Potential Salmonid Refugia

Establishment and maintenance of salmonid refugia areas containing high quality habitat and sustaining fish populations are activities vital to the conservation of our anadromous salmonid resources (Moyle and Yoshiyama 1992; Liet al. 1995; Reeves et al. 1995). Protecting these areas will prevent the loss of the remaining high quality salmon habitat and salmonid populations. Therefore, a refugia investigation project should focus on identifying areas found to have high salmonid productivity and diversity. Identified areas should then be carefully managed for the following benefits:

- Protection of refugia areas to avoid loss of the last best salmon habitat and populations. The focus should be on protection for areas with high productivity and diversity;
- Refugia area populations which may provide a source for re-colonization of salmonids in nearby watersheds that have experienced local extinctions, or are at risk of local extinction due to small populations;
- Refugia areas provide a hedge against the difficulty in restoring extensive, degraded habitat and recovering imperiled populations in a timely manner (Kaufmann, et al. 1997).

The concept of refugia is based on the premise that patches of aquatic habitat provide habitat that still retain the natural capacity and ecologic functions that support wild anadromous salmonids in such vital activities as spawning and rearing. Anadromous salmonids exhibit typical features of patchy populations; they exist in dynamic environments and have developed various dispersal strategies including juvenile movements, adult straying, and relative high fecundity for an animal that exhibits some degree of parental care through nest building (Reeves et al. 1995). Conservation of patchy populations requires conservation of several suitable habitat patches and maintaining passage corridors between them.

Potential refugia may exist in areas where the surrounding landscape is marginally suitable for salmonid production or altered to a point that stocks have shown dramatic population declines in traditional salmonid streams. If altered streams or watersheds recover their historic natural productivity, either through restoration efforts or natural processes, the abundant source populations from nearby refugia can potentially re-colonize these areas or help sustain existing salmonid populations in marginal habitat. Protection of refugia areas is noted as an essential component of conservation efforts to ensure long-term survival of viable stocks, and a critical element towards recovery of depressed populations (Sedell, 1990; Moyle and Yoshiyama 1992; Frissell 1993, 2000).

Refugia habitat elements include the following:

- Areas that provide shelter or protection during times of danger or distress;
- Locations and areas of high quality habitat that support populations limited to fragments of their former geographic range; and
- A center from which dispersion may take place to re-colonize areas after a watershed and/or sub-watershed level disturbance event and readjustment.

Spatial and Temporal Scales of Refugia

These refugia concepts become more complex in the context of the wide range of spatial and temporal habitat required for viable salmonid populations. Habitat can provide refuge at many scales from a single fish to groups of them, and finally to breeding populations. For example, refugia habitat may range from a piece of wood that provides instream shelter for a single fish, or individual pools that provide cool water for several rearing juveniles during hot summer months, to watersheds where conditions support sustaining populations of salmonid species. Refugia also

include areas where critical life stage functions such as migrations and spawning occur. Although fragmented areas of suitable habitat are important, their connectivity is necessary to sustain the fisheries. Today, watershed scale refugia are needed to recover and sustain aquatic species (Moyle and Sato 1991). For the purpose of this discussion, refugia are considered at the fish bearing tributary and subbasin scales. These scales of refugia are generally more resilient than the smaller, habitat unit level scale to the deleterious effects of landscape and riverine disturbances such as large floods, persistent droughts, and human activities (Sidell et al. 1990).

Standards for refugia conditions are based on reference curves from the literature and CDFG data collection at the regional scale. The assessment team uses these values in its EMDS models and stream inventory, improvement recommendation process. Li et al. (1995) suggested three prioritized steps to use the refugia concept to conserve salmonid resources.

- Identify salmonid refugia and ensure they are protected;
- Identify potential habitats that can be rehabilitated quickly;
- Determine how to connect dispersal corridors to patches of adequate habitat.

