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ESTABLISHING BASELINE KEY ECOLOGICAL FUNCTIONS OF FISH AND WILDLIFE FOR SUBBASIN PLANNING

Final Report 2001

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Establishing Baseline Key Ecological Functions of Fish and Wildlife for Subbasin Planning

for
Bonneville Power Administration
Project No. 2000-074-02 – Contract No. 00007328

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August 15, 2001

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Abstract

As we strive to manage the Columbia River Basin for its sustainable, productive, and diverse ecosystems, we are, in fact, managing these systems to provide an a array of ecological functions upon which these systems are based. These ecological functions avail themselves as an important tool with which to assess our historical and current habitat conditions, as well as proposed future or ideal conditions under differing management scenarios. So what are key ecological functions (KEFs) and which ones are involved? Key ecological functions refer to the major ecological roles played by an organism in its ecosystem that can affect environmental conditions for themselves or other species, or that directly influences other organisms (Marcot and Vander Heyden 2001). Currently, 111 KEFs are identified for fish and wildlife species as a result of Task 1of this project. Even though the assessment phase of this project encompasses the entire Columbia River Basin, only a subset of KEFs (58) that are associated with the lotic systems, which includes 7 – anadromous fish, 20 - co-occurring resident fish, and 137 - wildlife species linked to salmon are addressed.

Since the basin has not be systematically surveyed for each fish and wildlife species, baseline conditions for each KEF are determined by developing basin-wide species range maps using the following information: wildlife-habitat type associations, county and ecoprovince occurrence, literature (like individual state atlases), and expert peer review. This approach produced a set of species range maps that depict a species potential for occurrence given the current or historic conditions. It is this potential occurrence that serves as a baseline condition to determine the key ecolgical functions. The results offer a framework and a set of baseline assessments that can be done with existing databases. Thus, allowing resource managers the ability to assess future management activities against this norm and guide their activities in prioritizing inventory, monitoring, and mitigation efforts with ecosystem-based management.

This project uses the species distributions in conjunction with a set of wildlife-habitat relationship matrices to construct and assess a functional analysis for each of the 62 subbasins. The analysis compares functional changes from historic to current conditions across the Columbia River Basin and address community functional patterns, geographic functional patterns, and species functional roles. Products from this work include: 1) current distribution maps for fish and wildlife species (including winter range maps for birds); 2) historic distribution maps for native fish and wildlife species; 3) list of KEFs for each anadromous, resident fish, and wildlife species (species functional profiles); 4) KEF assessment of community and geographic functional patterns for each of the 62 subbasins in the Columbia River Basin; and 5) a set of functional profiles based on the species and wildlife-habitat occurrence within each subbasin.

Introduction

An array of 111 KEFs has been established for fish and wildlife species (Table 1- found at the end of this report) within the Columbia River Basin. Since, each fish or wildlife performs different functions within a given area or ecosystem the ability to evaluate the functions individual or groups of species perform allows resource managers insight into how a functioning system works. Management activities that alter habitat conditions also alters the array of species that are supported by those habitats, and thus, alter the KEFs they can provide. Work under this project evaluates KEFs as they relate to selective fish and wildlife species that are associated with salmon. Which means, this project examines KEFs in relationship to 7 – anadromous fish, 20 - co-occurring resident fish, and 137 - wildlife species that are linked to salmon. KEFs of wildlife species have been recently reported (O'Neil et al. 2001and is included with this report), but for the first time KEFs profiles for a select number of fish are provided in this report. In addition, historic and current species distributions within the entire Columbia River Basin are also included along with subbasin profiles of KEFs in tabular and graphical form. Conducting this project, allows us to offer a framework to assess KEFs, provides another tool in assessing ecological trajectories, and provides an initial baseline assessment of KEFs to help guide subbasin planning.

Background: Key Ecological Functions

Our approach uses the existing descriptions and databases of species' habitat associations and key ecological functions (KEFs) as developed for the *Wildlife-Habitat Relationships in Oregon and Washington Project* (Johnson and O'Neil 2001) that has been modified to include additional species within the Columbia River Basin. The term *key ecological functions* refer to the major ecological roles played by an organism in its ecosystem that can affect environmental conditions for themselves or other species, or that directly influences other organisms (Marcot and Vander Heyden 2001). Collectively, KEFs influence the overall biodiversity, productivity, and sustainability of ecosystems.

A classification system and database of KEFs was first developed for plant, invertebrate, and vertebrate species of in the interior West U.S. (Marcot et al. 1997; also see Morrison et al. 1998) and later for vertebrates of Washington and Oregon (Marcot and Vander Heyden 2001). In these projects, ecological roles of species, as identified by panels of species experts, were organized into hierarchical classifications and coded into relational databases as mostly categorical data. By querying the database, one can determine the array of KEFs associated with a given individual species or species group, the array of species sharing a given KEF category, and other information about the species' habitat requirements, life history patterns, potential influence of management activities on their habitat elements and KEFs, and other environmental relations. The ecosystem manager could use this approach to determine the degree to which species assemblages contribute to ecological functioning of the ecosystem, and the degree to which species communities remain fully functional in light of management influences on habitat and environmental conditions.

METHODS

The methods used in the first stage of this project are described here to give the reader an idea of what information has already been collected and what the steps are to develop the information. Initially, we began by modifying the database that was developed for the *Wildlife-Habitat Relationships in Oregon and Washington* project (the CD-ROM of these data sets are available upon request). In reviewing the species lists by county for each of the seven states that lie within the Columbia River Basin, only 18 new wildlife species needed to be added to the database. Information for 6 of the data matrices was filled out for each species. Information for 146 fish species that occurred in the Columbia River Basin was partially adapted to several matrices from the Wildlife-Habitat Relationships project: Habitat Types, Habitat Elements or KECs, and KEFs . Additions were also made to the life histories and habitat elements matrices to accommodate specific fish needs and descriptions. Expert panels that were held in October and November 2000, where panelists filled out the prepared data forms, filled out these matrices. However, due to time and costs in setting up and collecting this information, not all data collected was fully scribed into the existing data formats and tables.

Determining Species Range Maps

We developed GIS-based distribution maps for historic and current distribution of fish and wildlife species. The strategy for mapping the ranges of the fish and wildlife species in the Columbia River Basin (CRB) is to use the 5th Order HUC as the analysis unit. The process involves: 1) Compiling county-level species occurrence data; 2) Creating 5th Order HUC/wildlife-habitat (current and historic) GIS data layers for the CRB; 3) Create a relational database and GIS program to develop draft species/HUC relationships GIS coverages; 4) Expert review/edit GIS coverages; and 5) Create final maps.

The first step involved collecting and adding species/county occurrence records for Idaho and the CRB counties in Wyoming, Montana, Utah, and Nevada. These records were collected from GAP, ICBEMP, and from each state. These records were in a variety of formats, some requiring extensive conversion procedures to add to the Oregon and Washington database. For example, several of the states' GAP data only had species tied to vegetation polygons in an Arc/Info coverage. An Arc/Info AML (Advanced Macro Language) program had to be developed by NHI to convert these data to county occurrence records. Also, a significant amount of time has been spent sorting out species which names varied by state and incorporating a standard species coding system. Additionally, several new species, not occurring in Oregon or Washington had to be added to the database.

Step 2 developed a 5th Order HUC GIS coverage, spanning the entire Columbia River Basin, and tied it to the NHI Current and Historic Wildlife-Habitat Types Arc/Info Grids. NHI decided to use 5th Order HUCs as an analysis unit because they provide a more natural and higher resolution boundary than county boundaries and the level of resolution is comparable with the mapping scales. Sixth Order HUCs were considered, but NHI determined that these were too detailed given the 1:100,000 and 1:1,000,000 scales of the wildlife-habitat data. The idea behind using HUCs as the analysis unit is to produce maps with more natural appearing boundaries that are easily edited during the expert review process using ArcView (Step 4). Once the HUC occurrences of a species is determined, a species range can be mapped by HUC for small-scale regional maps, or for more detailed large-scale maps, the HUCs can be combined with the wildlife-habitat grids using an AML to produce a Grid for each species' range.

The 5th Order HUCs coverage was developed by dissolving an NHI updated version of the Northwest Power Planning Council's 6th Order HUCs. To determine which wildlife-habitats occur in each HUC, NHI developed an Arc/Info AML that overlays the HUC coverage with the wildlife-habitat grids to count total acreage of each habitat class in each HUC. This method was necessary, as opposed to a traditional coverage on coverage overlay, due to the complexity and large size of the current wildlife-habitat Grid. Without using extensive generalization techniques, converting this Grid to a vector coverage produces a file too large to process with Arc/Info. The AML also generated a table of 5th Order HUC/wildlife-habitat combinations, for both current and historic conditions, that was imported into the NHI database described in the next step.

