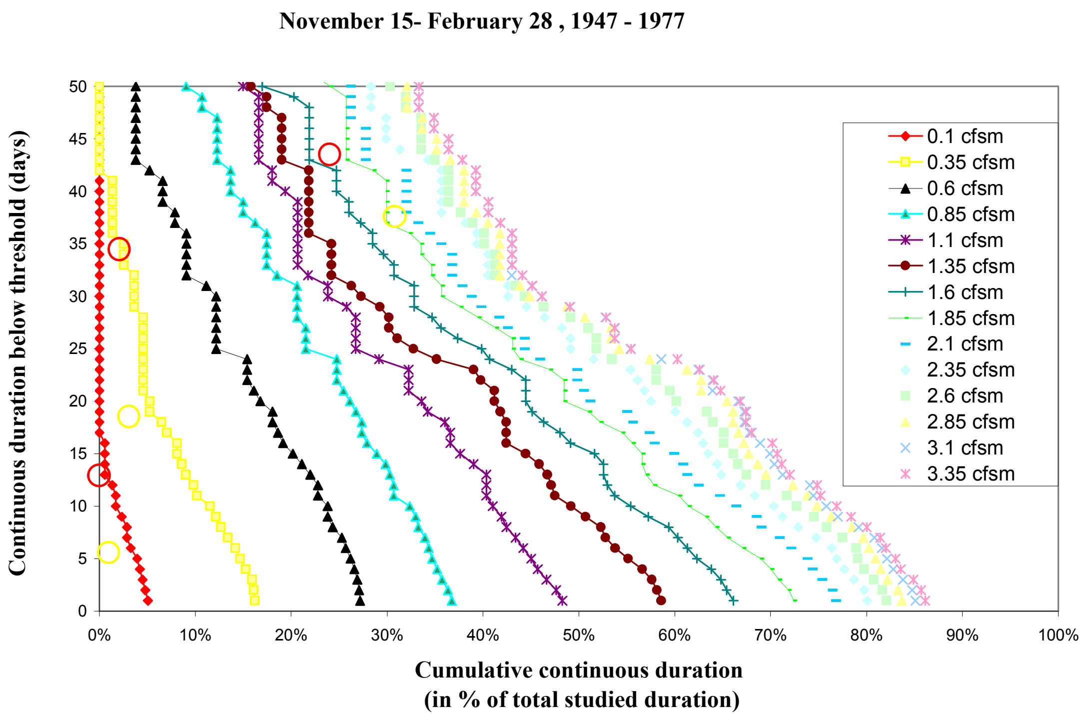

Figure 10: UCUT curves for Weekeepeemee overwintering bioperiod.

Figure 11 presents flow based UCUT curves for USGS gauge in on the Pomperaug in the overwintering season. Events of flows lower than 0.1 cfsm are chosen as demarcating *rare* levels. The *critical* level was chosen with 0.35 cfsm and *common* levels with 1.85 cfsm. There are hardly any inflection points visible on the UCUT curves. We attempted to identify common and catastrophic durations at 10 days for the *rare* threshold, 20 days and 35 for the *critical* and 37 days and 43 days for the *common* threshold respectively.

