Ecosystem Restoration: Systemwide Central Valley Chinook Salmon

What Is This Indicator and Why Is It Important?

This indicator reports the in-river escapement (the estimated number of adult salmon escaping ocean harvest and inland recreational fishing and successfully returning each year to spawn) of adult Chinook salmon in the Sacramento and San Joaquin river systems in California's Central Valley (see the Technical Note for a discussion of the value of cohort replacement rate as an alternative indicator). Some Central Valley salmon populations have experienced severe declines in the past several decades, for a variety of reasons, and of these the winter run is endangered and the spring run and steelhead are threatened. Central Valley salmon in general, and individual runs in particular, are therefore of special concern.

As with the other salmon indicators that focus on specific runs, this indicator emphasizes the instream conditions that are the locus of restoration efforts and that may influence the success of four key phases of the species' survival and reproduction (see conceptual model in Figure 1). This indicator alone is clearly not sufficient to evaluate progress toward the AFRP doubling targets. Any such evaluation would necessarily include a broader range of indicators and information (see Technical Note). However, measures of instream conditions are a valuable part of this broader portfolio of indicators and can provide important insight into the progress of specific restoration actions and the effect of instream conditions on salmon populations.

What Has Happened To Affect the Indicator?

Salmon runs in the Sacramento and San Joaquin rivers have been affected by a combination of factors, beginning in the mid-1800s when hydraulic gold mining methods resulted in severe sedimentation in many streams. In addition, the human population increase in California during this period was associated with a large increase in salmon harvest, the development of large salmon canneries, and subsequent overharvest. More recently, the construction of dams for water diversion and storage, the beginning of water export operations in the delta in the 1950s (federal Central Valley Project) and 1960s (State Water Project), and continued habitat degradation from a variety of causes (e.g., instream gravel mining, flow modifications, physical disturbance from recreational activities) have reduced available habitat, increased mortality of both adults and juveniles, and led to increased predation in some locations (Figure 1).

There have been a wide variety of attempts within the Central Valley system to offset these impacts and to restore salmon populations, some of them more successful than others. These attempts fall into four broad categories. The first is controlling temperature with upstream water releases, through engineering modifications such as the temperature control device at Shasta Dam, or through policies such as those in the Environmental Water Account (EWA) and the FERC relicencing agreements for dams on the Tuolumne River system. The second is improving access to and restoring or protectiong salmon habitat. Access can be improved through modifying dam operations as at the Red Bluff Diversion Dam on the Sacramento River or removing dams as on Butte Creek. Habitat restoration and protection include a wide range of activities from land purchases to engineering projects that reconstruct natural channels and floodplains. The third category is managing indirect losses presumed to result from water operations. These losses can be addressed through a variety of actions such as studies to reduce predation by non-native fish on juvenile salmon in the Clifton Court Forebay, closing the Delta Cross Channel in the early spring to retain smolts in the mainstem of the Sacramento River, and the Vernalis Adaptive Management Plan (VAMP) which increases flows with the intent of enhancing juvenile passage through the Delta. The fourth category includes efforts to directly support production through hatchery releases, with hatcheries now in operation on five rivers throughout the Central Valley. Major agreements such as the Four Pumps Agreement, the Tracy Agreement, the Anadromous Fish Restoration Project (AFRP), the Environmental Water Account (EWA), and the CALFED Ecosystem Restoration Program (ERP) have all adjusted policies and/or provided project funding related to one or more of the four categories of actions described above. An additional category of restoration actions focuses on modifying ocean and inland harvest regulations to protect particular runs at higher than average risk.

There are three major (and somewhat overlapping) targets for the recovery of Central Valley salmon stocks. The 1988 California Salmon, Steelhead Trout, and Anadromous Fisheries Program Act declares that it is the policy of the state to significantly increase the natural production of salmon and steelhead trout by the end of the 20th century. The Act directs the California Department of Fish and Game to develop a plan and a program to double the current natural production of salmon and steelhead trout resources. This state policy was then augmented by the passage of the Central Valley Project Improvement Act in 1992. This federal act established the Anadromous Fish Restoration Project (AFRP), with its goal of doubling natural salmon populations, and the Anadromous Fish Screening Program (AFSP), with its focus on screening pumps of all kinds (e.g., irrigation, water export) that were causing an impact on fish. In addition, NOAA Fisheries has established draft recovery goals for the Sacramento River winter run of an average of 10,000 spawning females over a 15-year period.