Step 3 is the development of the relational database, which will produce the input to create, using an AML, the draft species range GIS coverages. When this step is completed draft GIS coverages are developed for 27 fish and 137 wildlife species. An example of a fish and wildlife range map follows:

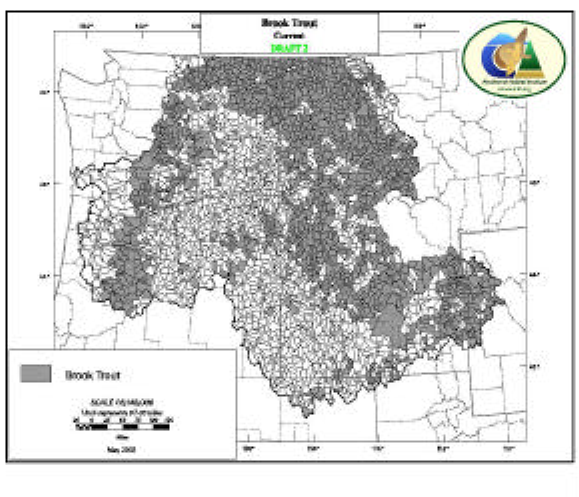

Figure 1. Range Map of the Brook Trout for the entire Columbia River Basin. Map depicts species range with the 5th HUCs shown.

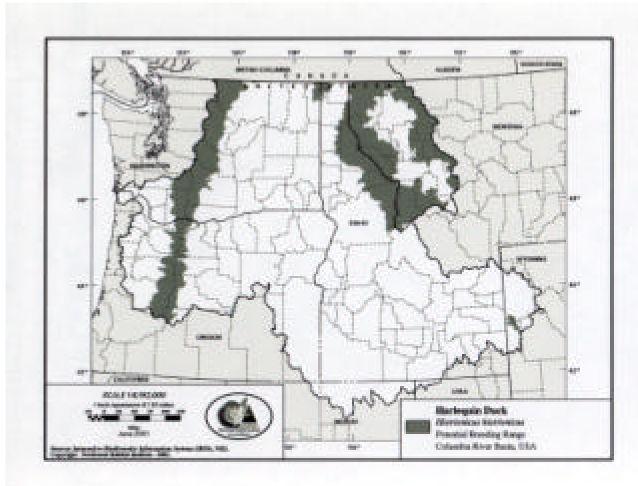

Figure 2. Breeding Range Map of the Harlequin Duck for the entire Columbia River Basin. Map depicts species range without the 5th HUCs shown.

In Step 4, maps were either sent out to species experts for comment and corrections or were reviewed against existing published information. Fish range maps were determined initially by using the ICBEMP data created for presence and historic ranges. This information was developed by acquiring data from over 140 biologists throughout the basin and from pre-existing data sets in Oregon, Washington, Montana and Idaho. These data were available only for the eastside of the Cascades. Contacting area fish biologists and using the Oregon State University fish collection database filled in the westside of the Cascades. The wildlife range maps were developed using existing publications (Lord 1902, Bailey 1936, Gabrielson and Jewett 1940, Jewett et al. 1953, Hall 1981, Chapman and Feldhamer 1982, Nussbaum et al. 1983, Johnsgard 1986, Leonard et al. 1993, Scott 1993, Raynes and Wile 1994, Gilligan et al. 1994, Storm and Leonard 1995, Csuti et al. 1997, Groves et al. 1997, Dvornich et al. 1997, Smith et al. 1997, Johnson et al. 1997, Contreras 1997, Verts and Carraway 1998, Hart et al. 1998, and Fisher et al. 2000) by a person who did not create the map. The final step was to produce the final range map.

Determining Key Ecological Functions

The 22 fish KEFs were combined with the wildlife KEF data matrix (Table 1 at the end of this report). Remember that the *Wildlife-Habitat Relationships in Oregon and Washington Project* data relates: wildlife species to habitats (macrohabitats or vegetation communities, structural conditions, and key environmental correlates or KECs) and to KEF categories; and KECs to management activities (Fig. 3). In this way, database queries can determine the sets of KEFs for species occurring, for various life history needs, in specific wildlife habitats with specified structural conditions and KECs, and the influence of management activities on functional categories of such species.

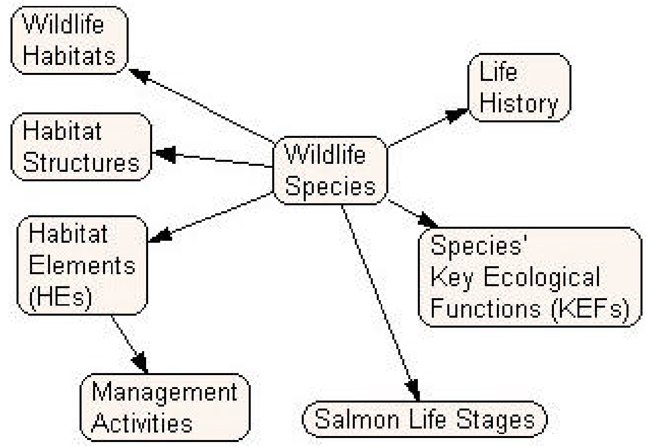

Figure 3. Diagram of data matrices developed by the Wildlife-Habitat Relationships in Oregon and Washington project in which the fish information was incorporated.

We followed the “taxonomy” of functional patterns of KEFs presented by Marcot and Vander Heyden (2001). This taxonomy identifies various parameters of community functional patterns, geographic functional patterns, individual species’ functional roles, and functional responses of species assemblages. Because the data matrix on species’ KEFs consists mostly of categorical data, we used species counts as a unit of measure. The number of species performing a similar ecological role (KEF category) is defined as the *functional redundancy* of that KEF category (Walker 1992). Our assumption is that greater functional redundancy imparts greater resilience of a system to perturbations, stresses, and changes (Fonseca and Ganade 2001, Peterson et al. 1998).

However, to determine a value for functional redundancy we must account for the amount and proportions of wildlife habitats because they differ among types and time period (historic and current) within a watershed. To account for this, we multiplied the values of functional redundancy for each KEF category for each pertinent wildlife-habitat type, by the percent of each wildlife habitat type in the watershed, keeping these products separate for historic and current time periods. We called these products “weighted redundancy values.” This is an interim step only and does not have any specific ecological meaning.

For example, the raw functional redundancy value for KEF category 1.1.2 (the key ecological function category “secondary consumer”) in the Lowland Conifer-Hardwood Forest wildlife-habitat type, is 40 wildlife species (Table 2). The current proportion of this wildlife habitat type in the example subbasinis 0.326 (168,200/208,685 in Figure 4). Multiplying these values gives 40 x 0.326 = 13.07. This is the weighted redundancy value for this wildlife habitat type in this watershed, for this particular time period. Such calculations were done for all other wildlife habitat types in this watershed, and then carried into the next step.

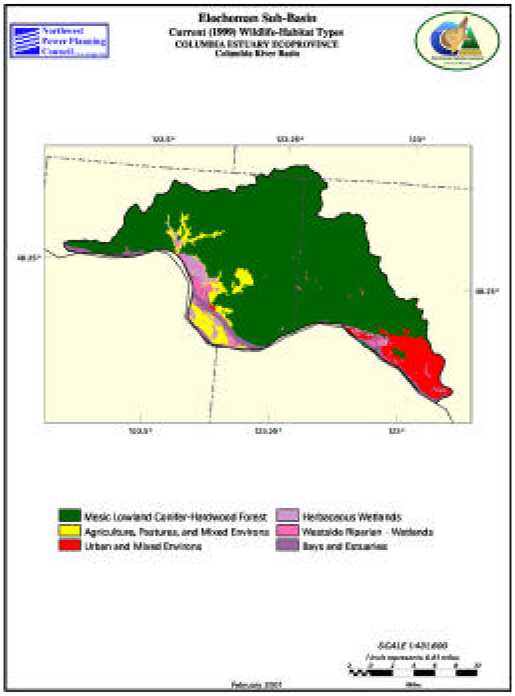

Figure 4. Depicts the current wildlife-habitat type map for the Elochoman Subbasin.

Current Wildlife-Habitat Type Acreage Summaries for Elochoman Sub-Basin:

Habitat ID	Habitat Name	Estimated Acreage
H1	Westside Lowlands Conifer-Hardwood Forest	168,200
H19	Agriculture, Pastures, and Mixed Environs	10,055
H20	Urban and Mixed Environs	13,898
H22	Herbaceous Wetlands	4,768
H23	Westside Riparian-Wetlands	3,621
H28	Bays and Estuaries	8,145
	Estimated Total Acres:	**208,685**

Table 2. Estimated acreage of each wildlife-habitat type within the Elochoman subbasin.

