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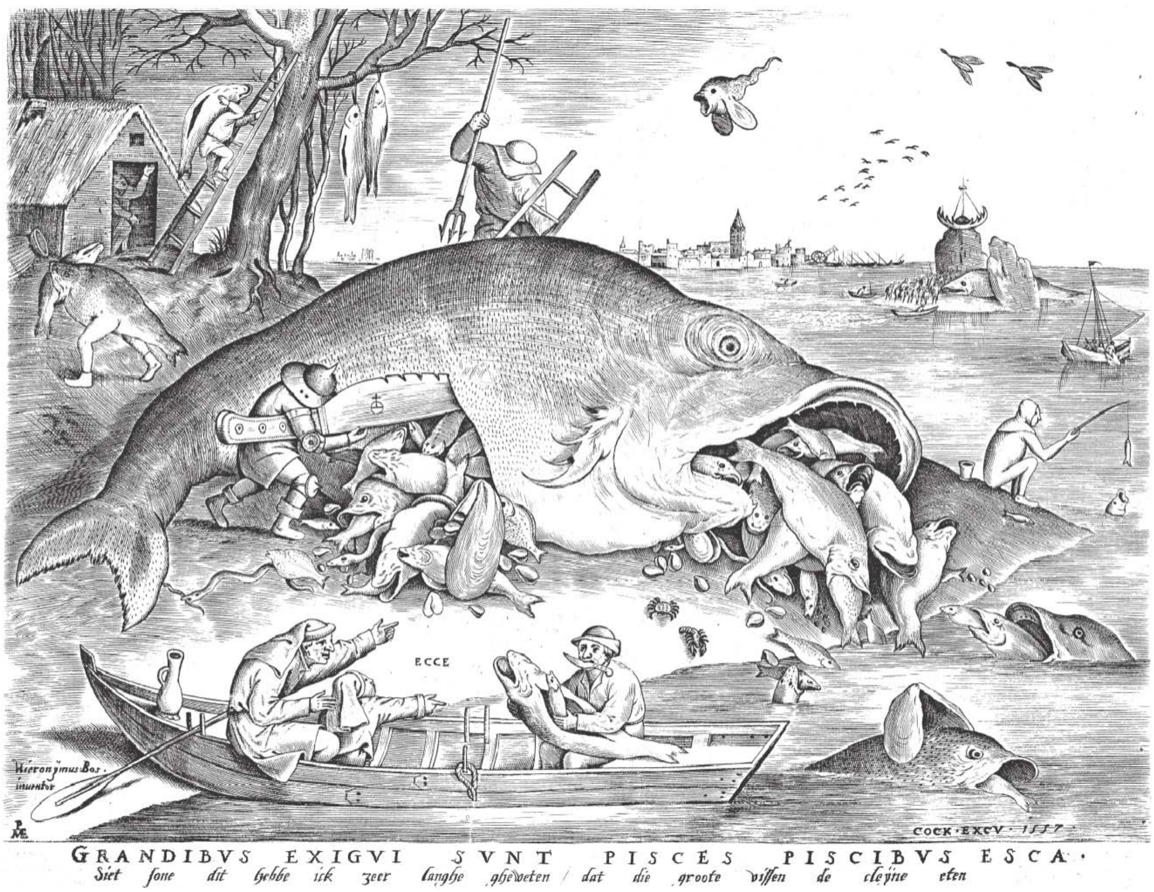
Columbia River Food Webs: Developing a Broader Scientific Foundation for Fish and Wildlife Restoration



EXECUTIVE SUMMARY

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(see full document at www.nwcouncil.org/foodweb)

Food Webs: Key Components of Ecosystem Resilience and Productivity

Food webs describe pathways by which energy, nutrients and other materials make their way to species of cultural and economic interest. Food webs are often thought of as reflections of habitat, yet many other factors shape the internal organization, linkages, productivity and resilience.[1] Species diversity, the mix of native and non-native species, chemical contaminants, habitat carrying capacity, nutrient delivery and cycling, competition, predation, disease and associated system-scale processes are all deeply involved in shaping food webs. Nevertheless, highly complex food webs have been successfully manipulated at large scales to improve water conditions as well as recreational fisheries while, at the same time ill-advised manipulations have resulted in serious environmental issues – the introduction of mysids being one example.

