Environ Biol Fish (2013) 96:131–133
DOI 10.1007/s10641-012-0099-x

An introduction to the use of electronic tagging to provide insights into salmon migration and survival

Philip T. Sandstrom · R. Bruce MacFarlane · Steven T. Lindley · A. Peter Klimley

Received: 9 November 2012 / Accepted: 27 November 2012 / Published online: 9 December 2012

The west coast of North America serves as home for five species of semelparous salmon and the iteroparous steelhead and cutthroat trout, all in the genus *Oncorhynchus*. Currently, only Chinook salmon (*O. tshawytscha*) and steelhead trout (*O. mykiss*) reside in the rivers and streams of California's Central Valley. By contrast, the coastal streams of California contain coho salmon (*O. kisutch*), Chinook salmon and, to a much lesser extent, cutthroat trout (*O. clarki*).

The rivers and streams of the Central Valley are unique because they host four Chinook salmon runs identified by the season when most adults return to freshwater to spawn. These seasons include winter, spring, fall, and late-fall (Fry 1961; Stone 1874). Of the four runs, the fall run is the most abundant, largely due to supplementation by hatchery production (Fisher 1994). Fall-run juvenile Chinook salmon emigrate to the ocean soon after hatching. Some of their spring-run and winter-run counterparts engage in similar conduct, thereby exhibiting what is known as ocean-type behavior. Late-fall and some spring-run juveniles use a different strategy, remaining in freshwater for a few weeks to several months before outmigrating to the ocean at a larger size. This pattern is described as stream-type behavior. The ocean-type juveniles spend relatively little time in streams and enter the ocean at a small size [80 mm fork length (FL)]. The stream-type juveniles enter the ocean at 120–180 mm FL. These larger stream-type smolts are also called yearlings.

Central Valley steelhead are currently recognized only as winter run, although in the past there may have been a summer run as wÏell (Needham et al. 1941). Juvenile steelhead vary in freshwater residency and age at ocean entry. While many enter the ocean as smaller sub-yearlings, others enter as larger yearlings or when even older. Populations of coho salmon migrate upstream and spawn in coastal streams and larger rivers outside of the Central Valley, especially in the area north of the Golden Gate, the estuarine exit for Central Valley salmonids.

Today salmon populations are only a fraction of their historical abundance, primarily because of the loss of spawning habitat that has resulted from dam construction. Sacramento River winter-run Chinook salmon are classified as endangered under the U.S. Endangered Species Act (ESA) of 1973, with Central Valley steelhead and spring-run Chinook salmon listed

P. T. Sandstrom (✉) · A. P. Klimley
Department of Wildlife, Fish, and & Conservation Biology,
University of California, Davis,
One Shields Ave.,
Davis, CA, USA
e-mail: ptsandstrom@ucdavis.edu

R. B. MacFarlane · S. T. Lindley
Fisheries Ecology Division, Southwest Fisheries Science
Center, National Marine Fisheries Service,
110 Shaffer Rd.,
Santa Cruz, CA, USA

as threatened, and Central Valley fall and late-fall run Chinook categorized as candidate species. Current threats to the recovery of these species include continued degradation of remaining spawning and rearing habitat as well as direct and indirect mortality caused by water diversions along the Sacramento River and in the Delta. In the Klamath-Trinity river system, the second largest watershed in California, coho salmon stocks are threatened, whereas Chinook salmon and steelhead populations appear to be relatively healthy. The major threats to the sustenance of Klamath-Trinity salmon populations include dams and land use.

The salmonids inhabiting the California Central Valley have continued to decline in recent years. Because of this trend, commercial and recreational fisheries in this region have been restricted or closed for the past 4 years. Fish and wildlife managers have derived data concerning survival and movement of salmonids from smolts captured in rotary screw traps carrying coded wire tags (CWT), which identify individuals and carcass surveys. CWT were developed in the 1960s to study juvenile salmonids (Jefferts et al. 1963), and they have subsequently been used in mass marking (Hager 1975). In the 1960s researchers used Lea's hydrostatic tags, a small celluloid cylinder with instructions for the person who captures the fish sealed inside, to study the movements of salmon (Moriarty 1962). Researchers also used other external marking techniques, including the clipping of the adipose fin, affixation of a flat disk to the dorsal fin, insertion of a tethered dart into the musculature with identifying script on it, and tags attached to the operculum. More contemporary methods of marking are now available, such as visual implant elastomers, chemical marking, and electronic tagging. This special issue of Environmental Biology of Fishes features several articles that describe the survival, movement, and behavior of juvenile and adult salmonids through the use of electronic archival and acoustic tags.