KEF	H1	H19	H20	H22	H23	H28
1_1_1	19	14	14	11	17	6
1_1_1_1	0	2	1	3	2	2
1_1_1_11	0	2	1	2	2	2
1_1_1_13	1	1	1	1	1	0
1_1_1_2	9	9	8	6	9	5
1_1_1_3	0	0	0	1	0	0
1_1_1_4	1	1	1	2	1	0
1_1_1_5	14	11	12	7	13	4
1_1_1_7	1	1	1	1	1	0
1_1_1_9	5	2	2	2	3	0
1_1_2	40	28	28	33	47	27
1_1_2_1	32	24	21	27	39	24
1_1_2_1_1	29	23	21	23	33	16
1_1_2_1_2	10	7	5	12	18	17
1_1_2_2	22	13	15	19	28	18
1_1_2_2_1	10	5	6	10	15	16
1_1_2_3	11	7	7	6	10	6
1_1_3	2	1	2	2	2	2
1_1_4	12	11	10	10	14	8
1_1_5	2	1	1	1	2	1
1_2_1	26	19	16	20	29	14
2	3	1	1	1	2	5
3_1	4	4	4	5	5	3
3_10	7	4	4	5	7	3
3_11	7	6	5	5	8	2
3_12	11	11	10	11	13	4
3_13	1	1	1	3	2	1
3_14	9	5	5	10	8	2
3_15	3	3	3	2	3	4
3_16	3	3	4	3	4	2
3_2	10	7	6	11	11	5
3_4	17	15	14	13	19	11
3_4_1	3	1	1	1	2	0
3_4_2	2	0	0	0	1	0
3_4_4	3	5	3	6	7	7
3_4_5	12	9	10	6	10	4
3_4_6	4	5	3	6	8	7
3_5	2	1	1	2	2	1
3_5_1	2	1	1	2	2	1
3_5_2	1	1	1	1	1	1
3_6	8	5	5	6	9	7
3_6_1	8	5	5	5	8	6
3_6_2	1	0	0	0	0	0
3_6_3	0	0	0	1	1	1
3_7	5	2	2	2	4	1
3_7_1	3	1	1	0	2	0
3_7_2	1	1	1	1	1	0
3_7_3	1	0	0	1	1	1
3_8	3	2	2	1	2	1
3_8_2	3	2	2	1	2	1
3_9	1	1	1	1	1	0
4_1	3	3	2	4	5	5
4_3	0	4	2	4	4	6
5_1	1	1	1	1	2	1
6_1	1	1	1	2	1	0
6_2	1	1	1	1	1	0
8_1	1	1	1	1	1	0

Table 3. Depicts a functional redundancy profile by showing each KEF by wildlife-habitat type for the Elochoman subbasin.

We next summed the weighted redundancy values across all wildlife habitat types for each KEF category, again separately for historic and current conditions. This resulted in what we called the “summed weighted redundancy values across all habitats” within the subbasin for historic and current time periods, for each category KEF. This is the final result of functional redundancy for each KEF category across all wildlife habitats within a watershed.

Following the above calculation example, the summed weighted redundancy values for KEF category 1.1.2 in the example subbasin was 23 for the historic time period and 19 for the current time period. These values are the area-averaged number of wildlife species associated with this KEF category, across all wildlife habitats present in this subbasin at each time period. Please note that because of mapping resolutions some habitats are difficult to depict, hence, habitats like open water, herbaceous wetlands, and riparian habitat are probably underrepresented for most subbasins. But, this is not a problem for most terrestrial, upland wildlife habitat types.

Further, we calculated the rate of change of the summed weighted redundancy values between time periods. For historic and current periods, this is calculated as [(current - historic)/historic]. For example, for KEF 1.1.2, the change from 21 to 19 was calculated as (19-23)/23 = -.17. This means that the summed weighted functional redundancy for KEF 1.1.2 decreased by a factor of .17 (or 17 %) from historic to current conditions. Comparing time periods in this way aided identifying which KEFs increased or decreased the most.

We also averaged the summed weighted functional redundancy values, across all KEF categories, by adding the values across KEF categories and dividing by the number of KEF categories. This provided a value representing the mean functional redundancy (number of wildlife species) across all KEF categories and wildlife habitat types, for each time period. Such mean functional redundancy values do not reveal which KEFs changed, however, so one would also want to inspect the KEF category-specific values and changes. Similar mean functional redundancy values compared across time periods or watersheds may still result for major shifts in KEF-specific values. Still, mean functional redundancy values may be useful to track when values vary substantially.

Maps that depict changes are particularly useful for quickly identifying geographic areas with consistent and salient changes in KEF redundancy across time periods. For example, increases, declines, or no-change in functional redundancy for each KEF can be mapped to show where, geographically, such changes occurred. Additionally, maps can be produced to compare other time periods (like historic to future, or current to future), to compare outcomes of management alternatives at a given time period, or to compare changes in total functional diversity or mean functional richness.

RESULTS AND DISCUSSION

Determining Species Range Maps

Maps illustrating current potential occurrences for 29 fish, 2 amphibian, 6 reptile, 87 bird, 30 mammal, and 15 marine mammal species were developed. Birds were by far the most difficult to sort out because timing of occurrence could determine the length of their association with salmon. Hence, individual range maps that represented year round occurrence were developed for each fish, amphibian, reptile, mammal and marine mammal species. Birds, however, have range maps that show 78 species breeding seasons, 2 species post breeding season, 7 species breeding and wintering seasons together, and 63 species winter seasons. These maps can be found in Appendix 1; several range maps do not show any occurrence within the Columbia River Basin but are included because they often occur along the coast of Oregon and/or Washington and still have an association (and possible influence) with salmon.

Historic range maps that depict potential occurrence were developed for 18 fish, 2 amphibian, 4 reptile, 66 bird, 29 mammal, and 6 marine mammal species. Only native species were modeled and the maps illustrate both year round or breeding and feeding potential for the birds. There was no attempt to breakout winter range occurrence for the birds. These maps can be found in Appendix 2.

Determining Ecological Functions

The analysis presented here provides a basis for determining the potential array of KEFs associated with a wildlife habitat, how those KEFs can change over time historically, and how patterns of KEFs can vary geographically among wildlife habitats. The ecological basis for the analysis of functional redundancy is in the presumption that KEFs with higher levels of functional redundancy can be more resilient or resistant to changes in the environment (Jaksic et al. 1996), and that, overall, systems with greater average functional redundancy will be more diverse and functionally stable over time (Naeem 1998, Rastetter et al. 1999, Walker 1992, MacNally 1995, Peterson et al. 1998). Such assertions have not been well studied for the wildlife communities of the Columbia River Basin, so analyses of KEFs and functional redundancy should be taken as testable, working hypotheses of effects on ecosystem diversity, productivity, and resilience.

Three appendices are developed that determine the ecological functions present within each subbasin. Appendix 3A give individual subbasin profiles for each KEF based on the number of wildlife species associated with salmon that perform the KEF. Additionally, the total number of species that perform the KEF within the Columbia River Basin is given along with the subbasin's contribution (percentage of the total) to the basin. For example, 15 of the 32 species (or 47%) that control terrestrial vertebrate populations through predation or displacement [KEF 3.2] occur within the Snake Headwaters (Appendix 3A p.67). Hence, from a Columbia River Basin perspective those situations were the subbasin contributes about 50% or more of a KEF should be considered important to the salmon-wildlife link. Another way to review the results would be to color ramp all values to see each subbasin's contribution to the overall basin. Last of all, a table is included in Appendix 3A that lists the number of species by province by KEF so to give planners an idea of how their subbasin fits into their province.

Other subbasin assessments that were done are of wildlife-habitat types by KEF (Appendix 3B), which profiles each of the 62 subbasins based on their current wildlife-habitat map that is available for subbasin planning (www.nwhi.org/ibis). Also, maps that depict changes in geographic patterns of KEFs from historic to current conditions were also produced and can be found in Appendix 4.

Finally, since only a very small subset of fish species range maps and KEFs were developed they were not incorporated into the analysis found in Appendix 3A, 3B, and 4 because the small sample tended to skew results. For instance, highest number of wildlife species associated with any one KEF is 77 (Flathead subbasin) while the highest number of fish species is 19. Additionally, For of the 27 fish species evaluated 9 are introduced which means that in doing a comparison from historic to current conditions a minimum of a third of the possible functions would increase; while only 2 of the 137 wildlife species are considered introduce species. The information that was collected by the Fish Expert Panel Process was separated out and can be found in Table 5 thru 14 at the end of this report.

Determining Community Functional Patterns

Functional richness and mean functional redundancy -- To what degree do wildlife species associated with salmon and selective resident fish in the Columbia River Basin in ecological functions? The total number of KEF categories pertaining to one or more species of the 137 wildlife species associated with salmon – the *functional richness* of this entire species assemblage – is 82 KEFs (this includes some categories and subcategories of KEFs [see Table 1]). This is greater than the total functional richness of the individual assemblages of amphibians, reptiles, or mammals. The number of species performing the same ecological functions in a community is its *functional redundancy* (Brown 1995). Figure 4 illustrates a single KEF's (1.1.4 – carrion feeder) geographic pattern for the functional redundancy values when the salmon-wildlife species assemblage is evaluated for the total number of species that perform KEF and then compared from historic to current conditions.

The exact steps to obtain the functional redundancy values are first the Wildlife-Hhabitat Relationships database is queried to list all wildlife species associated with each of the wildlife habitats that occur in the subbasin at each time period. The query is then linked to their KEFs so that a list of all KEF categories for all species in each wildlife habitat is produced. Next, the number of wildlife species is counted for each KEF category, in each wildlife habitat. This is a measure of functional redundancy for each KEF category, for each wildlife habitat. Next, data on acres of each wildlife habitat type for each time period was converted to proportions; these became the weighting factors for functional redundancy values. Figure 5 depicts the upper and lower percentages of these values.