The concept of a food web remains one of the most useful – and most challenging – ideas in ecology. It describes feeding habits and food (trophic) relationships between species within an ecosystem or within a particular place. Although actual trophic relationships are sometimes difficult to sample, measure, describe and model, they are of immense practical and theoretical importance. They characterize, in a relatively simple way, how energy, nutrients, toxins and biomass are transferred from producers to consumers. There are several well known approaches to describing and quantifying trophic relationships within communities. Food chains and food webs traditionally illustrate only connections between species, whereas food networks or food budgets illustrate the relative transfer rates of energy, nutrients, toxins or biomass through thousands of connections. Collectively, these can be quantified and modeled to produce an understanding of how nutrients and energy are assimilated into productive fisheries or, at the other extreme, how they contribute to degraded environmental conditions.

Food webs relate directly to the Northwest Power and Conservation Council's (NPCC or Council) Columbia River Fish and Wildlife Program, which seeks to establish and maintain an ecosystem that sustains an abundant, productive and diverse community of fish and wildlife (NPCC 2009-09:6). Food webs fuel that ecosystem, providing the theme for this review. Incorporating a food web perspective into management efforts helps sustain the ecological system and provide for more productive and resilient fisheries.

The objectives of this report are to provide a fundamental understanding of aquatic food webs in the Columbia River Basin and to illustrate and summarize their influences on native fish restoration efforts. The spatial scope addresses tributaries, impoundments, the free-flowing Columbia and Snake rivers, as well as the estuary and plume. Achieving the Council's vision for the Columbia River Fish and Wildlife Program (NPCC 2009-09) of sustaining a "productive and diverse community" that provides "abundant" harvest, is best accomplished through a time-prioritized action plan, one that complements other approaches while addressing important challenges and uncertainties related to the Basin's food webs. Note that the oceanic food webs, although of immense importance in sustaining fish populations, are not considered beyond the plume since they involve an additional set of complex and rapidly evolving issues. An analysis of oceanic food webs of relevance to the Columbia River requires a separately focused effort (e.g., Hoegh-Guldberg and Bruno 2010).

Implications for Restoration

Food webs reveal insights into basic properties underpinning productivity and resilience that cannot be obtained from an exclusive focus on hydrosystem, habitat, hatcheries and harvest (the four H's). Restoration activities have traditionally focused on physical habitat, an approach that assumes local habitat structure and quality dictate fish production. Physical characteristics of riverine habitats traditionally have been thought to constrain fish production. More importantly, traditional freshwater food web illustrations have typically conveyed the notion that most fish food is produced within the local aquatic habitat itself. In reality, much of the food comes from external or very distant sources – including subsidies from marine systems borne by adult returns of

[1] Resilience is the ability of the biotic system to absorb and recover from perturbations

anadromous fishes, from fishless headwater tributaries that transport prey downstream, and from adjacent streamside and estuarine vegetation and associated riparian and terrestrial habitats. Key trophic pathways and food sources vary over time and space throughout watersheds. When restoration activities are not successful, it is often because they do not take a sufficiently broad view of watershed drivers, including food webs and the processes that regulate food availability. It is well recognized that many fishes use an array of habitat types to complete their life cycles, and thereby encounter a diverse array of important prey resources – and this is fundamental to effective restoration.

Food web structure and processes associated with them determine how system components act collectively – sometimes synergistically – to underpin the resilience and productivity of the larger ecosystem. Each food web component, whether a primary producer, an external input of organic matter, a microbial decomposer or a tertiary consumer, responds to changes in environmental conditions. Further, when a predator impacts its prey, the influence can extend well beyond the prey, reverberating throughout the entire food web as a "cascading trophic interaction."