Refugia and Metapopulation Concept

The concept of anadromous salmonid metapopulations is important when discussing refugia. The classic metapopulation model proposed by Levins (1969) assumes the environment is divided into discrete patches of suitable habitat. These patches include streams or stream reaches that are inhabited by different breeding populations or sub-populations (Barnhart 1994,; McElhany et al. 2000). A metapopulation consists of a group of sub-populations which are geographically located such that over time, there is likely genetic exchange between the sub-populations (Barnhart 1994). Metapopulations are characterized by 1) relatively isolated, segregated breeding populations in a patchy environment that are connected to some degree by migration between them, and 2) a dynamic relationship between extinction and re-colonization of habitat patches.

Anadromous salmonids fit nicely into the sub-population and metapopulation concept because they exhibit a strong homing behavior to natal streams forming sub-populations, and also have a tendency to stray into new areas. The straying or movement into nearby areas results in genetic exchange between sub-populations or seeding of other areas where populations are at low levels. This seeding comes from abundant or source populations supported by high quality habitat patches which may be considered as refugia.

Habitat patches differ in suitability and population strength. In addition to the classic metapopulation model, other theoretical types of spatially structured populations have been proposed (Li et al. 1995; McElhany et al. 2000). For example, the core and satellite (Li et al. 1995) or island-mainland population (McElhany et al. 2000) model depicts a core or mainland population from which dispersal to satellites or islands results in smaller surrounding populations. Most straying occurs from the core or mainland to the satellites or islands. Satellite or island populations are more prone to extinction than the core or mainland populations (Li et al. 1995; McElhany et al. 2000). Another model termed source-sink populations is similar to the core-satellite or mainland-island models, but straying is one way, only from the highly productive source towards the sink subpopulations. Sink populations are not self-sustaining and are highly dependant on migrants from the source population to survive (McElhany et al. 2000). Sink populations may inhabit typically marginal or unsuitable habitat, but when environmental conditions strongly favor salmonid production, sink population areas may serve as important sites to buffer populations from disturbance events (Li et al. 1995) and increase basin population strength. In addition to testing new areas for potential suitable habitat, the source-sink strategy adds to the diversity of behavior patterns salmonids have adapted to maintain or expand into a dynamic aquatic environment.

The metapopulation and other spatially structured population models are important to consider when identifying refugia because in dynamic habitats, the location of suitable habitat changes (McElhany et al. 2000) over the long term from natural disturbance regimes (Reeves et al. 1995) and over the short term by human activities. Satellite, island, and sink populations need to be considered in the refugia selection process because they are an integral component of the metapopulation concept. They also may become the source population or refugia areas of the future.

Methods to Identify Refugia

Currently there is no established methodology to designate refugia habitat for California's anadromous salmonids. This is mainly due to a lack of sufficient data describing fish populations, metapopulations and habitat conditions and productivity across large areas. This lack of information holds true for basins especially in terms of metapopulation dynamics. Studies are needed to determine population growth rates and straying rates of salmonid populations and sub-populations to better utilize spatial population structure to identify refugia habitat.

Classification systems, sets of criteria and rating systems have been proposed to help identify refugia type habitat in north coast streams, particularly in Oregon and Washington (Moyle and Yoshiyama 1992; FEMAT 1993; Li et al. 1995; Frissell et al. 2000; Kisup County, 2000). Upon review of these works, several common themes emerge. A main theme is that refugia are not limited to areas of pristine habitat. While ecologically intact areas serve as dispersal centers for stock maintenance and potential recovery of depressed sub-populations, lower quality habitat areas also play important roles in long-term salmonid metapopulation maintenance. These areas may be considered the islands, satellites, or sinks in the metapopulation concept. With implementation of ecosystem management strategies aimed at maintaining or restoring natural processes, some of these areas may improve in habitat quality, show an increase in fish numbers, and add to the metapopulation strength.

A second common theme is that over time within the landscape mosaic of habitat patches, good habitat areas will suffer impacts and become less productive, and wink out and other areas will recover and wink in. These processes can occur through either human caused or natural disturbances or succession to new ecological states. Regardless, it is important that a balance be maintained in this alternating, patchwork dynamic to ensure that adequate good quality habitat is available for viable anadromous salmonid populations (Reeves et al. 1995.)