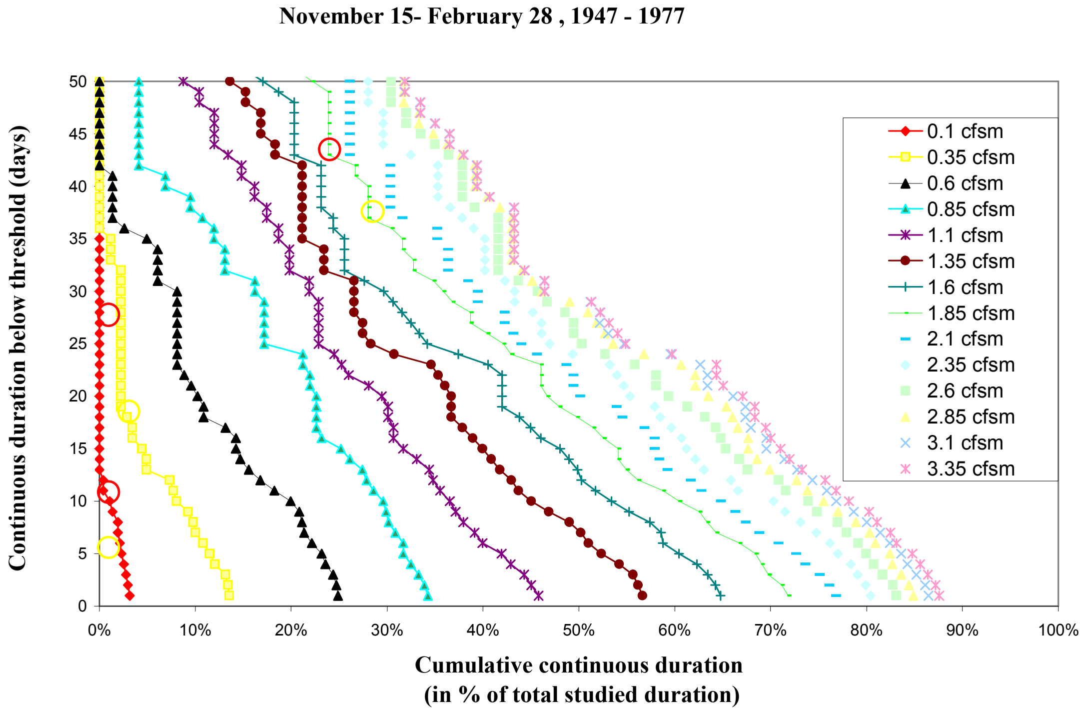

Figure 11: UCUT curves for Pomperaug overwintering bioperiod

American shad spawning

Figure 12 presents UCUT curves for American shad spawning habitat in the Nonnewaug River. 49% CA of habitat is selected as a *rare* threshold. The UCUT curves show dramatic increase of frequency when the threshold moves to 50 % CA. The *common* threshold is identified with 54 % CA.

For the determination of longest common duration for *rare* habitat events, the lowest of the two inflection points corresponding with 3 days was selected. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 7 days. The UCUT for the *critical* event has an inflection point at 10 days and catastrophic duration of 13 days. For the *common* level the inflection points were estimated with 19 days for common durations and 22 days for a catastrophic duration.