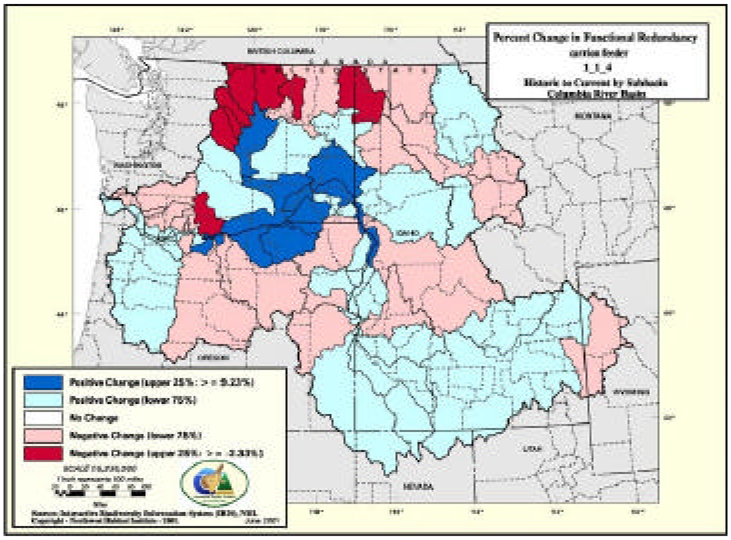

Figure 5. Shows the change in geographical patterns for Functions Redundancy of KEF 1.1.4 – carrion feeders when 22 fish and 137 wildlife species are compared from historic to current conditions.

Total Functional Diversity – this is akin to a species richness assessment. The total array of KEF categories weighted by their redundancy, i.e. the number of functions times the mean functional redundancy across all functions is *total function diversity.* The evaluation tallies the total number of species by KEF category for a given wildlife-habitat type and then calculates the mean number of species per KEF category. Figure 6a and 6b are examples of a comparison from historic to current wildlife habitat conditions that shows by subbasin the areas where total diversity for wildlife species associated with salmon has increased (in blue) or decreased (in red).

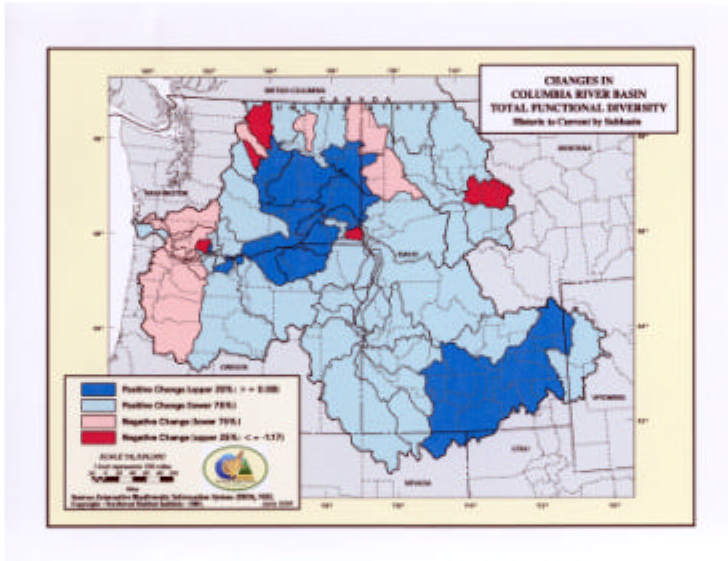

Figure 6a. Depicts the change in geographical patterns for total function diversity when 27 fish and 137 wildlife species are compared from historic to current conditions.

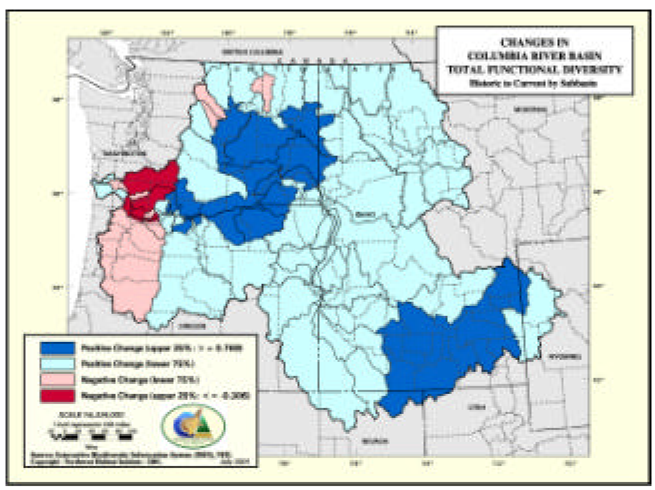

Figure 6b. Depicts the change in geographical patterns for total function diversity for only the 137 wildlife species when they are compared from historic to current conditions.

Functional profiles. – A *functional profile* compares functional redundancy among habitats for specific functions, and can be useful for identifying habitats that are particularly rich or poor in specific functions (Marcot and Vander Heyden 2001). Table 2 depicts an example using KEFs and Wildlife-Habitat Types. That is, wildlife species that are secondary consumers (KEF-1.1.2) and also have an association with salmon have a greater number of species performing this function in Westside Riparian/Wetlands (47) than those in Agriculture (28).

Overall, the point of comparing such functional profiles among habitats is to determine which habitats support specific functions the most or the least. It might be useful to managers to know when only a few species provide a specific function in a given habitat, to help craft management guidelines for those species to ensure that the system remains "fully functional."

Geographic Functional Patterns

Because species ranges can be mapped based on their association with certain habitats, maps can also be produced that display geographic patterns of functional redundancy for given species' KEFs (as has been done for some abiotic functions; e.g., see Noronha and Goodchild 1992). Examples are shown in Figures 4 and 5, which display total functional diversity and functional redundancy within the Columbia River Basin. Most of these species are birds, and the map depicts changes in functional redundancy for this KEF comparing historic (circa 1850) to current (2000) conditions.

Maps produced for each KEF category could help managers to locate where they might wish to restore or maintain conditions for specific functions. For example, Dale et al. (2000) noted, "Particular species and networks of interacting species have key, broad-scale ecosystem-level effects." In fact, for the specific area of the Columbia River Basin shown in Figure 6a and 6b, geographic patterns of change in other KEFs do indeed differ; and change can also be compared from current time to future time under various land planning alternatives (NWPPC, in prep.). In this way, managers can project future geographic effects on ecological functions, to identify land areas needing special attention to avoid significant declines in specific KEFs and to help them select planning alternatives that best match stated goals for maintaining interacting, functional forest mammal communities and their ecosystems.

Determining Species' Functional Roles

Critical functional link species and critical functions. – *Critical functional link species* are the one or few species in a habitat that perform a specific function. Their removal would signal serious decline or loss of that function. *Critical functions* are the specific functions they provide (Marcot and Vander Heyden 2001). As an example, in Table 2 for KEF 1.1.1.7 only 1 species is listed for 5 of the 6 habitat types that perform the function of feeding on roots. As it turns out, only one species performs this function in each habitat, which is the black bear. In this example, it would be considered a critical functional link species.

Functional breadth and functional specialization of species. – The array of functions performed by a species is its *functional breadth*. Species with very few functions are *functional specialists* and those with many functions are *functional generalists* (Marcot and Vander Heyden 2001). An example of the functional breadth of a species can be found in Table 4., which shows a total of 8 KEFs for American badger. A functional specialist would be the turkey vulture that performs 4 functions while the black bear is considered a functional generalist because it performs 32 functions [wildlife species KEF information can be found on the enclosed CD-Rom]. Fish KEF associations can be found in Tables 8 thru 12 (which are at the end of this report).

1.1	**heterotrophic consumer**
1.1.2	**secondary consumer (primary predator or primary carnivore)**
1.1.2.2	**vertebrate eater (consumer or predator of herbivorous vertebrates)**
3.11	**primary burrow excavator (fossorial or underground burrows)**
3.11.1	**creates large burrows (rabbit-sized or larger)**
3.2	**controls terrestrial vertebrate populations (through predation or displacement)**
4.3	**diseases that affect other wildlife species**
5.1	**physically affects (improves) soil structure, aeration (typically by digging)**

Table 4. KEFs of the American Badger.

Caveats and Assumptions of the Functional Approach

KEF analyses should not be viewed in isolation of other and more basic understanding of the autoecology and demography of individual species. That a particular category of KEF is present or maintained in a riparian faunal community does not mean that all native riparian species associated with that habitat are equally well conserved or even present. We intend that the kinds of functional assessments to complement, not replace, species-specific conservation.

Marcot and Vander Heyden (2001) listed a number of caveats pertaining to this type of functional assessment, including the following:

- KEFs represent mostly the collective judgment of panels of species experts, and largely were not based on empirical studies. Results should be viewed as repeatable, testable working hypotheses and should be validated and refined through field research.
- Some KEF categories are incompletely represented, especially those on nutrient cycling and disease transmission.
- Results of functional assessments are best initially interpreted at the level of fairly broad geographic areas, such as ecoprovinces or subbasins, rather than at individual project or stand areas, (because of informational constraints and understanding) or else there could be high errors of comission of functions.

An additional caveat is that the Wildlife-Habitat Relationships and ICBEMP data sets do not represent how KEFs for a given species might vary in different habitats or with presence or absence of specific environmental conditions or elements, such as particular prey items. Such knowledge of species' KEFs is largely unstudied (Marcot 1997).