What the Data Show

Escapement has fluctuated widely from the early 1950s to the present, generally alternating between periods with high escapement and those with low escapement, with no obvious trend apparent in the 50-year record shown (Figure 2). These aggregate data are useful in providing both a broad overview of the status of salmon populations and a picture of variability at the system level. In addition, aggregate data provide a needed context for evaluating data from individual runs at the local scale. By themselves, however, the aggregate data are not explanatory, either of systemwide or local trends. They mask the differential role of hatchery releases and of local factors in different runs and, without other data, are insufficient to explain the role of fisheries or of shifting ocean conditions. This indicator must therefore be combined with other indicators in order to provide a meaningful picture of how changes in instream habitat conditions affect natural production.

Discussion

A wide range of impacts has affected the sustainability of Chinook populations in the Central Valley over the past 150 years. Important efforts to mitigate some of these impacts (e.g., hatchery construction, screens on Delta export pumps) have focused primarily at the system level. However, drastic declines in certain runs, along with the identification of specific limiting factors in some cases, have made it clear that restoration actions must consider both site-specific and systemwide efforts (see, for example, the writeups on the Butte Creek and Sacramento River runs).

Despite the apparent need for site-specific restoration actions, it is difficult to assess their impact at the population level for three main reasons. First, salmon are influenced by a complex interplay of factors that range from the levels of flow and temperature in individual streams to large-scale and long-term shifts in ocean climate conditions. Thus, understanding whether a change in abundance is due to a single factor or a combination is exceedingly difficult, except in the most dramatic cases. Second, the large numbers of hatchery fish in many runs cloud the ability to track population trends in naturally spawned salmon. Third, changes in ocean harvest rates can obscure changes due to inland habitat conditions (see Technical Note for further detail.)

The presumed value of the indicators for individual runs, which focus primarily on instream conditions and the restoration actions that have improved these, is therefore based on the following assumptions:

- In some cases instream conditions have been assumed to be limiting (e.g., inadequate flows, lethal temperatures, barriers to passage) and removing these should result in a visible signal in either measures of the limiting conditions, salmon abundance, or both
- Where instream conditions are not presently limiting, improving them could still improve the overall resilience of the run by providing an extra buffer during inevitable downturns
- It is not necessarily realistic to expect to see a linear relationship between restoration actions and escapement or cohort replacement rate, because of the complexity of the interactions between instream, Central Valley-wide, and ocean conditions
- However, it is reasonable to expect to see a relationship between restoration actions and metrics that reflect important aspects of instream salmon habitat
- Over the long term, and accounting for other factors such as ocean harvest, we expect to see an increase in population levels and in measures of populations' ability to withstand, and rebound from, periods of unfavorable conditions.