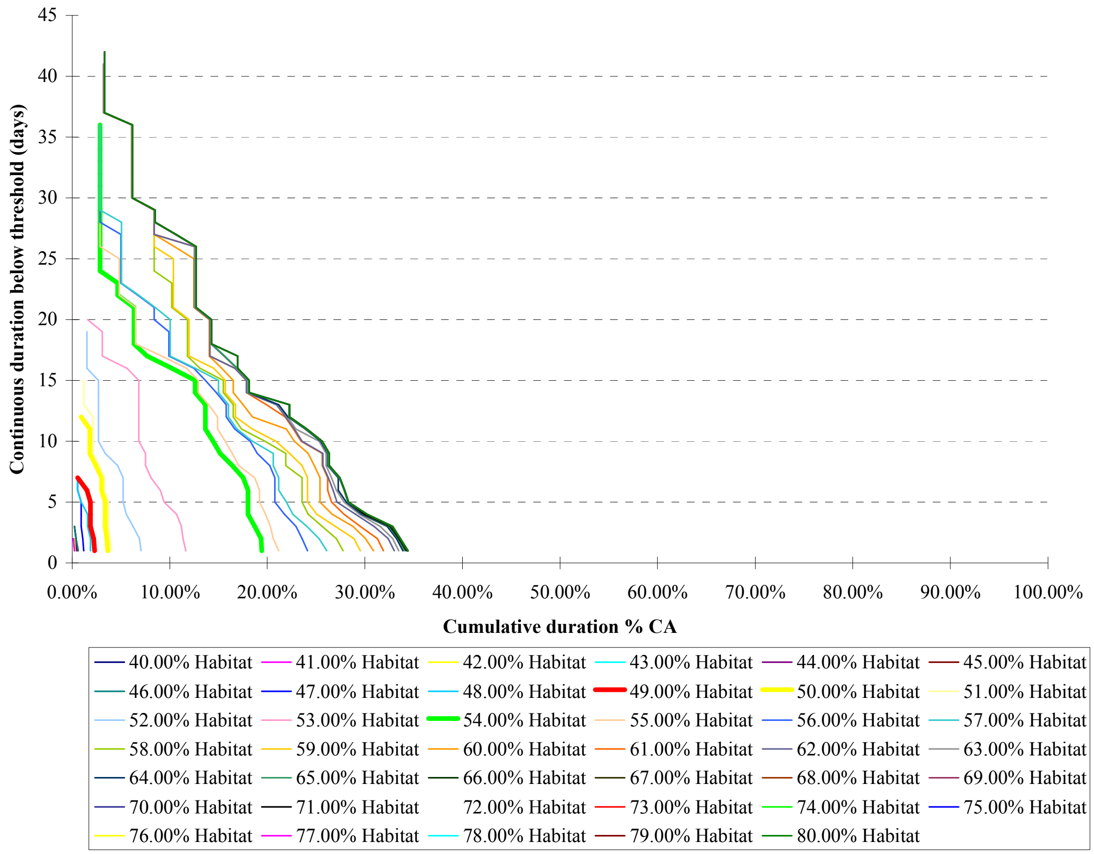

Figure 12: UCUT curves for Nonnewaug American shad spawning.

Figure 13 presents UCUT curves for American shad spawning habitat in the Weekeepeemee River. 9% CA of habitat is selected as a *rare* threshold. The UCUT curves show dramatic increase of frequency when the threshold moves to 11 % CA. The *common* threshold is identified with 13 % CA.

For the determination of longest common duration for *rare* habitat events, the lowest of the two inflection points corresponding with 11 days was selected. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 17 days. The UCUT for the *critical* event has an inflection point at 17 days and catastrophic duration of 25 days. For the *common* level the inflection points were estimated with 21 days for common durations and 37 days for a catastrophic duration.