Recent advances in electronic tagging technology have expanded the horizon of our knowledge about salmon migration and offer much more information on movement dynamics and area-specific survival. This new information provides a view into the previously-described 'black box' of when and where significant mortality occurs, thereby facilitating improved fishery management and species recovery. Coded, acoustic transmitters have been placed within the peritoneal cavity of salmon smolts. Tagged smolts have been subsequently released into rivers to record their reach-specific rates of movement and survival through using arrays of tag-detecting receivers. Archival tags, which determine the geographic coordinates of fish based on light duration and intensity, have now been miniaturized sufficiently to be placed on steelhead, an iteroparous species making yearly migrations out of the watershed and into the ocean before returning to its spawning site on successive years. Receivers have been miniaturized to the point where they can be attached to large species creating mobile receivers. In 2006 a study funded by CALFED—a joint state and federal program that addresses water issues in the Central Valley and San Francisco Estuary—commenced to examine the survival and movement rates of juvenile steelhead trout and late-fall Chinook salmon in the Sacramento River. This study formed the foundation of the California Fish Tracking Consortium, a group of researchers from universities, federal and state resource agencies, private consulting groups, and public utility districts. Since 2006, the Consortium has maintained more than 325 receivers in the Sacramento/San Joaquin watershed, San Francisco Estuary, and coastal ocean. This acoustic receiver array is among the largest in the world, spanning more than 600 km from the upper Sacramento and San Joaquin Rivers to Point Reyes, which is located 60 km north of the Golden Gate. Researchers have studied a diversity of species at various scales in this watershed. The majority of articles published in this special edition focus on salmonid data collected from the acoustic array in the Sacramento/San Joaquin Rivers, delta, estuary, and the ocean.

In addition to the work of interest to the California Fish Tracking Consortium, this volume includes articles that describe tagging investigations in the Klamath-Trinity watershed and estuary, Humboldt Bay (northern California), and the coastal fjords of British Columbia. It also includes work that offers an innovative preview of the use of mobile ocean tracking.

Above all, the purpose of this special issue is to share the findings of a diverse group of researchers who participated in an electronic tagging symposium held at the University of California Davis, Bodega Marine Laboratory, in May of 2010 with the scientific community and resource managers. New tagging technologies allowed these researchers to better describe the migrations of salmonids in the Central Valley, northern California, and Canada. The results of many studies, although still in their infancy, are presented in this volume. We have arranged the articles in the special issue in terms of the following four categories: 1) technologies and their limitations; 2) behavior and physiology of salmonids; 3) migratory behavior of salmonids, both in the watershed and the open ocean; and 4) rates of survival between reaches and along different migratory pathways throughout the watershed.

We would like to express our heartfelt appreciation to David Noakes, Ayrene Dialogo, and Lynn Bouvier of Environmental Biology of Fishes for their hard work and assistance during the review process. Without their effort this special edition would not have been possible. Funding for the symposium at Bodega Marine Laboratory was provided by CALFED, and many of the published works are a direct or indirect result of the CALFED contract U-05-SC-047.

References

Fisher FW (1994) Past and present status of central valley Chinook Salmon. Conserv Biol 8:870–873

Fry DH (1961) King Salmon spawning stocks of the California Central Valley, 1949–1959. California Fish Game 47:55–71

Hager R (1975) A technique for mass recovery of coded wire tags from young salmonids. Progressive Fish Culturist 37(1):51

Jefferts KB, Bergman PK, Fiscus HF (1963) A coded wire identification system for macro-organisms. Nature 198:460–462

Moriarty C (1962) Movement of salmon. Nature 196:595

Needham PR, Smith OR, Hanson HA (1941) Salmon salvage problems in relation to Shasta Dam, California, and notes on the biology of the Sacramento River salmon. Abstract, Transactions of the American Fisheries Society, 17th annual meeting.

Stone L (1874) Report of operations during 1872 at the United States salmon hatching establishment on the McCloud River. pp. 168–215 *in* U.S. Commission on Fish and Fisheries, Report for 1872 and 1873, Part II, Washington, D.C.