Recovery Potential Metrics Summary Form

Indicator Name: ELEVATION

Type: Stressor exposure

Rationale/Relevance to Recovery Potential: Specific to waters with bio-impairments involving coldwater fish populations. For a given state or sub-state region, the range of elevations among different bio-impaired waters may provide part of the basis for comparing the likelihood of reestablishing coldwater temperature regimes, all other factors aside. Lower elevations correlate with greater vulnerability of coldwater aquatic communities and difficulty in their restoration, especially in consideration of expected climate change. Secondarily, the warmer water temperature regimes can increase chemical pollutant availability or toxicity and oxygen depletion.

How Measured: Mean elevation of the specific stream/river segment. Field data or models may be usable to estimate elevation thresholds below which recovery of a coldwater system or species is unlikely.

Data Source: The National Elevation Dataset (NED) (See: http://nhd.usgs.gov/index.html) is adequate for arraying a set of waters into quantiles based on mean elevation. High resolution elevation data should be used for any assessment units at HUC12 level or smaller. The Elevation Derivatives for National Applications (EDNA) has been derived from the NED and is hydrologically conditioned to improve hydrologic flow representation (See: http://edna.usgs.gov/). NHD plus contains information on maximum and minimum elevation for each flowline (http://www.horizon-systems.com/nhdplus/).

Indicator Status (check one or more)
______ Developmental concept.
___x__ Plausible relationship to recovery.
______ Single documentation in literature or practice.
___x__ Multiple documentation in literature or practice.
______ Quantification.

Comments: This metric is best used when based on the temperature preferences of a target species, and may be most useful in geographic areas where elevation differences alone account for a range from coldwater to warmwater regimes.

Examples from Supporting Literature (abbrev. citations and points made):

- (Flanagan et al. 1999) In the study area, the geographical distinction between cold- and warm-water fisheries closely follows the distinction between the Northeastern Highlands and Northeastern Coastal Zone ecoregions (fig. 15). The landform surface also is important in determining the temperature of a stream because of differences in elevation…. Kimball (1986) showed that for Massachusetts the location of cold-water streams was closely dependant on elevation. Cold-water fisheries generally were limited to streams throughout the state that had a minimum mean basin elevation of 190 ft.
- (Rahel et al 1996) trout and salmon are the dominant species in high elevation aquatic systems throughout north America, but warming temperatures could restrict coldwater fishes to increasingly higher elevations which are fewer in number and more isolated.
- (Grau et al., 2003) Forest recovery tends to occur in areas of marginal agriculture: at high elevations, on steep slopes, within reserve areas, far from roads, in areas with net population out-migration, and in small farm areas located near preexisting forests. Urban

areas expand at lower elevations, on flat topography, and closer to roads and urban areas (Thomlinson et al. 1996, Helmer 2003). The landscape features that favor urbanization are the same ones that favor intensive agriculture. For example, between 1977 and 1994, new urban areas replaced 6% of the island's prime agricultural lands (López et al. 2001) (1160).

- (Scarnecchia and Roper, 2000) The differences in distribution and mean densities of the three species indicated that each type of fish differed in its use of tributaries (Table 3). Steelhead trout were found in all nine tributaries, Chinook salmon in eight and coho salmon in five. Each species was found at highest densities in different tributaries: steelhead trout in the higher-elevation tributaries; Chinook salmon in the mid-elevation tributaries; and coho salmon in the lower-elevation tributaries. All three species were found at higher densities in pools than riffles in tributaries.
- (Scarnecchia and Roper 2000) The percentage of hatchery-reared fish generally increased with decreasing elevation; more than 80% of the Chinook salmon observed in Stouts Creek, the lowest elevation tributary, were hatchery-reared. The hatchery fish moved great distances; hatchery fish found in Stouts Creek had been released more than 40 km upstream in the mainstem South Umpqua River.
- (Scarnecchia and Roper 2000). Although specific nodal habitats such as Dumont Creek may provide important refuges in the short term (Sedell et al. 1990; Frissell et al. 1993), except for this nodal habitat, these species demonstrated considerable segregation throughout the basin. Protection of tributaries for stock maintenance, for example, should emphasize high-elevation tributaries for steelhead trout, mid-elevation tributaries for Chinook salmon and low-elevation tributaries for coho salmon….Because downstream portions of the rivers are linked to upstream portions and tributaries in a complex river continuum (Vannote, Minshall, Cummins, Sedell & Cushing 1980; Gregory, Swanston, McKee & Cummins 1991), protection of upstream mainstem and tributary habitat would also affect habitat quality in the lower mainstem. Thus, maintenance of habitat quality of high-elevation tributaries may be critical to the protection of Chinook salmon populations which preferentially inhabit the mainstem. The observed segregation among species combined with the high basin-wide mobility of juveniles indicated that maintenance of habitat at the basin scale (Thomas 1993), rather than a few small watersheds, will be necessary over the long-term.
- (Bohlin, Pettersson and Degerman 2001) A second main conclusion is that altitude affected recruitment in migratory and resident populations differentially. In stream-resident trout altitude had no significant effect (Fig. 5), suggesting that the environmental cline along streams has limited effect on the fitness of resident trout within this altitude range. In contrast, the yearling density in migratory populations declined significantly with altitude, as predicted from the cost theory… We therefore suggest that the effect of altitude on recruitment is related to a cost of migration increasing with stream length and slope through metabolic costs and /or loss rates.
- (McHugh and Budy 2005) Patterns of fish-species replacement along altitudinal gradients occur commonly in mountain rivers and streams throughout the world (Taniguchi and Nakano 2000). This phenomenon — termed altitudinal species zonation because of the distinct species zones observed along upstream– downstream gradients — occurs in response to factors operating differentially across elevations. Zonation may be due to the response of individual species to the availability of suitable habitat conditions that vary with elevation (e.g., temperature; Vincent and Miller 1969; Rahel and Hubert 1991; Bozek and Hubert 1992). For instance, each species may have a different thermal physiology and thus exhibit a distribution pattern reflecting the spatial arrangement of suitable temperatures within a river network (Magoulick and Wilzbach 1998*a*).(McHugh and Budy 2005) Thus, while we present evidence of a negative effect of exotic brown trout on native cutthroat trout, temperature-mediated competition does not satisfactorily explain zonation in our system. Rather, we suggest that altitudinal segregation is due to an abiotic determination of brown trout's upstream limit, coupled with their demonstrated ability to negatively impact cutthroat trout when they co-occur. Specifically, we believe

that brown trout have invaded as far upstream as their thermal physiology permits and during this process have displaced cutthroat trout from downstream reaches.

- (McHugh and Budy 2005) In conclusion, extreme cold incubation conditions may offer the best explanation for the lack of self-sustaining, local populations of brown trout at high elevations of our system as well as in other western North American streams (Vincent and Miller 1969; Rahel and Nibbelink 1999; de la Hoz Franco and Budy 2005).
- (McHugh and Budy 2005) While brown trout invasions may have slowed in streams like the Logan River (i.e., they have had ~100 years to invade suitable habitats), this may change under future climatic and land-management scenarios. If temperatures increase, brown trout distributions may shift upstream (Keleher and Rahel 1996) and thus reduce the extent of remaining cutthroat trout populations. Indeed, brown trout distributions have been observed to change rapidly in invaded systems during periods of climate change (e.g., drought; Closs and Lake 1996).