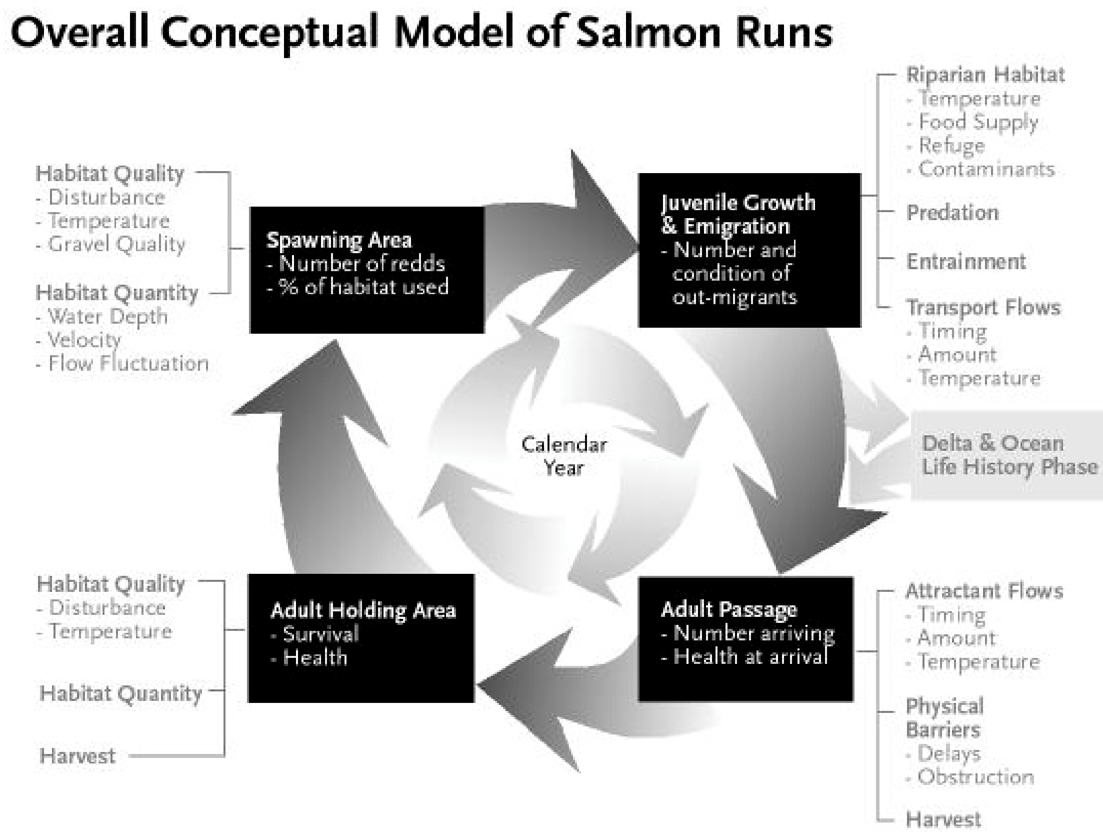

Figure 1. Generic conceptual model of factors affecting the various life-history phases of Chinook salmon in the Central Valley. The figure emphasizes the instream factors and processes that can be affected by restoration actions and de-emphasizes those in the Delta and the ocean. It therefore focuses attention on one subset of actions being taken while keeping other factors in context. The arrows in the inner circle, connecting the months of the year, are meant to indicate that the calendar year can be turned, like a dial, to reflect the timing specific to individual runs.

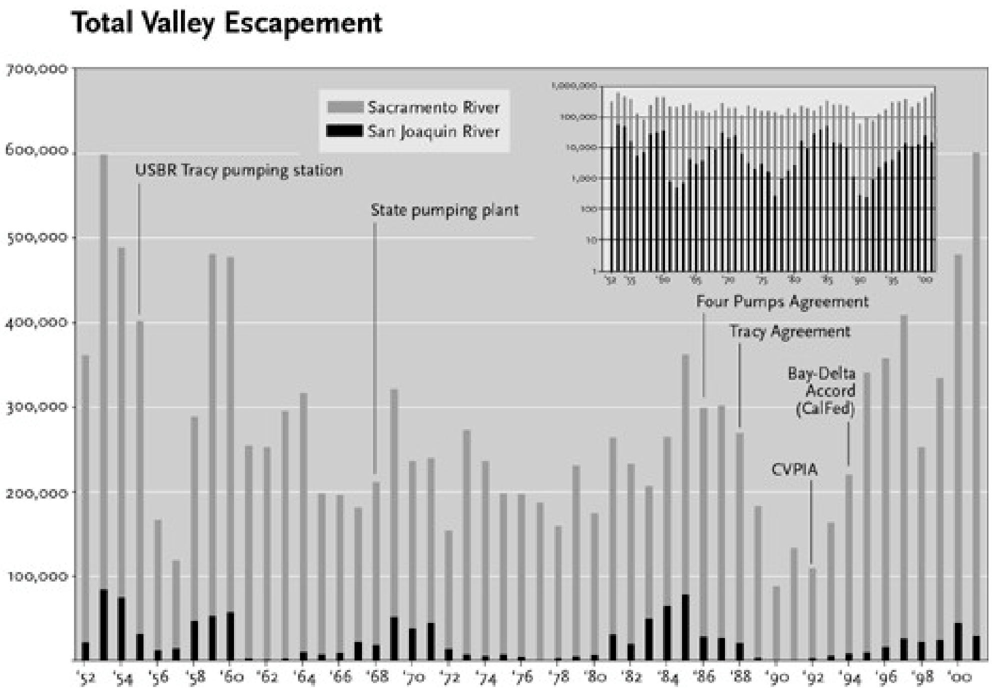

Figure 2. Aggregate total escapement, including in-river spawners and hatchery returns, for Central Valley Chinook populations, broken into escapement for the Sacramento and San Joaquin river systems. Significant events are superimposed on the escapement trend, and the inset shows escapement values on a log scale. USBR refers to the U.S. Bureau of Reclamation and CVPIA to the Central Valley Project Improvement Act. (See Technical Note for a discussion of the components of escapement estimates.)

