Integrated models to support management of winter-run Chinook salmon

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Background

Winter-run Chinook salmon are listed as Endangered under the US Endangered Species Act, and federal actions that could impact this species are subject to review by the National Marine Fisheries Service (NMFS). California relies on a complex system of dams, reservoirs and conveyance facilities to capture, store and move water across the state. Winter-run Chinook are heavily influenced by this system, and proposed changes to the configuration or operation of the system can affect them at various times and places in complex ways, making it difficult to predict impacts without careful analysis. We[1] have developed a system of linked models to enable evaluation of the impacts of many kinds of fish, water, and habitat actions.

Overview of Models

By coupling mostly existing models and a life cycle model developed in house, we can account for the effects of climate variation and change, water project design and operations, fishing, hatchery operations, and many kinds of habitat restoration on winter-run Chinook. The models include CALSIM II (operations research model of the state and federal water projects), HEC-RAS (a 1-D hydraulic model of the Sacramento River), DSM2 (a 1-D hydraulic model of the Delta and upper bay), ePTM (a modification of DSM2's particle tracking model that includes a sophisticated representation of juvenile salmon migration behavior and predation), habitat quality models that predict rearing capacity under various flows, WRLCM (Winter Run Life Cycle Model, a stage-based stochastic population dynamics model, described in some detail below). The biological models have parameters that have been estimated from relevant data. Inputs typically include climate, channel geometry, hydrology, and the operating rules of the water project, fishery, and hatchery. Outputs include simulated abundances of various life stages over many decades.

The Winter-run Chinook Life Cycle model

The WRLCM is a stage-structure model that included density-dependent reproduction and migration of juvenile stages, temperature-dependent egg mortality (similar to the "Martin model"), flow-dependent migration and survival, ocean fishery impacts (from the Winter Run Harvest Model), and optionally, hatchery propagation and reintroduction to currently unoccupied areas. Migration through the Delta is modeled in detail with the ePTM. In the ePTM, there is no direct flow-survival relationship, but one emerges from changes in residence time and migration routes as flows and water project operations change Delta circulation. In the river, one effect of flows is on habitat capacity (e.g., floodplain or floodway activation) and migration cues, which partly determines where in the system juvenile salmon rear.

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Applications to Date

The models have been used to support biological opinions on California WaterFix and the more recent re-initiation of consultation on long-term operations. We have also analyzed possible effects of reintroducing winter-run Chinook to areas above Shasta Dam. We are currently working on analyzing proposed changes to through-Delta conveyance and impacts of the proposed Sites Reservoir.

This model, like others of this population, suggests that winter-run Chinook are relatively unproductive. Making more habitat of the quality already available will have only modest benefits. Increasing survival rates of eggs (which are subject to frequent and sometimes high rates of thermal mortality), rearing juveniles, and migrating smolts would do much more to improve the status of the population than simply making more habitat available.

Potential Applications

The models can be used to assess the likely impact of a variety of habitat restoration actions, and we are collaborating on a Delta Science Program-funded project that is developing broad-sense recovery goals for Central Valley salmonids and evaluating whether to-be-identified restoration actions are likely to achieve these goals. Because the models include physically-based hydraulic models, we can readily evaluate how restoration actions that change bathymetry and land-surface elevation (e.g., floodplain reconnection, Delta island flooding) will impact salmon.

Limitations

One important limitation comes from the lack of information on how habitat restoration affects the productivity of habitats (i.e., the survival of fish rearing in it). The models readily characterize how such actions change the capacity of habitats (i.e., how many fish can rear there), but the model is less sensitive to changes in capacity than it is to productivity. Studying how productivity changes in restored habitats would be extremely valuable.