The Council's vision of restoring and maintaining ecosystems that sustain an abundant, productive and diverse community of fish and wildlife through the Fish and Wildlife Program (NPCC 2009-09) is an important challenge. The ISAB's assertion is that prospects for doing that can be improved through a food web perspective. Implementing a food web perspective for the Columbia River would complement other approaches, such as the focus on habitat restoration, and thereby enhance our collective ability to meet the Council's vision.

Report Structure and Rationale

The report has five complementary sections. General concepts and applications related to food webs are examined initially (Section A), followed by a brief description of the physical setting (Section B), a detailed discussion of key environmental processes affecting food web characteristics (Section C), an examination of food webs in typical habitats (Section D) and a system perspective integrating our findings with contemporary and emerging issues (Section E). The four appendices describe a variety of methods used in food web investigations (Appendix A), the legal and policy web surrounding restoration activities in the Basin (Appendix B), pesticides used in the Basin (Appendix C), and give a list of common and scientific names used in the report (Appendix D).

The ISAB proposes a systematic action plan dealing with three thematic concerns. The first is to address key threats to the resilience and productivity of the Basin's food webs. There is a need to understand the aggregate capacity of the Basin to produce fish while restoring degraded ecosystems and food webs to a healthy state. This means moving in many cases toward food webs containing both new and old elements (i.e., hybrid food webs) and able to persist under a set of environmental conditions that have changed substantially over the last century. The second thematic concern is to fill a very large number of perplexing information gaps and critical uncertainties impeding progress. Efforts are needed to fill those gaps progressively and systematically, as we work our way forward. The third concern is to protect the healthy ecosystems and productive food webs we currently have, while reclaiming and restoring those that are degraded. That means identifying what is still healthy and what is not, and characterizing why and how those that continue to function well do so.

Addressing Key Threats to Resilience and Productivity

Foods webs of the Columbia River are productive yet potentially fragile. Human presence in the region is growing rapidly, hatchery production of fishes is nearly ubiquitous, chemical use is widespread, expansion of non-native species continues unabated, and the climate is changing inexorably. The net result is that the Basin's food webs continue to change, and there is a considerable range of challenges to be faced. During the course of this evaluation, three critical and several highly important threats were consistently identified by the ISAB. These require proactive efforts, but there are three particular issues in need of immediate attention:

Uncertainty about the Aggregate Carrying Capacity of the Columbia River. Massive annual releases of juvenile fish from hatcheries affect wild food webs and stocks of *wild* fish. There are approximately 130-150 million hatchery salmon and steelhead added to the system annually. The thousands of metric tons of food used to raise them, as well as the natural foods required to maintain them in the river, affect the capacity of the Columbia River to support naturally-produced native fishes. Additionally, since nutrients and organic matter constitute the basic fuels for food webs, changes to the amounts and forms can significantly affect food web productivity and resilience. These changes result from the continuing losses of marine- and riparian-derived nutrients, altered land-based leaching of nutrients and organic matter, and increasing atmospheric deposition of nitrogen and micro-nutrients. The ISAB recommends that new work should:

> Determine the ability of the system to provide sufficient food to support viable populations of fishes and other organisms for the long term. Data on the seasonal consumption demand and energetic carrying capacity of major habitat types are currently lacking or inaccessible for juvenile fishes, and the information is needed for system-wide planning purposes. A monitoring strategy is needed that tracks the food demands of *wild* native, artificially propagated native and non-native organisms as well as the spatial and temporal movement of nutrients and organic matter relative to what comes in and from whence it has come. Collectively, these determine the aggregate carrying capacity of the Basin for aquatic organisms.