Assessment Team Approach to Identifying Refugia

The interdisciplinary team identified and characterized refugia habitat by using expert professional judgment and criteria developed for North Coast watersheds. The criteria used considered different values of watershed and stream ecosystem processes, the presence and status of fishery resources, forestry and other land uses, land ownership, potential risk from sediment delivery, water quality, and other factors that may affect refugia productivity. The expert refugia team encouraged other specialists with local knowledge to participate in the refugia identification and categorization process.

The team also used results from information processed by EMDS at the stream reach and planning watershed/subbasin scales. Stream reach and watershed parameter evaluation scores were used to rank stream and watershed conditions based on collected field data and air photo analysis. Stream reach scale parameters included pool shelter rating, pool depth, embeddedness, and canopy cover. Water temperature data were also used when available. The individual parameter scores identified which habitat factors currently support or limit fish production (see EMDS and limiting factors sections).

Planning watershed scale parameters used are road density, number of stream crossings, road proximity to streams, riparian cover, and LWD loading potential. The refugia team used the potential sediment production and other planning watershed scale EMDS evaluations in a similar manner as they became available.

When identifying anadromous salmonid refugia, the team took into account that anadromous salmon have several non-substitutable habitat needs for their life-cycle. A minimal list (NMFS 2000) includes:

- Adult migration pathways;
- Spawning and incubation habitat;
- Stream rearing habitat;
- Forage and migration pathways;
- Estuarine habitat.

The best refugia areas are large and meet all of these life history needs and therefore provide complete functionality to salmonid populations. These large, intact systems are scarce today and smaller refugia areas that provide for only some of the requirements have become very important areas, but cannot sustain large numbers of fish. These must operate in concert with other fragmented habitat areas for life history support and refugia connectivity becomes very important for success. Therefore, the refugia team considers relatively small, tributary areas in terms of their ability to provide at least partial refuge values, yet contribute to the aggregated refugia of larger scale areas. Therefore, the team's analyses use the tributary scale as the fundamental refugia unit.

The team created a tributary scale refugia-rating worksheet (CDFG Appendix F). The worksheet has 21 condition factors that were rated on a sliding scale from high quality to low quality. The 21 factors were grouped into five categories:

- Stream condition;
- Riparian condition;
- Native salmonid status;
- Present salmonid abundance;
- Management impacts (disturbance impacts to terrain, vegetation, and the biologic community).

Tributary ratings were determined by combining the results of air photo analyses results, EMDS results, and data in the CDFG tributary reports by a multi-disciplinary, expert team of analysts. The various factors' ratings were combined to determine an overall tributary rating on a scale from high to low quality refugia. Tributary ratings were subsequently aggregated at the subbasin scale and expressed a general estimate of subbasin refugia conditions. Factors with limited or missing data were noted. In most cases there were data limitations on 1 – 3 factors. These were identified for further investigation and inclusion in future analysis.

The assessment team has created a hierarchy of refugia categories that contain several general habitat conditions. This descriptive system is used to rank areas by applying results of the analyses of stream and watershed conditions described above and are used to determine the ecological integrity of the study area. A basic definition of biotic integrity is "the ability [of an ecosystem] to support and maintain a balanced, integrated, and functional organization comparable to that of the natural habitat of the region" (Karr and Dudley 1981).

The Report of the Panel on the Ecological Integrity of Canada's National Parks submitted this definition:

The Panel proposes the following definition of ecological integrity: "An ecosystem has integrity when it is deemed characteristic for its natural region, including the composition and abundance of native species and biological communities, rates of change and supporting processes. "In plain language, ecosystems have integrity when they have their native components (plants, animals and other organisms) and processes (such as growth and reproduction) intact.