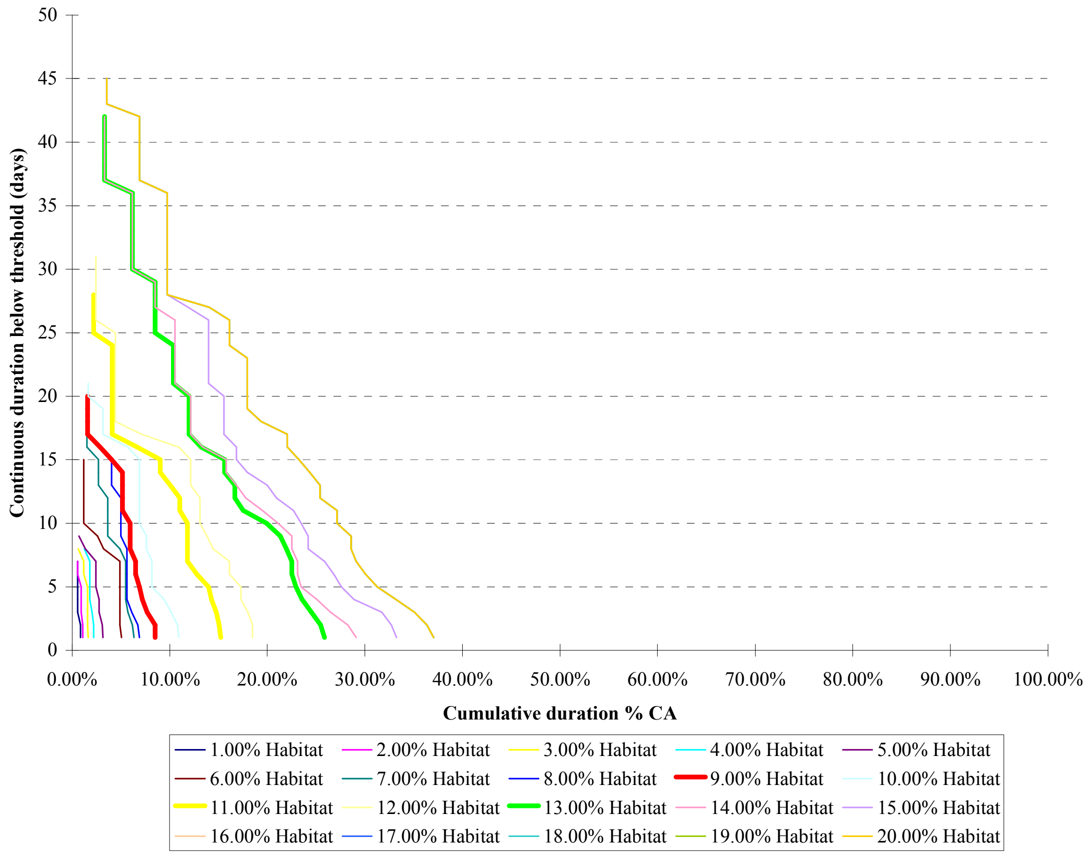

Figure 13: UCUT curves for Weekeepeemee American shad spawning.

Figure 14 presents UCUT curves for American shad spawning habitat in the Pomperaug River. 14% CA of habitat is selected as a *rare* threshold. The UCUT curves show dramatic increase of frequency when the threshold moves to 16 % CA. The *common* threshold is identified with 28 % CA.

For the determination of longest common duration for *rare* habitat events, the lowest of the two inflection points corresponding with 4 days was selected. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 11 days. The UCUT for the *critical* event has an inflection point at 10 days and catastrophic duration of 13 days. For the *common* level the inflection points were estimated with 19 days for common durations and 22 days for a catastrophic duration.

