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Evaluation of Alternative Marking/Tagging Systems for Hatchery Produced California Fall-run Chinook Salmon

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Executive Summary

Background

Since the late 1970s, West Coast salmon hatchery production has included some level of marking fish with adipose fin clips (ADC, a common mark shared across hatcheries) along with tagging individual release groups with coded-wire tags (CWT, which include a numeric code identifying fish back to the hatchery, brood year, and individual release group of origin). A coordinated coastwide marking and tagging program along with standardized sampling of ocean harvest, river harvest, natural area spawning escapement, and hatchery returns provides the information legally required to manage salmon stocks under the Pacific Salmon Treaty, and this coordinated coastwide system also provides the inputs needed for cohort reconstructions used in the harvest management of Central Valley and Klamath-Trinity Chinook salmon (*Oncorhynchus tshawytscha*) stocks under the Pacific Fishery Management Council, and the data necessary for hatcheries to evaluate program and release group performance, manage broodstock selection, and assess interactions with natural-origin fish.

Initially, not all hatchery fish were marked or tagged, but all hatchery fish that received a tag also received a mark (and vice versa). At present, 25% of all fall-run Chinook salmon produced at major production hatcheries in California receive an ADC and an accompanying CWT, a system known as constant fractional marking (CFM). Smaller hatchery programs or individual experimental release groups are marked and tagged at 100%, allowing for rare stock enrichment such that a single sampling rate can (ideally) yield adequate recoveries of tags from rare stocks and small release groups without expensive oversampling of abundant stocks. Similarly, experimental releases can be marked and tagged at 100% to yield sufficient tag recoveries with a smaller release group than if only a fraction of the experimental fish were marked and tagged.

Desire for mark-selective fisheries (MSF) and/or the ability to identify hatchery-origin fish in real-time and/or to identify all hatchery-origin fish in natural spawning areas led to the proposal (and in some areas of the Pacific Northwest, adoption) of mass marking schemes under which fish from some hatcheries are all marked (ADC), but do not necessarily all receive tags (CWT). This has posed substantial challenges for the existing coastwide CWT sampling program and modeling the effects of MSF has proven difficult, hampering the ability to plan fishery season structures or set quotas, and leaving substantial uncertainty in management success at achieving target exploitation rates. Areas with mass marking have, in most cases, adopted the use of electronic tag detection as a supplement/replacement for ADC visual inspection to determine whether individual fish contain CWT.

In 2009, the Executive Committee of the Cal-Neva Chapter of the American Fisheries Society proposed 100% marking (mass marking using ADC) of all fall-run Chinook salmon produced at Central

Valley (CV) and Klamath-Trinity (KT) Basin anadromous fish hatcheries. The West Coast Regional Office of NMFS, the California Department of Fish and Wildlife, and the U.S. Fish and Wildlife Service therefore jointly requested formation of a scientific workgroup (WG) to assess the potential benefits (protection of natural and ESA-listed Chinook salmon, reducing introgression effects due to stray hatchery fish, possible increases in harvest, and others) and needs for new infrastructure, equipment and personnel, that are associated with alternative marking and tagging strategies, some of which incorporate MSF. In response, a WG was formed of a broad range of scientists with specific knowledge of CV and KT salmon populations, salmon fishery assessment and management, freshwater and marine ecology of salmonids, and/or hatchery operations selected from federal and state agencies, academic institutions, tribal fisheries agencies, and private consultant groups. The material in this report reflects the WG discussions as well as insights gained by some authors while working on a report to the Pacific Salmon Commission (PSC) evaluating the potential for genetic parentage-based tagging (PBT) to supplement or replace CWT. Feedback on the report was solicited from all WG members, and all WG participants providing feedback were invited to join as coauthors. Feedback was received from all WG members. Although one WG member declined authorship, no objections to the report were raised.

This report summarizes the authors' assessment of the potential benefits and supporting needs of 11 proposed alternative marking and tagging systems, including the CFM status quo. We evaluated several modifications to the current system while maintaining CWT as the tag of choice, but varying the level of marking and/or tagging. For each proposed system, we evaluated 22 criteria involving conservation of CV and KT fall-run Chinook salmon, conservation of other salmon stocks, management of salmon fisheries, and management of salmon hatcheries. Our evaluation of these criteria took into account impacts on sampling costs, compatibility with existing harvest management models, allowance for rare stock enrichment, compatibility with marking and tagging of natural-origin fish, and achievement of potential new goals including real-time or post-hoc identification of all hatchery-origin fish, identification of all hatchery-origin fish back to stock of origin, and whether a system would be conducive to MSF. We also evaluated several alternative marking/tagging systems in which PBT was used in place of CWT, and one hybrid system using both CWT and PBT.

When considering any changes to marking and/or tagging rates, it is important to realize that in addition to the obvious direct costs of increased marking or tagging, changes to tagging rates may, and changes to marking rates will, affect the cost of sampling and tag recovery (assuming fixed hatchery production levels). Any reduction in sampling rates will reduce the information available on stocks (or individual release groups) that are already marked/tagged at 100% (undoing rare stock enrichment), such as Sacramento River winter-run Chinook salmon. Alternative tagging technologies (e.g., PBT or RFID tags) will change unit costs and potentially change the optimal mark/tag/sample rates, but do not eliminate this tradeoff. And, to provide needed information for conservation, harvest, and hatchery management, local marking and tagging practices must be compatible with the tag recovery sampling programs used coastwide (or at the very least in both California and Oregon, for CV and KT stocks).