Proliferation of Chemicals and Contaminants. There has been widespread and abundant introduction of synthetic chemicals into the Basin, and the amounts and diversity of those chemicals are stunning as well as of great concern. Bioaccumulation and biomagnification of chemical contaminants can reduce or eliminate critical components of the food web, leading to food shortages for higher trophic levels. Further, it can reduce the ability of species and individuals to cope with normal environmental stresses due to behavioral deficiencies, slower somatic growth rates and increased disease susceptibility. This problem is rapidly expanding and could negate many of the restoration efforts. Further, fish migrating from the oceans to fresh water transport persistent industrial pollutants acquired at sea. The positive feedback of nutrient additions from spawning adults is important, but there is also some negative feedback from pollutant delivery from the ocean. The net balance is unclear and needs careful documentation. Consistent with the Council's 2009 Fish and Wildlife Program (Sections D.1.g., p. 16 and D.2, p. 42), but not currently being fully implemented, the ISAB recommends that further work should:

> Engage with regional partners in pinpointing, quantifying and mapping the spatial patterns of these chemicals within the Basin, in measuring their transfer and accumulation rates, and in understanding the vulnerabilities of the region's food webs to them. The Council should continue to work diligently with other regional agencies to implement the recently completed interagency Columbia River Basin Toxics Reduction Action Plan and update it regularly, so that we can deal with current and future chemical insults to the system in timely fashion, before they become even more serious problems. This has to be a large, ongoing and collective regional effort.

Consequences of Non-native Species: Hybrid Food Webs. Continuing introduction and proliferation of non-native species, and their still poorly understood impacts on the native biota heighten the need to manage "novel, hybrid or no-analogue" food webs[2] in the future, those for which we have no historical reference. The Western Governors' Association Policy Resolution 10-4 on Combating Invasive Species has moved this issue forward for the western Region. The ISAB recommends that further work should:

> Mount a region-wide monitoring program on the temporal pace and spatial extent of non-native introductions, indentifying impending problems while they are still small and manageable. Once indentified, we should intervene quickly whenever and wherever invasive problems are likely to emerge, averting problems when possible, or slowing them down, when not completely avoidable. It is also timely to reevaluate our stocking practices for non-native species, in the larger context of the regional concern for production and conservation of its native biota. Some policy changes may be in order.

Beyond meeting these pressing threats, we need to anticipate and head off a variety of others that are impending, before they too become urgent. In general, we need to understand the consequences of:

[2] The terms "novel, hybrid, and no-analogue" are used synonymously in this report when referring to existing and future food webs for which there is no historical reference.

Altered Nutrient Organic Matter (Energy), Water, and Thermal Sources and Flows. Nutrients and organic matter constitute the fuels for food webs. Water flow and temperature directly control their availability and incorporation into food webs. Continuing losses of marine-derived nutrients and riparian-derived organic matter, in addition to increased land-based leaching of nutrients and organic matter, accelerating eutrophication, ongoing atmospheric deposition of nitrogen and micro-nutrients, as well as water storage, extraction and flow manipulation, collectively threaten to alter the Basin's food webs (Chapters D.4, D.6, and D.8). The ISAB recommends that further work should:

- Assess the magnitude of these problems and be able to predict the consequences of such alterations.

Disconnects among Critical Habitats and their Food Webs. Connectivity and timing impact the availability of the preferred foods of migrating juvenile fishes. Broad-scale changes in temperature, nutrient and chemical regimes, hatchery programs and habitat restoration affect the connectivity and timing of organisms with their food supplies. The Fish and Wildlife Program has already begun to address this issue in its restoration activities, but we need to extend those efforts considerably. The larger point is that we need to manage for total system productivity, rather than attempting to optimize each of a great many local system components independently. There are three related needs for effective reconnection of critical habitat, and the ISAB recommends further work should:

- Identify and quantify the critical connections between place-based production of foods and the timing of seaward movements by juvenile anadromous fishes, based on mechanistic understanding of their relationships within the Basin.
- Mount large-scale catchment projects, in both rural and urban locations, bringing diverse scientific and resource management expertise to bear, and delivering science of real management value. The Fish and Wildlife Program currently funds some floodplain restoration work, but a systematic campaign to restore floodplain food webs and reconnect them to the main channel is also needed.
- Establish the links between river discharge, floodplain inundation and fish production, and evaluate the food-web effects of large scale and seasonally appropriate floodplain inundation. The supplemental BiOp calls for NOAA to develop a life-cycle model, which should evaluate how to deliver the fish to the right place at the right time, with the right blend of food resources.