SUMMARY

The information presented in this report and companion appendices represents an evaluation of key ecological functions for a subset of fish and wildlife that occur within the Columbia River Basin. Key ecological functions refer to the set of ecological roles played by fish and wildlife in their ecosystems. Such roles can influence the capacity of the ecosystem to support other species and are important new ways of tracking effects of land planning. Our analysis method can aptly display the trends in ecological functions across time periods, such as historic to current, and current to future under planning alternatives. The trends are shown as levels of "functional redundancy" which is the average number of wildlife species playing each functional role, and the higher redundancy may mean more resilient and robust ecosystems. In general, ecosystems with all the original ecological functions still present can be said to be "fully functional." Our analyses can help trace the degree to which ecosystems remain fully functional under different management strategies.

With our approach, it is possible, and easy, to determine which KEF categories have suffered declines or increases, what are the associated wildlife species, and which wildlife habitats, structural conditions, and key environmental correlates (specific habitat elements and substrates) that would be useful to highlight in a conservation or restoration program, if the objective is to provide for "fully functional" wildlife communities and ecosystems.

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Table1

Key Ecological Functions Matrix

The purpose of building a database of Key Ecological Functions of vertebrates is to provide a consistent framework from which to consider the ecological roles of wildlife in the management of populations, habitats, and ecosystems.

1. *Trophic relationships*
    - 1.1 heterotrophic consumer
        - 1.1.1 primary consumer (herbivore) (also see below under Herbivory)
            - 1.1.1.1 foliovore (leaf-eater)
            - 1.1.1.2 spermivore (seed-eater)
            - 1.1.1.3 browser (leaf, stem eater)
            - 1.1.1.4 grazer (grass, forb eater)
            - 1.1.1.5 frugivore (fruit-eater)
            - 1.1.1.6 sap feeder
            - 1.1.1.7 root feeders
            - 1.1.1.8 nectivore (nectar feeder)
            - 1.1.1.9 fungivore (fungus feeder)
            - 1.1.1.10 flower/bud/catkin feeder
            - 1.1.1.11 aquatic herbivore
            - 1.1.1.12 feeds in water on decomposing benthic substrate
            - 1.1.1.13 bark/cambium/bole feeder
            - 1.1.1.14 decomposing bentic substrate
            - 1.1.1.15 periphyton
            - 1.1.1.16 phytoplankton eater
        - 1.1.2 secondary consumer (primary predator or primary carnivore)
            - 1.1.2.1 invertebrate eater
                - 1.1.2.1.1 terrestrial invertebrates
                - 1.1.2.1.2 aquatic macroinvertebrates
                - 1.1.2.1.3 freshwater or marine zooplankton
                - 1.1.2.1.4 benthic invertebrates
            - 1.1.2.2 vertebrate eater (consumer or predator of herbivorous vertebrates)
                - 1.1.2.2.1 piscivorous (fish eater)
                - 1.1.2.2.2 amphibian eater
                - 1.1.2.2.3 bird eater
                - 1.1.2.2.4 mammal eater
                - 1.1.2.2.5 reptile eater
            - 1.1.2.2 ovivorous (egg eater)
            - 1.1.2.3 prey (fish)
        - 1.1.3 tertiary consumer (secondary predator or secondary carnivore)
            - 1.1.3.1 piscivorous
            - 1.1.3.2 ovivorous fish eggs
            - 1.1.3.3 amphibian eater
            - 1.1.3.4 bird eater
            - 1.1.3.5 mammal eater
            - 1.1.3.6 reptile eater
        - 1.1.4 carrion feeder
        - 1.1.5 cannibalistic
        - 1.1.6 coprophagous (feeds on fecal material)

1.1.7 feeds on human garbage/refuse
1.1.7.1 aquatic (e.g. offal and bycatch of fishing boats)
1.1.7.2 terrestrial (e.g. landfills)
1.2 prey relationships
1.2.1 prey for secondary or tertiary consumer (primary or secondary predator)
2 Aids in physical transfer of substances for nutrient cycling (C,N,P, etc.)
2.1 carrier of nutrients
2.2 carrier of heavy metals
2.3 agent for sediment movement
3 Organismal relationships
3.1 controls or depresses insect population peaks
3.1.1 influences aquatic invertebrate population peaks
3.1.2 influences zooplankton population peaks
3.1.3 influences vertebrate population peaks
3.2 controls terrestrial vertebrate populations (through predation or displacement)
3.3 pollination vector
3.4 transportation of viable seeds, spores, plants or animals
3.4.1 disperses fungi
3.4.2 disperses lichens
3.4.3 disperses bryophtes, including mosses
3.4.4 disperses insects and other invertebrates
3.4.5 disperses seeds/fruits (through ingestion or caching)
3.4.6 disperses vascular plants
3.4.7 disperses aquatic invertebrates
3.5 creates feeding, roosting, denning, or nesting opportunities for other organisms
3.5.1 creates feeding opportunities (other than direct prey relations)
3.5.1.1 creates sapwells in trees
3.5.2 creates roosting, denning, or nesting opportunities
3.6 primary creation of structures (possibly used by other organisms)
3.6.1 aerial structures
3.6.2 ground structures
3.6.3 aquatic structures
3.7 user of structures created by other species
3.7.1 aerial structures
3.7.2 ground structures
3.7.3 aquatic structures
3.8 nest parasite
3.8.1 interspecies parasite
3.8.2 common inter-specific host
3.9 primary cavity excavator in snags or live trees
3.10 secondary cavity user
3.11 primary burrow excavator (fossorial or underground burrows)
3.11.1 creates large burrows (rabbit-sized or larger)
3.11.2 creates small burrows (less than rabbit-sized)
3.12 uses burrows dug by other species (secondary burrow user)
3.13 creates runways (possibly used by other species)
3.14 uses runways created by other species)
3.15 pirates food from other species
3.16 inter-specific hybridization
3.17 lessens channel gradient
3.18 bio-indicator species

4 Carrier, transmitter, or reservoir of vertebrate diseases

- 4.1 diseases that affect humans
- 4.2 diseases that affect domestic animals
- 4.3 diseases that affect other wildlife species

5 Soil relationships

- 5.1 physically affects (improves) soil structure, aeration (typically by digging)
- 5.2 physically affects (degrades) soil structure, aeration (typically by trampling)

6 Wood structure relationships (either living or dead wood)

- 6.1 physically fragments down wood
- 6.2 physically fragments standing wood

7 Water relationships

- 7.1 impounds water by creating diversions or dams
- 7.2 creates ponds or wetlands through wallowing

8 Vegetation structure and composition relationships

- 8.1 creates standing dead trees (snags)
- 8.2 herbivory on trees or shrubs that may alter vegetation structure and composition (browsers)
- 8.3 herbivory on grasses or forbs that may alter vegetation structure and composition (grazers)

Fish Expert Panel Process Findings

Table 5. Status and occurrence of the 27 fish species evaluated for KEFs.

Common Name	OR	WA	ID	MT	NV	WY	UT
Arctic grayling	Introduced	Introduced	Introduced	Both		Introduced	Introduced
Brook trout	Introduced	Introduced	Introduced	Introduced	Introduced	Introduced	Introduced
Brown trout	Introduced	Introduced	Introduced	Introduced	Introduced	Introduced	Introduced
Bull trout	Native	Native	Both	Native	Native		
Burbot		Native	Native	Native			
Chinook salmon	Native	Native	Both				
Chum salmon	Native	Native	Extinct				
Coho salmon	Native	Both	Both	Introduced	Native		
Cutthroat trout (coastal)	Native	Native					
Cutthroat trout (westslope)	Native	Native	Both	Native	Both	Both	Both
Cutthroat trout (Yellowstone)			Native	Native	Native	Native	Native
Golden trout	Introduced	Introduced	Introduced	Introduced	Introduced		
Lake trout	Introduced	Introduced	Introduced	Both	Introduced	Introduced	Introduced
Mountain whitef ish	Introduced	Introduced	Introduced	Introduced	Introduced	Introduced	Introduced
Northern pike	Introduced	Introduced	Introduced	Both	Introduced	Introduced	Introduced
Paiute sculpin	Native	Native	Native		Native	Native	
Peamouth	Native	Native	Native	Native			
Rainbow trout (non-anadromous)	Native	Native	Native	Native	Native	Native	Native
Redband trout	Native	Native	Native	Native	Native		
River lamprey	Native	Native					
Shorthead sculpin	Native	Native	Native	Native			
Sockeye salmon	Introduced	Both	Both	Introduced	Introduced	Introduced	
Steelhead	Both	Both	Both	Both	Both	Introduced	Introduced
Threespine stickleback	Native	Native					
Torrent sculpin	Native	Native	Native	Native			
White sturgeon	Both	Native	Both	Native			
Yellow perch	Introduced	Introduced	Introduced	Introduced	Introduced	Introduced	Introduced

Table 6. Twenty-seven fish associations with wildlife-habitat types by fish life stage.