Technical Note: Systemwide Salmon

The Indicator

Goal: This indicator reflects two key goals of the CALFED Ecosystem Restoration Program's (ERP) Strategic Plan:

Goal 1—Achieve recovery of at-risk native species dependent on the delta and Suisun Bay as the first step toward establishing large, self-sustaining populations of these species; support similar recovery of at-risk native species in the bay-delta estuary and its watershed; and minimize the need for future endangered species listings by reversing downward population trends of native species that are not listed.

Goal 2—Maintain and/or enhance populations of selected species for sustainable commercial and recreational harvest, consistent with the other ERP strategic goals.

In addition, the California Department of Fish and Game has been charged, under the California Salmon, Steelhead Trout, and Anadromous Fisheries Program Act, to double the natural production of these species. Similarly, the U.S. Fish and Wildlife Service's Anadromous Fish Restoration Project, under the Central Valley Improvement Act, is charged with making all reasonable efforts to at least double natural populations of anadromous fish in the Central Valley. The AFRP doubling target was established in reference to the average escapement during the baseline period of 1967–1991. Despite the apparent specificity of the AFRP doubling targets, however, comparing escapement or other indicators of population trend is complicated by issues such as, among others, the uncertainty of escapement estimates and the inability to accurately account for the hatchery component in all runs. In addition, comparing an indicator of population size to the target could be accomplished with a number of different statistical techniques, and on different temporal and spatial scales, and these details have not yet been determined.

Response Time: Responses to restoration actions must be considered in the context of three time scales:

- Immediate (4 years) processes reflected in changes in individual year classes
- Intermediate (9–20 years) processes reflected in an overall pattern of year classes over several generations
- Long-term (decades) processes reflected in sustained changes in population size and in the population's ability to weather natural cycles of favorable and unfavorable conditions.

Modifications to salmon habitat (e.g., through restoration actions) are typically reflected in escapement (or other indicators of population trend) in no less than three to five years, which corresponds to the life cycle of Chinook salmon. Long-term population changes are probably reflected in at least three to five generations, which would encompass 10–25 years. This time frame allows for anticipated variability in population size over time due to changes in most environmental factors within and outside the watershed. These include short- to medium-term ocean conditions (El Niño and La Niña), floods, drought, and recreational and commercial harvest. Thus, the full impact of the restoration actions implemented since the early 1990s may not be apparent until approximately the 2002–2017 time frame. However, there are even longer-term factors that strongly influence salmon production and escapement success. Primary among these is the Pacific Decadal Oscillation (PDO), a decadal shift in ocean climate conditions that has been demonstrated to be strongly correlated with salmon abundance. The PDO shifted in 1977 from a cold-water regime favorable to salmon along the Washington, Oregon, and California coasts to an unfavorable warm-water regime; it shifted back to a cold-water regime in

1998. Because of this long temporal scale, the actual status of the population can only be assessed over the long term.

Given the many sources of variability in this system, the range of time frames they operate on, and the complex interactions among them, it may be difficult or impossible in many instances to draw definitive conclusions about the results of restoration actions.

The Data

<u>Data Collection, Quality, and Limitations:</u> There are several important issues related to the collection, interpretation, and use of escapement data, as well as to its use in deriving cohort replacement rates (CRR), which are widely considered to provide additional useful information about population trends. As Figure 3 illustrates, the overall production of any individual run (or of the Central Valley system as a whole) is comprised of inland escapement plus ocean harvest. Inland escapement, in turn, is made up of inland harvest plus in-river spawners, plus hatchery returns. Derivation of CRR requires estimates of both production and the age structure of the population. There are data collection and data quality constraints involved in each data component shown in Figure 3, as summarized in the following paragraphs. All escapement data presented in this draft of the salmon indicators are the sum of the estimates of in-river spawners and hatchery returns.