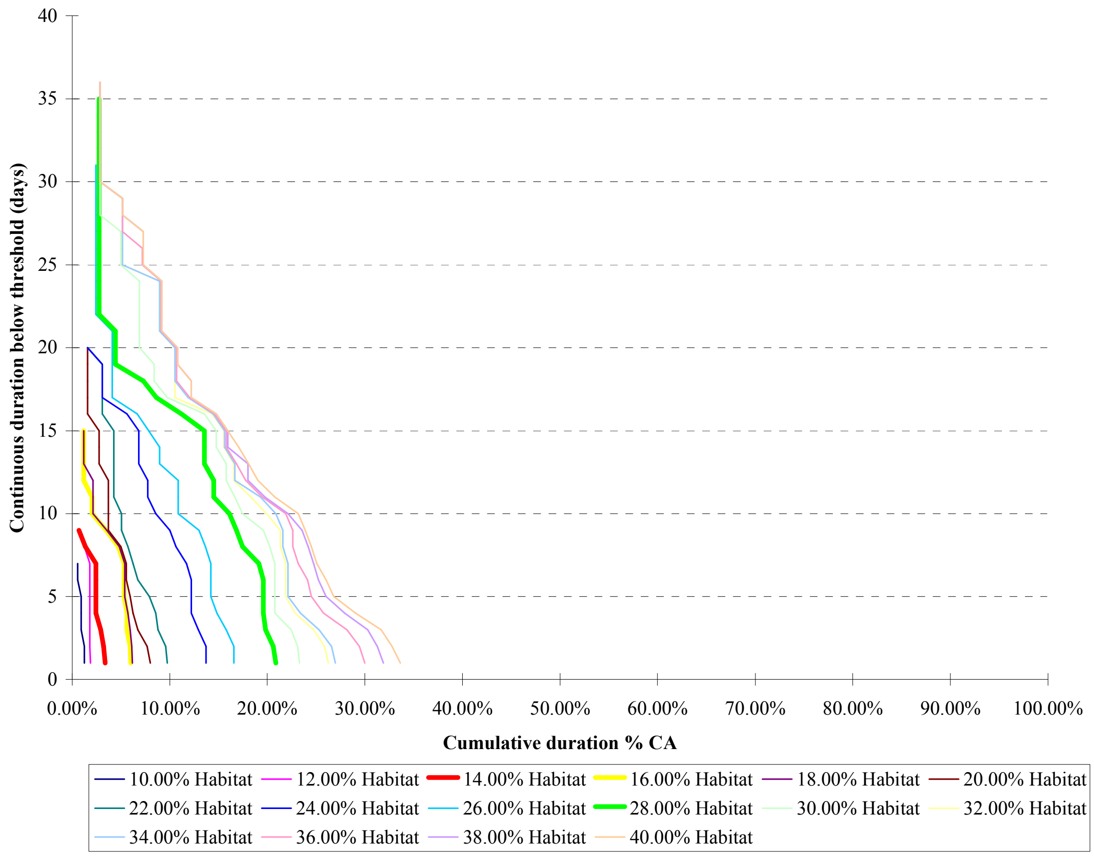

Figure 14: UCUT curves for Pomperaug American shad spawning.

Resident adult spawning

Figure 15 presents UCUT curves for resident fish spawning habitat in the Nonnewaug River. 33% CA of habitat is selected as a *rare* threshold. The UCUT curves show dramatic increase of frequency when the threshold moves to 34 % CA. The *common* threshold is identified with 40 % CA.

For the determination of longest common duration for *rare* habitat events, the lowest of the two inflection points corresponding with 6 days was selected. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 10 days. The UCUT for the *critical* event has an inflection point at 7 days and catastrophic duration of 12 days. For the *common* level the inflection points were estimated with 15 days for common durations and 27 days for a catastrophic duration.

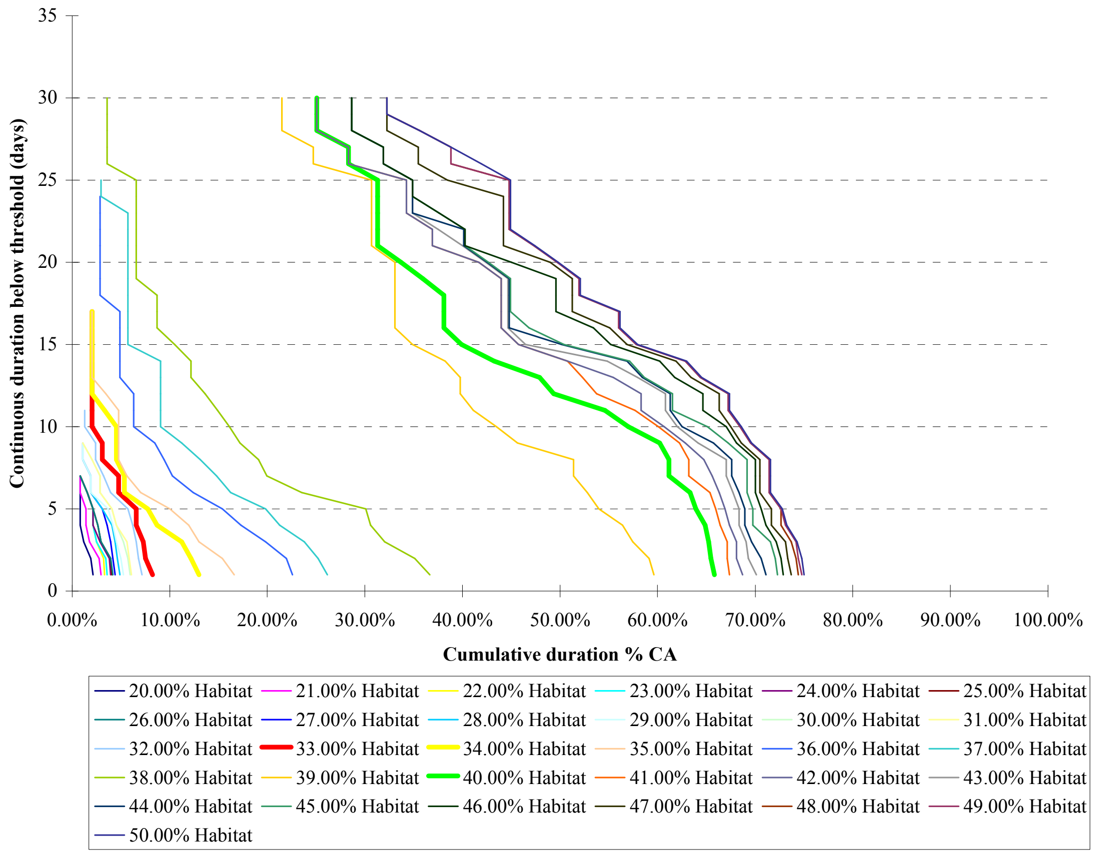

Figure 15: UCUT curves for Nonnewaug resident adult spawning.