Assessment Team Salmonid Refugia Categories and Criteria:

High Quality Habitat, High Quality Refugia
- Maintains a high level of watershed ecological integrity (Frissell 2000);
- Contains the range and variability of environmental conditions necessary to maintain community and species diversity and supports natural salmonid production (Moyle and Yoshiyama 1992; Frissell 2000);
- Relatively undisturbed and intact riparian corridor;
- All age classes of historically native salmonids present in good numbers, and a viable population of an ESA listed salmonid species is supported (Li et al. 1995);
- Provides population seed sources for dispersion, gene flow and re-colonization of nearby habitats from straying local salmonids;
- Contains a high degree of protection from degradation of its native components.

High Potential Refugia
- Watershed ecological integrity is diminished but remains good (Frissell 2000);
- Instream habitat quality remains suitable for salmonid production and is in the early stages of recovery from past disturbance;
- Riparian corridor is disturbed, but remains in fair to good condition;
- All age classes of historically native salmonids are present including ESA listed species, although in diminished numbers;
- Salmonid populations are reduced from historic levels, but still are likely to provide straying individuals to neighboring streams;
- Currently is managed to protect natural resources and has resilience to degradation, which demonstrates a strong potential to become high quality refugia (Moyle and Yoshiyama 1992; Frissell 2000).

Medium Potential Refugia
- Watershed ecological integrity is degraded or fragmented (Frissell, 2000);
- Components of instream habitat are degraded, but support some salmonid production;
- Riparian corridor components are somewhat disturbed and in degraded condition;
- Native anadromous salmonids are present, but in low densities; some life stages or year classes are missing or only occasionally represented;
- Relative low numbers of salmonids make significant straying unlikely;
- Current management or recent natural events have caused impacts, but if positive change in either or both occurs, responsive habitat improvements should occur.

Low Quality Habitat, Low Potential Refugia
- Watershed ecological integrity is impaired (Frissell, 2000);
- Most components of instream habitat are highly impaired;

- Riparian corridor components are degraded;
- Salmonids are poorly represented at all life stages and year classes, but especially in older year classes;
- Low numbers of salmonids make significant straying very unlikely;
- Current management and / or natural events have significantly altered the naturally functioning ecosystem and major changes in either of both are needed to improve conditions.

Other Related Refugia Component Categories:

Potential Future Refugia (Non-Anadromous)
- Areas where habitat quality remains high but does not currently support anadromous salmonid populations;
- An area of high habitat quality, but anadromous fish passage is blocked by man made obstructions such as dams or poorly designed culverts at stream crossings etc.

Critical Contributing Areas
- Area contributes a critical ecological function needed by salmonids such as providing a migration corridor, conveying spawning gravels, or supplying high quality water (Li et al. 1995)
- Riparian areas, floodplains, and wetlands that are directly linked to streams (Huntington and Frissell 1997).

Data Limited
Areas with insufficient data describing fish populations, habitat condition watershed conditions, or management practices.

Steps to Identifying Refugia:

The interdisciplinary team identifies and characterizes refugia habitat by using expert professional judgment and criteria developed for North Coast watersheds. The criteria include the status of extant fishery populations and stream and watershed conditions affecting them. The team also considers the status and trends in processes delivering watershed products including the transport and routing of water, sediment, wood, nutrients, and heat through the system. Thus, the level of natural and land use disturbances – past, present, and future – are considered as well. This process provides insights concerning current watershed conditions, processes, and trends. It also projects likely outcomes for refugia status in the future.

Step One: A refugia rating team is established. The team includes the interdisciplinary assessment team plus local landowners or other experts.

Step Two: The team meets in an expert session to consider:
Ecological Management Decision Support system outputs and LFA conclusions based on stream reach scale. EMDS parameters include pool shelter rating, pool depth, embeddedness, and canopy cover. LFA parameters include these and others like flow, water quality, fish passage, etc.