Common Name	Rivers and streams	Lakes and Ponds	Herbaceous Wetlands	Bays and Estuaries	Inland Marine Deeper Waters	Marine Nearshore	Marine Shelf	Oceanic
Arctic grayling	I, C, Sp	Ad, R, C						
Brook trout	A	A						
Brown trout	A	Ad, R, C						
Bull trout	A	Ad, R		S, Ad	Ad	Ad, S		
Burbot	A	A						
Chinook salmon	A	S, R		Sp, S	S, Ad	Ad, S	Ad	Ad
Chum salmon	I, Sp, C, R			S, Sp, C	Ad, S	Ad, S	Ad	Ad
Coho salmon	A	R, S		S, C	Ad	Ad	Ad	Ad
Cutthroat trout (coastal)	A	R, S, Ad	R	S, Ad		R, Ad		
Cutthroat trout (westslope)	A	R, S, Ad	R					
Cutthroat trout (Yellowstone)	A	R, S, Ad	R					
Golden trout	A	C, Ad, S, R						
Lake trout		A						
Mountain whitefish	A	Ad,R						
Northern pike	A	A						
Paiute sculpin	A	A						
Peamouth	A	A						
Rainbow trout (non-anadromous)	A	R, C, Ad						
Redband trout	A	R,C, Ad						
River lamprey	A							
Shorthead sculpin	A							
Sockeye salmon	Sp, C, I	I, Sp, R, C		S, Sp	S, Sp	S, Sp	Ad	Ad
Steelhead	Sp, R, C, S, I	Sp, S		S	Ad	Ad, S	Ad	Ad
Threespine stickleback	A	A	A	S, Ad		Ad, S	Ad	Ad
Torrent sculpin	A	A						
White sturgeon	A	A		Ad, S, Sp	Ad	Ad	Ad	Ad?
Yellow perch	A	A						

A- All life stages pertinent to a given species; Ad - Adults; mature individuals not including sexually mature salmonids returning to spawning grounds; I - Incubation stage including eggs and alevin (larvae that has not hatched yet); C – Carcasses; R - Rearing stage including fry (life stage between full absorption of the yolk sack and parr or fingerling stage, which is typically reached by the end of 1st year) and parr (young fish, usually in its 1st or 2nd year, generally between 2-25 cm long; S - Smolt; juveniles, one or more years old that have undergone physiological adaptations to marine environment; the seaward migrant stage of anadromous fish; and Sp - Spawning; sexually mature adults migrating to their spawning grounds.

Table 7. Twenty-seven fish associations with anthropogenic key environmental correlates.

Common Name	Roads	Paved	Unpaved	Bridges	Diseases transmitted by domestic animals	Animal harvest and persecution	Refuse	Toxic chemical use	Herbicides fungicides
Arctic grayling									
Brook trout	Negative	Negative	Negative					Negative	
Brown trout	Negative		Negative						
Bull trout	Negative		Negative						
Burbot	Negative	Negative	Negative						
Chinook salmon	Negative		Negative			Negative		Negative	Negative
Chum salmon									
Coho salmon	Negative		Negative					Negative	Negative
Cutthroat trout (coastal)	Negative		Negative					Negative	Negative
Cutthroat trout (westslope)	Negative		Negative					Negative	Negative
Cutthroat trout (Yellowstone)	Negative		Negative					Negative	Negative
Golden trout									
Lake trout								Negative	Negative
Paiute sculpin	Negative	Negative							
Rainbow trout (non-anadromous)	Negative	Negative	Negative						
Redband trout	Negative	Negative	Negative						
River lamprey	Negative	Negative	Negative	Negative				Negative	Negative
Sockeye salmon	Negative	Negative	Negative						
Steelhead	Negative		Negative						
Torrent sculpin	Negative	Negative	Negative						
White sturgeon						Negative		Negative	

Table 7. Continuing the 27 fish associations with anthropogenic key environmental correlates.

Common Name	Insecticides	Fertilizers	Pesticides	Fire fighting chemicals	Culverts	Irrigation ditches	Pollution	Chemical	Sewage	Water
Arctic grayling							Negative			Negative
Brook trout					Negative	Negative				Negative
Brown trout							Negative	Negative	Negative	Negative
Bull trout					Negative	Negative	Negative	Negative	Negative	Negative
Burbot										
Chinook salmon	Negative	Negative	Negative	Negative		Negative	Negative	Negative	Negative	Negative
Chum salmon					Negative					
Coho salmon	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative
Cutthroat trout (coastal)	Negative	Negative	Negative		Negative	Negative	Negative	Negative	Negative	Negative
Cutthroat trout (westslope)	Negative	Negative	Negative		Negative	Negative	Neative	Negative	Negative	Negative
Cutthroat trout (Yellowstone)	Negative	Negative	Negative		Negative	Negative	Negative	Negative	Negative	Negative
Golden trout										
Lake trout	Negative	Negative	Negative				Negative	Negative	Negative	
Paiute sculpin					Negative	Negative				
Rainbow trout										

Common Name	Insecticides	Fertilizers	Pesticides	Fire fighting chemicals	Culverts	Irrigation ditches	Pollution	Chemical	Sewage	Water
Redband trout										
River lamprey	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	Negative	
Sockeye salmon (anadromous)					Negative					
Steelhead					Negative	Negative	Negative	Negative	Negative	Negative
Torrent sculpin					Negative					
White sturgeon	Negative		Negative				Negative	Negative		Negative

Table 8. Twenty-five fish associations with ecological key environmental correlates.

Common Name	Exotic Species	Exotic Plants	Exotic Animals	Predation by exotic species	Habitat structure change	Hybridization	Direct displacement by exotics	Insects irruptions	Beaver activity	Native species
Arctic grayling								Positive		
Brook trout	Negative		Negative			Negative	Negative	Positive	Positive	Positive
Brown trout	Negative		Negative			Negative	Negative	Positive		Negative
Bull trout	Both		Both	Positive		Negative		Positive		Positive
Burbot										Both
Chinook salmon	Negative	Negative	Negative	Negative	Negative			Positive		
Chum salmon									Negative	Positive
Coho salmon	Negative	Negative			Negative			Positive	Both	
Cutthroat trout (coastal)	Negative		Negative	Negative		Negative		Positive	Positive	Both
Cutthroat trout (westslope)	Negative		Negative	Negative		Negative		Positive	Positive	Both
Cutthroat trout (Yellowstone)	Negative		Negative	Negative		Negative	Negative	Positive	Positive	Both
Golden trout								Positive		
Lake trout	Both	Negative	Positive	Positive	Negative					Both
Mountain whitefish								Positive		Both
Northern pike	Both		Both	Both						Both
Paiute sculpin	Negative		Negative	Negative				Positive		Negative
Peamouth								Positive		
Rainbow trout	Negative		Negative	Negative				Positive		Negative
River lamprey										Positive
Shorthead sculpin										Negative
Sockeye salmon	Negative	Negative	Negative	Negative	Negative					Negative
Steelhead	Negative		Negative	Negative				Positive	Both	Negative
Torrent sculpin										Positive
White sturgeon										Positive
Yellow perch	Negative		Negative	Negative						Negative

Table 9. Fourteen fish associations with lake key environmental correlates.

Common Name	Zone	Open water	Submerged benthic	Shoreline	In water substrate	Boulders	Cobble and gravel	Sand and mud	Vegetation
Arctic grayling	Positive	Positive							Positive
Brook trout	Positive			Positive	Positive		Positive		
Burbot	Positive		Positive	Positive					
Golden trout									
Lake trout	Positive		Positive	Positive	Positive	Posit ive	Positive		
Mountain whitefish	Positive		Positive						
Paiute sculpin	Positive		Positive		Positive		Positive		
Peamouth	Positive	Positive	Positive	Positive	Positive		Positive	Positive	Positive
Prickly sculpin	Positive		Positive	Positive	Positive		Positive		
Rainbow trout	Positive		Positive	Positive	Positive		Positive		
Sockeye salmon	Positive	Positive	Positive	Positive	Both		Positive	Negative	
Torrent sculpin	Positive			Positive					
White sturgeon	Positive		Positive		Positive	Positive	Positive	Negative	
Yellow perch	Positive	Positive							

Table 10. Twenty-seven fish associations with organismal key ecological functions.

Common Name	Influences aquatic invertebrates peaks	Uses aquatic structures	Creates aquatic structures	Influences zooplankton population peaks	Influences vertebrate population peaks	Disperses fungi	Disperses aquatic invertebrates	Creates feeding opportunities
Arctic grayling				R			A	Ad
Brook trout							A	A
Brown trout							A	
Bull trout	R	A	Sp		Ad	Ad	A	Ad
Burbot				R			A	Ad
Chinook salmon	R	A	Sp				R	
Chum salmon		A	Sp			Ad		
Coho salmon	R	A	Sp	R	Ad	Ad	Ad, R	
Cutthroat trout (coastal)			Sp					A
Cutthroat trout (westslope)			Sp	R			A	A
Cutthroat trout (Yellowstone)			Sp	R			A	A
Golden trout								
Lake trout	R	A						
Mountain whitefish	A	A		A			A	
Northern pike								
Paiute sculpin						Ad	A	
Peamouth	A	A		A			A	
Rainbow trout	R	A	Sp			Ad	R	
Redband trout	R	A	Sp			Ad	R	

Common Name	Influences aquatic invertebrates peaks	Uses aquatic structures	Creates aquatic structures	Influences zooplankton population peaks	Influences vertebrate population peaks	Disperses fungi	Disperses aquatic invertebrates	Creates feeding opportunities
River lamprey		A	Sp					
Shorthead sculpin	A					Ad	A	
Sockeye salmon		A	Sp	R				
Steelhead	R	A	Sp			Ad	R	
Threespine stickleback			Sp					
Torrent sculpin	Ad			R		Ad	Ad	
White sturgeon		A						
Yellow perch								

Table 10. Continuing of 27 fish associations with organismal key ecological functions.