Figure 16 presents UCUT curves for resident fish spawning habitat in the Weekeepeemee River. 31% CA of habitat is selected as a *rare* threshold. The UCUT curves show dramatic increase of frequency when the threshold moves to 32 % CA. The *common* threshold is identified with 36 % CA.

For the determination of longest common duration for *rare* habitat events, the lowest of the two inflection points corresponding with 6 days was selected. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 9 days. The UCUT for the *critical* event has an inflection point at 9 days and catastrophic duration of 13 days. For the *common* level the inflection points were estimated with 15 days for common durations and 27 days for a catastrophic duration.

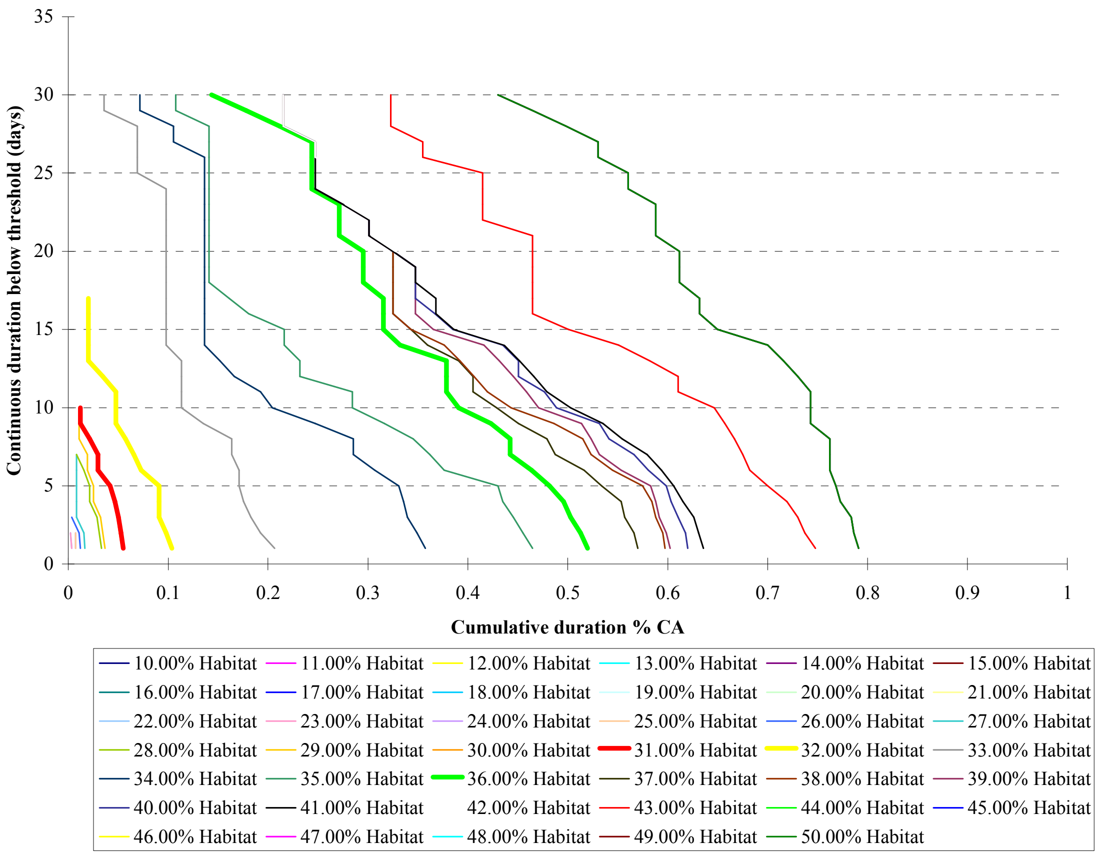

Figure 16: UCUT curves for Weekeepeemee resident adult spawning.