EMDS Planning Watershed scale parameters for road density, number of stream crossings, road proximity to streams, riparian cover, and LWD loading potential. These parameters are used to estimate watershed process disturbance levels and risk to streams.   The Basin Assessment Report's Integrated Analysis process is applied to each subbasin in the assessment area. These analyses consider the status and linkages between geology, vegetation history, land use, water quality, fluvial geo-morphology, stream habitat, and fishery status at the subbasin scale. Systematic, stratified, random samples of streams are also used within the subbasin units. These samples have only been used in one subbasin to date, but they provide the information to estimate the conditions on several stream parameters (Gallo, 2001). Local information provided by landowners and others well acquainted with the subject area.

Step Three: The refugia rating team uses the foregoing information to rate several fish, stream, and watershed components on a rating worksheet. Initially, team members complete the sections of the worksheet independently in the area of their expertise.

Step Four: The team collectively reviews the several independent ratings to validate the overall collective rating. The results of the tributary rating sheets are then collapsed into a rating for the Planning Watershed and subbasin scales within the basin context. Regional inter-basin comparisons can be made when the collection of large scale basin assessments is more complete.

CDFG Refugia Worksheet
The assessment team created a worksheet for rating refugia at the tributary scale (See Table 27). The worksheet has 21 condition factors rated on a sliding scale from high to low quality. The 21 factors are grouped into five categories: 1) stream condition; 2) riparian condition; 3) native salmonid status; 4) present salmonid abundance; and 5) management impacts (disturbance impacts to terrain, vegetation, and the biologic community). The tributary ratings are determined by combining the results of aerial photo analyses, EMDS, and data in the CDFG tributary reports by a multi-disciplinary, team of expert analysts. Ratings of various factors are combined to determine an overall refugia rating on a scale from high to low quality. The tributary ratings are subsequently aggregated at the subbasin scale and expressed as a general estimate of subbasin refugia conditions. Factors with limited or missing data are noted and discussed in the comments section as needed. In most cases there are data limitations on one to three factors. These are identified for further investigation and analysis.
The rating sheet is used by placing an "X" on a sliding scale extending from High Quality to Low Quality in each row of the rating sheet. The comments section can be used to explain items like missing data, or special situations like diversions or dams, etc.
After the sheets are completed, the ratings in each section are averaged as are the five sections' mean ratings to produce an overall summary rating for the sub-watershed (stream). These stream ratings are then normalized by stream distance and/or sub-watershed area and once more combined to produce a mean refugia rating useful for comparison between subbasins.
Although the range of variance within these layers is somewhat blurred through this lumping procedure, particulars and detail can be regained by focusing back down through the layers from subbasin to sub-watershed, stream, and finally to the individual parameters. In this manner guidance can be given to an analyst investigating opportunities for watershed improvements through restoration or management activities.

CDFG Refugia Rating Worksheet

Stream Name:			Date:
Raters:			
Ecological Integrity - Overall Refugia Summary Ratings:	High Quality; High Potential; Medium Potential; Low Quality (Other: *Non-Anadromous; Contributing Functions; Data Limited*)		
Stream Condition:	**High Quality**	**Medium Quality**	**Low Quality**
Stream Flow			
Water Temperature			
Free Passage			
Gravel			
Pools			
Shelter			
In-Channel Large Wood			
Canopy			
Nutrients			
Stream Summary Rating:			
Riparian Condition:	**High Quality**	**Medium Quality**	**Low Quality**
Forest Corridor Seral Stage			
Fluvial Dis-equilibrium			
Aquatic/Riparian Community			
Riparian Summary Rating:			
Native Salmonids Status: (Native Species and Age Classes)	**Present**	**Diminished**	**Absent**
Chinook			
Coho			
Steelhead			
Species Summary Rating:			
Salmonid Abundance:	**High**	**Medium**	**Low**
Chinook			
Coho			
Steelhead			
Abundance Summary Rating:			
Management Impacts:	**Low Impacts**	**Medium Impacts**	**High Impacts**
Disturbed Terrain			
Displaced Vegetation			
Native Biologic Integrity			
Impacts Summary Rating:			
Comments:			