Salmon ocean harvest is routinely monitored by the National Marine Fisheries Service (NMFS), but there are no naturally occurring markers that can be used to allocate ocean-caught fish to an individual run (e.g. Tuolumne River fall run). Hatchery fish that contain coded wire tags can be so allocated. However, not all hatchery fish are tagged, and the proportion tagged has varied among hatcheries and from year to year within the same hatchery. The allocation of ocean harvest to individual runs is typically made (as in CAMP (Comprehensive Assessment and Monitoring Program)) by applying the observed distribution of inland escapement across individual runs to the ocean harvest. While this provides a usable method for estimating the production of individual runs, it does not account for potential biases such as differential survival of populations spawning in different streams.

Inland escapement is comprised of inland harvest, in-river spawners, and hatchery returns. Inland harvest is reported each year by the California Department of Fish and Game and each hatchery estimates the numbers of fish returning to spawn. These estimates are relatively reliable, but it is not possible to distinguish, on return, between naturally spawned and hatchery-reared fish. Depending on the homing fidelity and straying rates of hatchery born and naturally spawned fish, some hatchery-produced adults may spawn in the wild or may stray and spawn in a non-natal stream. Conversely, some naturally produced adults may enter the hatchery and then be artificially spawned. This may confound attempts to correlate escapement trends with instream habitat conditions and with restoration actions designed to improve such conditions. The severity of this problem varies from run to run, depending primarily on the proportion of hatchery fish that are marked. Hatcheries that mark a high percentage of fish (as occurs for some hatcheries in the Sacramento River system) can produce more reliable estimates of the distribution of the hatchery spawned component. The persistence of this problem has led to an agreement in principle to mark a constant proportion of hatchery spawned fish, across all hatcheries and years.

The number of in-river spawners is difficult to measure, and the reliability of estimates varies. Methods have changed over the years, with the agencies responsible for monitoring sometimes using radically different methods in different streams or in the same streams in different years, and sometimes monitoring different areas of the same stream in different years. This makes comparison of estimates between streams and across years somewhat uncertain. For some older data, adequate documentation of sampling and estimation methods does not exist, making it impossible to determine the relative accuracy of such estimates or to identify and adjust for sources of bias. In addition, historical data are based on a variety of methods, including carcass counts, extrapolation based on spatial and/or temporal subsets of an entire run, and expert judgment. The length of the data record varies from run to run; in general, however, data for several runs are available from the early 1950s and in some cases from the 1940s.

While mark-recapture carcass counts are now widely used as the standard method for estimating the in-river component of escapement, some problems remain. Mark-recapture methods depend on a number of assumptions, principal among them that the marked animals will distribute randomly among the population during the interval before the recapture sampling. This assumption is often violated for carcasses, with differing consequences for the final escapement estimate depending on the size of the run, the area sampled, and the degree to which random resampling designs were used. The need to exchange information on escapement surveys and to develop improved methods for conducting surveys, combined with increased emphasis on escapement estimates as measures of restoration success, led to the formation of the interagency Salmonid Escapement Project Workteam, a subteam of the Intreragency Ecological Program's (IEP) salmonid team.

Cohort replacement rate (CRR) is widely considered to provide a more accurate picture of population trends than does the raw escapement estimate, which lumps returning adults of all age classes. However, CRR is currently calculated routinely only for the Sacramento River winter run, and, because the CRR requires information on the age structure of the population of each run, there are significant constraints on its more widespread application. Aging studies are not performed as a standard part of escapement monitoring. As a result, estimates of CCR must depend on assumptions about the population age structure, based on inferences from hatchery populations and qualitative observations about the dominance of 3-year old fish in most escapement runs. Thus, any estimate of historic trends using CCR as the indicator would necessarily be partly qualitative.

Flow and temperature measurements are typically available throughout the system, although the intensity of sampling, both spatially and temporally, varies from stream to stream and over time. There are no major data-quality issues with flow and temperature measurements because the technology for such monitoring has been well established for quite some time. The major issue with these data types is the spatial coverage of historical data, which often were not collected in locations that are now understood to be important for the success of salmon survival and reproduction in the streams.

The number and distribution of redds is another metric important to assessing the response of salmon populations to instream environmental conditions and the restoration actions intended to improve these. Methods vary from aerial surveys on the Sacramento River, where data extend back to the late 1960s, to visual surveys on smaller creeks such as Butte Creek, where surveys began only recently. However, this method is not useful for streams with large spawning runs.

Longer-Term Science Needs

Ensuring that population estimates are comparable throughout the system will require a substantial investment in improving sampling and data analysis methods, an effort that has just begun through the Salmonid Escapement Project Workteam. One aspect of escapement that deserves particular attention is the need to more reliably distinguish between naturally spawning fish and hatchery fish (e.g., through a comprehensive constant fractional marking program).