Figure 17 presents UCUT curves for resident fish spawning habitat in the Pomperaug River. 33% CA of habitat is selected as a *rare* threshold. The UCUT curves show dramatic increase of frequency when the threshold moves to 34 % CA. The *common* threshold is identified with 37 % CA.

For the determination of longest common duration for *rare* habitat events, the lowest of the two inflection points corresponding with 3 days was selected. The catastrophic duration begins where the curve moves very close to the x-axis and was selected with 6 days. The UCUT for the *critical* event has an inflection point at 3 days and catastrophic duration of 6 days. For the *common* level the inflection points were estimated with 15 days for common durations and 27 days for a catastrophic duration.

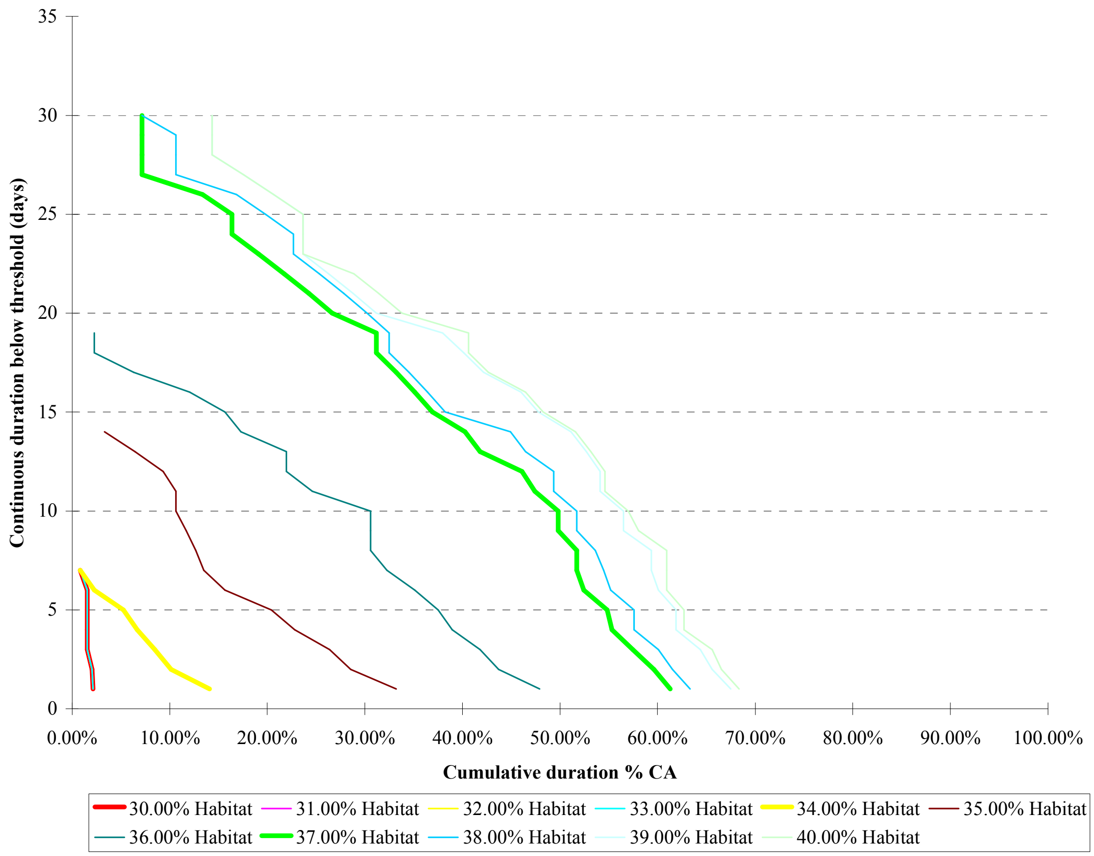

Figure 17: UCUT curves for Pomperaug resident adult spawning.