Plan for Environmental Change and Expect Some Surprises. Substantial habitat and other changes will continue over the remainder of this century. Management decisions made in this next decade (including the implementation of an FCRPS Biological Opinion) will affect food webs and other resources for the next several decades. Canadian and regional authorities are already planning for large scale water and power management needs for the next half a century. The ISAB recommends further work should:

- Insert the region's biota into the list of planning targets from the outset, ameliorating those changes we can do something about in the short run, and mitigating others over the long run. Provide forecasts over the next several decades, taking into account the anticipated climatic and anthropogenic changes that will impact the Basin's environment.
- Establish the planning goals for the Basin's complex biota and food webs, and mount modeling exercises to project the impact of alternative policy choices on all components. If accumulated experience is any guide, we can also anticipate that the Columbia River will continue to see unanticipated challenges from time to time.
- Establish a response system that can absorb short term ecological surprises readily, with strong rebound capacity. The ISAB urges the Council to set aside some funding for such challenges and for exploratory activities, to remain alert to impending challenges, and to provide early detection and proactive intervention when needed.

Fill Specific Knowledge Gaps

Proactive management of food webs can only be effective if we clear up several serious information gaps. Sadly, our base-level understanding of the Basin's food webs remains rudimentary. This report highlights a collection of vignettes on ecosystem and food web structure, but even those relatively well-studied exemplars reveal substantial and critical information gaps (see Chapter E.5). The ISAB suggests the Council consider extending current studies and projects to gather some of this much needed (additional) information as well as devote some resources and remedial attention to filling knowledge gaps. The challenges fall in four general areas: data gathering and synthesis, modeling, experimental testing of models, and evaluation of alternative policies. Specifically, we need to:

Data Gathering and Synthesis

- Determine the ability of the system to produce foods to support proposed or anticipated numbers of both wild and hatchery reared fishes at a level promoting adequate growth and/or successful migration.
- Fully understand the trophic consequences of adding hatchery fish to the system as well as the imported foods used to grow them and the waste products produced during rearing.
- Quantify incremental improvements in available foods and fish production derived from habitat-specific restoration activities, with special emphasis on floodplains.
- Mount a region-wide monitoring program to quantify the temporal pace and spatial extent of non-native introductions and continuing invasions, and to spot impending problems while still minor and manageable.
- Establish a monitoring strategy to track constituents and sources of contaminants, nutrients and organic matter, spatially and temporally. Further, determine the extent to which marine-derived nutrients are helpful, and, which pollutants and artificial chemicals are helpful and/or harmful.
- Identify the nutrients that enhance the productivity of food webs, and determine whether existing concentrations are limiting productivity. Keep in mind that ratios of nutrients also shape the structure of communities, and an imbalance of essential nutrients hampers productivity.

Modeling

- Quantify critical connections between place-based production of foods and the timing of movements by juvenile fishes, thereby establishing a mechanistic understanding of their relationships.
- Initiate directed studies and modeling of the impacts of the increasing chemical load on the organisms and thus on the structure, resilience and productivity of the aquatic food webs.
- Model how to get the fish where they need to be, when they need to be there, with the right blend of available food resources, thermal regimes and interactions with predators and competitors. Incorporate connected system thinking into management planning and coordinate agency efforts to improve total Basin productivity.
- Evaluate a broader application of seasonal environmental flows[3] to connect habitats, mitigate disruption and benefit ecological functions of food webs downstream.