Better estimates of juvenile production and survival would help improve understanding of the relationships among adult escapement, habitat features, and juvenile production and survival. Juvenile production could be estimated with wider use of rotary screw traps or trawls, hydroacoustic, fyke netting, and radio tagging. Studies could also add to knowledge of juvenile migration and survival rates. In addition, ongoing cohort analysis, by allowing returning adults to be split into groups based on the year they left the river, can help establish a tighter link between river conditions and the number of juveniles that survive to return as adult spawners.

While the escapement estimates provide an overall measure of trends for the entire system and for individual runs, they do not isolate the specific processes that may contribute to overall population condition. More sophisticated indices or metrics, such as overall smolt production or juveniles per spawning female, could be developed to provide an additional level of resolution about the function of instream processes.

More specific and quantitative recovery goals could be developed for Central Valley Chinook salmon to provide a clearer benchmark against which to measure progress. This would require more detailed conceptual and numerical modeling of the specific limiting factors in individual watersheds, population modeling, and additional monitoring and special studies. Finally, CALFED and other agencies could carefully and systematically document and assess the individual restoration actions intended to affect the Chinook salmon in the Central Valley. Performance assessments of these actions that result in quantitative estimates of change in key system parameters are ultimately necessary to document cause-and-effect relationships.

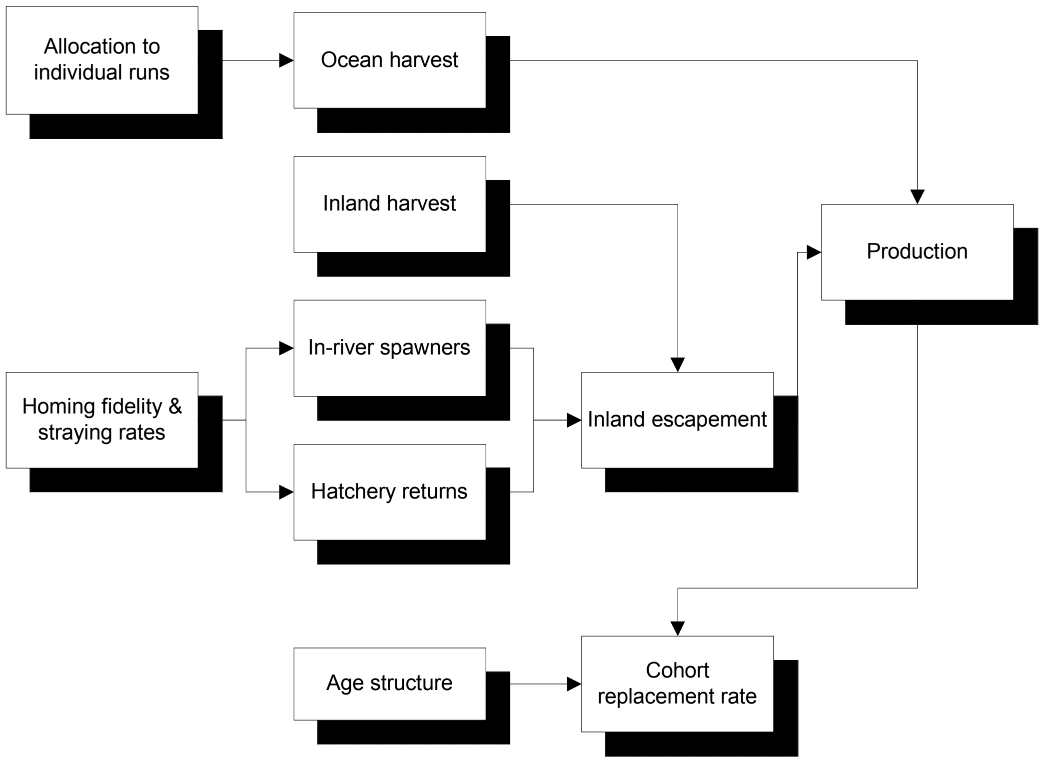

Figure 3. Data components needed to calculate estimates for each run of inland escapement, overall production, and cohort replacement rate. The degree of shading in the background for each box subjectively indicates the relative degree of completion, accuracy, and/or availability associated with each estimate.