Common Name	Interspecific host	Interspecific hybridization	Prey for secondary consumer	Carrier of nutrients	Carrier of heavy metals	Agent for sediment movement	Lessens channel gradient	BioIndicator Species
Arctic grayling			A					
Brook trout	A	Sp	A	Ad				
Brown trout	A	Sp	A					
Bull trout	A	Sp	A	Ad	Ad	Sp	Sp	A
Burbot	A		A					
Chinook salmon	A		A	Ad	Ad	Sp	Sp	A
Chum salmon	A	Sp	A	Ad	Ad	Sp	Sp	A
Coho salmon	A		A	Ad		Sp	Sp	A
Cutthroat trout (coastal)		Sp	A			Sp		A
Cutthroat trout (westslope)		Sp	A	A		Sp		
Cutthroat trout (Yellowstone)		Sp	A			Sp		
Golden trout								
Lake trout	A		A		Ad			A
Mountain whitefish	A		A					
Northern pike	A		A					
Paiute sculpin		Sp	A					
Peamouth	A	Sp	A	Ad	Ad			
Rainbow trout	A	Sp	A	Ad	Ad	Sp	Sp	A
Redband trout	A	Sp	A	Ad	Ad	Sp	Sp	A
River lamprey			A	Ad	Ad	Sp	Sp	A
Shorthead sculpin			A					
Sockeye salmon	A		A	Ad	Ad	Sp	Sp	A
Steelhead	A	Sp	A	Ad	Ad	Sp	Sp	A
Threespine stickleback	A		A					
Torrent sculpin			A					
White sturgeon			A	Ad				
Yellow perch	A		A					

Table 11. Twenty-seven fish associations with primary consumer key ecological functions.

Common Name	Aquatic herbivore	Decomposing benthic substrate	Periphyton	Phytoplankton eater
Mountain sucker	A		A	
Pacific lamprey		R		R
Paiute sculpin		A		A
Peamouth				Ad
Redside shiner				R
River lamprey		R		R
Sockeye salmon				Ad, R, S

Table 12. Twenty-seven fish associations with secondary consumer key ecological functions.

Common Name	Terrestrial invertebrates	Aquatic macro-invertebrates	Benthic invertebrates	Zoo-plankton	Piscivorous	Ovivorous	Bird eater	Mammal eater	Amphibian eater
Arctic grayling	A	A	A	R					
Brook trout	A	A	A	R	Ad	Ad, Sp	Ad	Ad	Ad
Brown trout	A	A	A		Ad	Ad	Ad	Ad	Ad
Bull trout	Ad	R	R	R	Ad				Ad
Burbot		A	A	R	Ad	Ad			
Chinook salmon	R	R	R		Ad				
Chum salmon	R	R, Ad	R, Ad	R, S, Ad	Ad				
Coho salmon	R, Ad	S, Ad	R, S, Ad	R, Ad	S, Ad, R	R			
Cutthroat trout (coastal)	A	A	A		Ad	Ad			Ad
Cutthroat trout (westslope)	A	A	A	R		Ad			
Cutthroat trout (Yellowstone)	A	A	A	R	Ad	Ad			Ad
Golden trout	A	A	A	A					
Lake trout	Ad, R	R, Ad	R, Ad	R	Ad				Ad
Mountain whitefish	A	A	A	A		A			
Northern pike		A	A	R	Ad	Ad	Ad	Ad	Ad
Paiute sculpin		A	A						
Peamouth	A	A	A	A					
Rainbow trout	R, Ad	A	A	R	Ad	R, Ad			Ad
Redband trout	R, Ad	A	A	R	Ad	R, Ad			Ad
River lamprey				R	Ad				
Shorthead sculpin		A	A						
Sockeye salmon	S, R, Ad	S, R, Ad	S, R, Ad	R, Ad	S, Ad				
Steelhead	Ad, R, S	R	R, S, Ad	R	S, Ad	R	Ad		Ad
Threespine stickleback	A	A	A	A		A			
Torrent sculpin		A	A	R	Ad	Ad			
White sturgeon		A	A	R	Ad	R			
Yellow perch		Ad	Ad	R	Ad	Ad			

Table 13. Twenty-five fish associations with tertiary consumer key ecological functions

Common Name	Carrion feeder	Cannibalistic	Piscivorous	Ovivorous fish eggs	Bird eater	Mammal eater	Amphibian eater	Reptile eater
Brook trout		Ad, Sp	Ad	Ad, Sp	Ad	Ad	Ad	Ad
Brown trout			Ad	Ad	Ad	Ad	Ad	
Bull trout	Ad	Ad	Ad	Ad	Ad	Ad	Ad	Ad
Burbot			Ad	Ad				
Chinook salmon		Ad	Ad					
Chum salmon	Ad		Ad					
Coho salmon	Ad	Ad	S, Ad, R	R			Ad	
Cutthroat trout (coastal)	Ad		Ad	Ad, Sp				
Cutthroat trout (westslope)	Ad			Ad				
Cutthroat trout (Yellowstone)	Ad		Ad	Ad, Sp				
Lake trout		Ad	Ad			Ad	Ad	
Mountain whitefish		A		A				
Northern pike	Ad	Ad	Ad	Ad	Ad	Ad	Ad	
Paiute sculpin	Ad	Ad						
Peamouth								
Rainbow trout	Ad	Ad	Ad	Ad		Ad	Ad	
Redband trout	Ad	Ad	Ad	Ad		Ad	Ad	
River lamprey			Ad					
Shorthead sculpin	Ad	Ad	Ad					
Sockeye salmon		Ad	Ad*					
Steelhead	Ad	Ad	Ad, S	R		Ad	Ad	
Threespine stickleback		Ad		Ad				
Torrent sculpin	Ad	Ad	Ad	Ad				
White sturgeon			Ad	R				
Yellow perch			Ad	Ad				

Table 14. Twenty-five fish associations with water characteristics key ecological functions.

Common Name	Dissolved oxygen	Oxygen range	Water depth	Depth range	Dissolved solids
Arctic grayling	Low tolerance	Prefer >6mg/L	Shallow and deep	Spawn in shallow water; adults occur both in shallow and deep water	Low
Brook trout	Low tolerance	>5 mg/L; lethal at 1.6-2.6 mg/L at 12-21 C)	Shallow and deep	Spawn in shallow water (~61 cm deep); in summer move to 4.6-8.2 m deep water	Low to medium
Brown trout	Low to moderate tolerance	> 5mg/L (letahl at 1.8 mg/L at 16 C)	Shallow and deep	Minimum depth: 0.24 m.	Low to medium high
Bull trout	Low tolerance	Prefer >6 mg/L; lethal at >2 mg/L	Shallow and deep	0-50 m	low to medium
Burbot		Lethal at <2.0 mg/L at 12-18 C	Shallow and deep	Prefer deep lakes. Mean summer depth 26 ft; winter 42.5 ft	