Restoration Actions and Experiments to Test Model Predictions and Assumptions

- Determine where and when fish growth is density dependent as well as when hatchery fish may displace or otherwise cause wild juveniles to move downstream due to food limitations. Experimental manipulation of the number and timing of hatchery releases is a logical method to quantify this.
- Use large-scale experiments to evaluate the relationships between survival (smolt to adult) during years of different ocean productivities and river conditions. Consider the impact of altering hatchery releases during years of predicted poor ocean or river survival. Survival in the ocean is perhaps density dependent, and may be related to food availability and

[3] The quality and quantity of water necessary to protect aquatic ecosystems and their dependent species and processes in order to ensure sustainable development of water resources (Arthington et al. 2010).

predation intensity. Survival in the river may be as well. Further, experiments should consider stage-specific size and growth to identify critical life stages and periods that impose important constraints on survival.

- Using a food web perspective, mount multidisciplinary, subbasin-scale catchment projects, including both rural and urban locations, to promote concentrated collaborative efforts among scientific investigators and resource managers. Use the projects to test predictions about the most effective food webs to sustain and enhance species of interest.
- Restore the floodplains (including those in the estuary) and floodplain-supported food webs, and reconnect them with the main channel. While doing so, establish the relationships between river discharge, floodplain inundation, food webs and fish production. Experiment with large scale and seasonally appropriate floodplain inundation, and evaluate the food web effects.

Evaluation of Alternative Policies with Models

- Reevaluate stocking practices for non-native species, in the context of the regional concern for production and conservation of native biota. Some policy changes may be in order.
- Model scenarios of different policy options with respect to nutrient additions (e.g., direct fertilization, carcasses) or reductions as a guide to future management efforts. The process to date has been guided more by perceptions of benefit than by hard proof of success.
- Establish planning goals for the biota and food webs for the foreseeable future, taking into account anticipated climatic and anthropogenic changes impacting the Basin's environment. Mount modeling exercises to project the impact of alternative policy choices on all components.

A Strategy for Protecting the Best and Restoring the Rest

The ISAB agrees with the 2009 Fish and Wildlife Program's habitat strategies of "building from strength" and identifying "stronghold areas," restoring ecosystems and protecting areas. It is clear that biotic conservation is most successful where actions are aimed at protecting ecosystems rather than by attempting to restore or reclaim them after the damage is done. For the Columbia River Basin, the realization is growing that a concerted effort to protect the food webs of critical environments will be needed, and Congress is considering legislation (H.R. 2055 and S. 817) that would direct federal, state, local and private stakeholders to develop conservation plans that make new investments in the healthiest salmonid runs. To accomplish that, we need to preserve the most productive food webs, even while steering degraded systems to a more productive status. Specifically:

Identify Properties Sustaining Desired Ecosystem States. In deciding which habitats to preserve and which to restore, we need a sense of what our desirable end-targets are to be. Initial identification of "desired end states" was part of the Subbasin Planning exercise (ISRP & ISAB 2004-13), and that process should be expanded to include consideration of the constituent food webs. We need to:

> Determine sustainable food web structures for each of the eight broad habitat types enumerated in Section D of this report. For each broad type of habitat, execute carefully matched comparisons (healthy versus degraded), developing a blueprint for what to protect and what to restore; and develop reasonable targets for measureable outcomes, so that we can gauge ongoing success as we move forward with the preservation and reclamation effort.

Sustaining Resilient Communities. Food webs are resilient to some perturbations and vulnerable to others. Changes of some species and sensitivity to some abiotic factors have little impact, but changes in others have drastic effects. We need to:

> Identify rapidly changing habitats that are matched with stable reference sites, and then examine how biotic components and abiotic parameters differ between them, translate those differences into "real time" and "real world" sensitivity analyses, by characterizing the changes that occur in the food webs, and extrapolate from these empirical comparisons to wider predictions, and from there to policy choices.