Common Name	Dissolved oxygen	Oxygen range	Water depth	Depth range	Dissolved solids
Chinook salmon	Low tolerance	Prefer >6 mg/L (lethal at 2.3-2.7 mg/L)	Shallow and deep	Min 0.24 m	Low to medium high
Chum salmon	Low tolerance	Prefer >6 mg/L (lethal at 2.0 mg/L)	Shallow	min 0.18 m	low to medium
Coho salmon	Low tolerance	Prefer >6 mg/L (lethal at 1.7-2.0 mg/L)	Shallow and deep		Low to medium high
Cutthroat trout (coastal)	Low tolerance	Prefer >6 mg/L	Shallow	Prefer depths of 46 cm	
Cutthroat trout (westslope)	Low tolerance	Prefer >6 mg/L	Shallow	Prefer depths of 46 cm	
Cutthroat trout (Yellowstone)	Low tolerance	Prefer >6 mg/L	Shallow	Prefer depths of 46 cm	
Golden trout	Low tolerance	>6 mg/L	Shallow and deep		Low to medium
Lake trout	Low tolerance	Prefer >6 mg/L; lethal at >2 mg/L	Deep	18-91 m; known to occur at depths of 398m; spawn in 0.3-30 m). Found in the lowermost areas of the lakes (hypolimnion).	Low to medium
Mountain whitefish	Low tolerance	Prefer >6 mg/L	Shallow and deep	upper 4.5-6.1 m of lakes; Usually no deeper than 9 m in northern lakes	Low to medium
Northern pike		lethal at 05-1.6 mg/L at 15-25 C	Shallow	Upper 5 m of water column	
Northern pikeminnow (or northern squawfish)	Moderate tolerance	Lethal at 1.4 mg/L (at 23 C)	Shallow and deep	In summer, found in the shallows; in winter in deep water. Adults tend to remain in deeper waters	
Peamouth	Moderate tolerance	Lethal at 1-2 mg/L	Shallow and deep	Found at 6.1 m off the bottom in winter; in shallow the est of the year; Typically < 61 m	
Rainbow trout	Low tolerance	Prefer >6 mg/L; lethal at 1.3-1.6 mg/L	Shallow and deep	Min for spawning is 0.18 m;	Low to medium
River lamprey	Low tolerance		Deep and moderately deep	26-33 m (85-108 ft)	
Shorthead sculpin	Moderate tolerance	Lethal at 1-2 mg/L	Shallow		
Sockeye salmon	Low tolerance	Prefer >6 mg/L; lethal at 2.3-2.7 mg/L	Shallow and deep	Shallow for spawning; deep rest of the year; min 0.15 m (12-18 m, but have been caught at 1.8 m)	Low to medium
Steelhead	Low tolerance	Prefer >6 mg/L; lethal at >2 mg/L	Shallow and deep	0.24 m	
Threespine sticklebakc					Low to high
Torrent sculpin	Low tolerance	Lethal at >2 mg/L	Shallow		
White sturgeon	Moderate tolerance	Prefer >5.0 mg/L; lethal at 1-2 mg/L	Deep	1-122 m; (39.0-88.6 ft, adults); 14-22 m (juveniles); seasonal movements to and from deep water have been reported.	
Yellow perch	High tolerance	>4.2 mg/L (summer); lethal at 2.0 mg/L	Shallow and moderately deep	Adults often found in 4.6-7.6 m deep water; young fish found in shallow water near shore	Low to medium high

Table 14. Continuing 25 fish associations with water characteristics key ecological functions.

Common Name	Solids range	Water PH	PH range	Water Temperature	Optimal Temperature	Temp range
Arctic grayling	250-5,000 mt/L	Moderate tolerance	6.5-8.5	Cool	8-22 C	
Brook trout	250-5,000 mg/L	Moderate tolerance	>5.5	Cool	12.8-19 C	<25.3 C
Brown trout	250-10,000 mg/L	Moderate tolerance	Adults can survive in peat watersat 4.5-5.0. Harmful at 9-9.5.	Cool	18.3-23.9 C	19.4-24 C; can survive 27.2 C for short time
Bull trout	250-5,000 mg/L	Low tolerance	6.5-8; lethal at 9.5-10 and 3.5-4.0; harmful at 9.0-9.5;	Cool	4-18C; spawning at 5.5-7.8 C	
Burbot				Cool	15.6-18.3 C	Upper limit: 23.3 C
Chinook salmon	250-10,000 mg/L	Low tolerance	lethal at 9.5-10 and 3.5-4.0; harmful at 9.0-9.5;	Cool	12-14 C (preferred temp)	upper lethal 24.8 C (spring); upper lethal 24.5 C (fall); fall chinook 10.6-19.4C; spring 3.3-13.3 C; summer 13.9-20 C
Chum salmon	250-5,000 mg/L	Low tolerance	lethal at 9.5-10 and 3.5-4.0; harmful at 9.0-9.5;	Cool	12-14 C (preferred)	0.5-25.4 C
Coho salmon	250-10,000 mg/L	Low tolerance	lethal at 9.5-10 and 3.5-4.0; harmful at 9.0-9.5;	Cool	12-14 C (preferred temp); for spawning 4-11 C	1.7-28.8 C
Cutthroat trout (coastal)				Cool	15.5 C	10-21.1 C
Cutthroat trout (westslope)				Cool	15.5 C	10-21.1 C
Cutthroat trout (Yellowstone)	10-700 mg/L	Moderate tolerance	5.6-10.0; do not occur in waters <5.0 pH	Cool	4.5-15.5 C	10-21.1 C; known to exitst in geothermal waters at 27 C
Golden trout	250-5,000 mg/L	Low tolerance	6.5-7.5	Cool	<22.2 C; spawn at 7-10 C	
Lake trout	250-5,000 mg/L	Low tolerance	6-8.5	Cool	10-18.3 C; optimal for growth 16.5 C; yearlings prefer 11.7 C	Upper lethal 23.5 C
Mountain whitefish	250-5,000 mg/L	Low tolerance		Cool	4.4-10 C	8.9-11.1 C
Northern pike		High tolerance	4.5<9.5 pH (can reproduce at 4.5-5.0 pH)	Wide range		Spawn at 4.4 C-11.1 C
Northern pikeminnow (or northern squawfish)		Moderate tolerance		Cool	20-22.8 C	Upper lethal in BC 26.4 C
Peamouth		Moderate tolerance		Cool	spawning 11-22.2 C	<27.2 C
Rainbow trout	250-5,000 mg/L	Low tolerance	6.5 -8.5 ; do not occur below 5.5-6.0	Cool	<20.9 C	13-21C
River lamprey				Cool		

Common Name	Solids range	Water PH	PH range	Water Temperature	Optimal Temperature	Temp range
Shorthead sculpin	250-5,000 mg/L	Moderate tolerance		Cool	13.2 C	10-17 C
Sockeye salmon	250mg/L - 5,000 mg/L	Low tolerance	6.5-7.5	Cool	12-14 C (preferred temp); spawning at 3-6.9 C	3.1-25.8 C; spawning max 10 C; embryo survival 13 C; generally avoid temp outside 4-18C
Steelhead		Low tolerance	lethal at 9.5-10 and 3.5-4.0; harmful at 9.0-9.5;	Cool	< 20.9 C	Can survive from 0-26.7 C; max 19 C; spawn at 8 C; embryo survival 15 C
Threespine sticklebakc	<20,000 mg/L			Cool	12-23 C	Spawn at 5-20 C (41-68 F)
Torrent sculpin	250-5,000 mg/L	Low tolerance		Cool	15.9 C	11-22 C
White sturgeon		Moderate tolerance		Cool	12-14 C	Spawn at 8.9-17.2 C; range 13.9-22.2 C; can survive 10-18C
Yellow perch	<10,300 mg/L	Moderate tolerance	4.0-9.0	Wide range	21-24 C	Spawn at 7. 8-12.8 C

Table 14. Continuing 25 fish associations with water characteristics key ecological functions.

Common Name	Water velocity	Velocity range	Water turbidity	Turbidity range	Salinity and alkalinity
Arctic grayling	Slow to moderate	0-1m/s	Low	<30 mg/L	Fresh
Brook trout	Slow	0.15-o.61 m/s			Fresh to marine
Brown trout	Slow to moderate	0.21-0.64 m/s	Low to moderate	Can tolerate slightly higher turbidities than other salmonids	Fresh
Bull trout	Slow to fast	0-1 m/s and up	Low tolerance	<30 mg/L	Fresh to marine
Burbot	Slow				Fresh to brackish
Chinook salmon	Slow to moderate	range 0.3-0.91 m/s; max 2.44 m/s	Low to moderate tolerance	30-300 mg/L	Fresh to marine
Chum salmon	Slow to moderate	0.46-0.1.01 m/s; max 2.44 m/s	Low to moderate tolerance	30-300 mg/L	Fresh to marine
Coho salmon	Slow	0.30 -0.91 m/s; max 2.44 m/s	Low to moderate tolerance	30-300 mg/L	Fresh to marine
Cutthroat trout (coastal)	Slow	<0.15 m/s			Fresh to marine
Cutthroat trout (westslope)	Slow	<0.15 m/s			Fresh
Cutthroat trout (Yellowstone)	Slow	<0.15 m/s			Fresh
Golden trout	Low to medium	0-1 m/s	Low tolerance	<30 mg/L	Fresh to marine
Lake trout	Slow		Low to moderate tolerance		Fresh to brackish
Mountain whitefish	Slow to moderate	0-1.0 m/s; found at 0.8 m/s in Utah	Low to moderately high tolerance	<300 mg/L	Fresh
Northern pike					Fresh to brackish
Northern pikeminnow (or northern squawfish)	Slow to moderate	<1.0-1.3 m/s			Fresh
Peamouth	Slow				Fresh to brackish
Rainbow trout	Moderate to fast	0.48-0.91m/s; max 2.44 m/s			Fresh to marine

Common Name	Solids range	Water PH	PH range	Water Temperature	Optimal Temperature
River lamprey	Slow				Fresh to marine
Shorthead sculpin	Slow to fast	<0.91 m/s; some inhabit slow shorelines of streams			Fresh
Sockeye salmon	Slow to moderate	0.21-1.01 m/s; max 2.13 m/s	Low to moderate tolerance	30-300 mg/L	Fresh to marine
Steelhead	Slow to moderately fast	0.40-0.91 m/s; max 2.44 m/s			Fresh to marine
Threespine sticklebakc	Slow				Fresh to marine
Torrent sculpin	Fast	0.43-1.2 m/s			Fresh
White sturgeon	Moderately fast to ast	0.4 m/s (adults); 0.61m/sec (juveniles)	Moderate to high tolerance	Prefer turbid environments (30-400mg/L)	Fresh to marine
Yellow perch			Low tolerance	<30 mg/L	Fresh to brackish