Hybrid Food Webs as Legitimate Targets, while Maintaining Productivity. Rather than insisting on pristine food webs as targets, we need to move toward productive and resilient food webs containing both new and old biotic elements and resistant to mild perturbations. We need to:

Synthesize what we know about biotic and abiotic factors, as well as processes, governing food web structure and function. We then need to build them into a very general food web modeling platform, such as the life-cycle model envisioned by NOAA, and then challenge the structure and resilience / sensitivity of the resulting food webs in the face of changing inputs. We envisage an effort on the pattern and scale of the COMPASS effort. We also need to ground-truth (benchmark) model predictions against empiric reality for the cases used to construct the model, as well as for others that it should be able to mimic.

Restore for a Changing World. Water quantity/quality, seasonal flow patterns, and non-native species introductions will respond to ongoing climate, population, chemical inputs and land use changes, and their effects are likely to conflict with some of the Council's restoration goals. Most current restoration plans implemented under the Fish and Wildlife Program or under the NMFS FCRPS Biological Opinion make little or no allowance for changing conditions and rarely address their influence on food webs. The Council and NOAA Fisheries, through the action agencies, should consider a targeted solicitation for proof-of-concept proposals that deal with conserving food webs in a changing environment. We need to:

- Build consideration of the likely effects of such changes into future habitat restoration projects; insist that restoration proposals explain (on the Taurus Proposal form) how the proposed actions will accommodate or otherwise respond to future conditions, especially as these relate to food webs; and develop landscape-based strategies that emphasize food web restoration in high impact areas and conservation in low impact areas.
- Carry out management experiments at a scale and control level similar to the habitat restoration experiments now being evaluated in intensively monitored watersheds (IMWs). Through the Integrated Status and Effectiveness Monitoring Program (ISEMP), establish meaningful long-term monitoring on all food web-related restoration/reclamation projects, and evaluate successes and failures. There are many uncertainties and threats to project success, and we need to assess the conditions under which success or failure is likely if we are to be effective. Further, initiate controlled proof-of-concept restoration demonstrations at a scale that is sufficient to provide confidence of benefits, rather than concentrating on "targets of opportunity" as choices for restoration/reclamation projects.

The Case for a Comprehensive Food Web Model. It is critical to connect growth performance in freshwater, estuarine and marine habitats. If fish have a difficult season in terms of growth during one or more freshwater habitats, can they compensate during later life stages? Throughout this report, the need for better quantitative food web and related bioenergetic models has arisen repeatedly. The need for a major modeling effort to build a "total system model" of the Basin is abundantly clear. The effort would be large and would need to be sustained, but necessary for understanding the Basin as an integrated system. It is unclear how to model a system as large or complex as the Columbia River Basin, but that is the challenge facing habitat restoration and management. The model could be developed in parallel with the life-cycle model envisioned by NOAA (Crozier et al. 2008).

A Time-Prioritized Action Plan

The ISAB suggests that the Council consider a systematic action plan addressing the concerns outlined above. We envision a concerted 12-year plan with an estimated *total* cost of at least $20-25 M. This estimate is given only to provide an initial sense of the scope and scale of the food web issues. The food web activities could be nested within the existing Fish and Wildlife Program, representing on the order of 1% of annual budget. Some of the suggested projects fall naturally under the Monitoring section of the Program, as they involve determination of the state of the system, both in advance of intervention and for progressive monitoring as the effort unfolds. Some fall under the Habitat section of the Program, as they involve efforts at habitat manipulation and/or restoration/reclamation. Some fall under the Production section of the Program, as they may involve adjustments to which fish are reared and released, in what numbers, and where. The rest of the suggested projects fall under the Research portion of the Program, particularly those aimed at filling information gaps.

Collectively, these investigations and activities need to be well integrated with the accelerating landscape-scale changes taking place, as well as being well coordinated with complementary research and management activities by agencies and Tribes. As we know so well, this is not a trivial task. Nevertheless, a focus on food webs provides a strong complement to the ongoing emphases on hydrosystem, habitat, hatcheries and harvest (the four H's).