Findings

The current CFM system (i.e., fractional marking and fractional tagging) allows for cost-effective estimation of the quantities required for harvest management models, evaluation of hatchery performance, rare stock enrichment, experimental release groups of moderate size, post-hoc estimation of the contribution and proportion of hatchery-origin fish in harvest, hatchery broodstock, and natural area escapement (and this proportion can be approximated in real-time if mark rates for dominant contributing stocks are known), and is compatible with marking and tagging (ADC+CWT) of natural-origin fish. The CFM system does not allow for real-time or post-hoc identification of all hatchery-origin fish, nor is it conducive to MSF.

Fully tagging but fractionally marking (as recommended by the California Hatchery Scientific Review Group) would allow for cohort reconstruction, rare stock enrichment, and experimental release groups of moderate size. In addition, in conjunction with electronic tag detection (ETD) it would allow for real-time identification of all hatchery-origin fish, assuming tagged natural-origin fish were not present in appreciable numbers, and allow for post-hoc identification of the stock of origin for all hatchery-origin fish. These systems would not be conducive to MSF (although a near-equivalent would be possible if fishermen employed ETD). Costs for existing sampling programs would not be expected to change substantially, since ETD would only be required for new sampling programs meant to identify hatchery-origin fish in real-time, or for post-hoc identification of stock of origin for hatchery-origin fish.

Fully marking but fractionally tagging (i.e., mass marking) would allow for cohort reconstruction, rare stock enrichment, moderate-sized experimental release groups if ETD was used to target sampling of only marked fish with tags, and identification of hatchery-origin fish in real-time, assuming any natural-origin fish are tagged but not marked (note that recovering such natural-origin fish would require ETD applied to all fish sampled, whether marked or unmarked, at considerable expense). These systems would be conducive to MSF. These systems would not allow for identification of all hatchery-origin fish back to their stock of origin, although stock proportions could be estimated post-hoc. Costs for existing sampling programs would increase because ETD would be required in all sampling strata (ocean fisheries, river fisheries, natural spawning areas, and hatchery returns). If recoveries of tagged but unmarked natural-origin fish were required, or double-index tagging (DIT) was used in an attempt to model the impacts of MSF, the increase in cost would be even greater because ETD would need to be applied to all fish sampled, whether marked or not.

Fully marking and fully tagging would allow for cohort reconstruction, but would not allow for rare stock enrichment, nor for moderate-sized experimental release groups. These systems would allow for identifying hatchery-origin fish in real-time, but only if no natural-origin fish were marked (note that recovering tagged but unmarked natural-origin fish would require ETD applied to unmarked fish), and would allow for post-hoc identification of all hatchery-origin fish back to their stock of origin. These systems would be conducive to MSF. Costs for existing sampling programs would increase substantially since roughly four times as many CWT recoveries would be expected. Sampling costs would increase even further if ETD were used to identify tagged but unmarked natural-origin fish or DIT groups used in evaluating MSF.

Analogs to each of these systems using PBT in place of CWT can be envisioned, noting that ETD would not be possible to screen out tagged but unmarked fish unless all fish whose parental broodstock was genotyped also received blank agency-wire tags (AWT). Without ETD, all marked fish in a sample would need to be genotyped (or all fish, if any tagged but unmarked fish were present, such as would be required to use DIT to evaluate MSF). In addition, changes in hatchery practice would be required to segregate discrete release groups tagged using unique sets of parents. Substantial changes would be needed in sample processing and centralized data storage compared to the current system of “head labs” and RMIS (Regional Mark Information System, www.rmpc.org). Use of PBT would allow for pedigree reconstruction with potential benefits for hatchery broodstock management and heritability studies. A full evaluation of the costs and benefits of replacing CWT with PBT is beyond the scope of this report, although we provide references to a 2015 report to the PSC and a review of that report by the PSC’s Committee on Scientific Cooperation (CSC). The CSC found that PBT was not currently a cost-effective replacement for CWT coastwide (note that no California-exclusive analysis was performed) but recommended revisiting the cost comparison as genetic technologies and economies of scale develop further.

This report also evaluates one hybrid system in which the current fractional marking and fractional tagging with CWT is maintained, along with additional 100% tagging via PBT. Like CFM, this system would allow for cohort reconstruction, rare stock enrichment, experimental release groups of moderate size, and is compatible with the marking and tagging of natural-origin fish. In addition, it would allow for post-hoc identification of all hatchery-origin fish back to their stock of origin, and post-hoc estimation of the proportion of hatchery-origin fish (this proportion can be approximated in real-time if mark rates for dominant contributing stocks are known). This system would not allow for real-time identification of all hatchery-origin fish, nor would it be conducive to MSF. Although there would be costs associated with genotyping broodstock (and natural area spawners, if higher precision in natural area spawner composition estimates was desired compared to what could be achieved based on CWT recoveries alone), it would not change costs for recovering CWT in existing CWT sampling programs.

Although this report is not intended to serve as a comprehensive analysis of all conceivable MSF options, we do survey the current status of modeling MSF and note that cohort reconstruction would not be possible for unmarked fish (even with the use of DIT) at the level of stratification (time/area/fishery) required for harvest management. By design, it would not be reasonable under MSF to assume that exploitation rates estimated for marked fish also applied to unmarked fish, thus current harvest models would not be usable if MSF were implemented under any of these systems. Models proposed or used to evaluate MSF in other areas all have significant problems and it is unclear whether these modeling challenges could ever be fully addressed. Even if these estimation challenges could be overcome, the degree to which fishing opportunity and harvest might be increased under MSF management is difficult to gauge with any degree of confidence as it depends on a large number of variables, but it would likely vary substantially across years. MSF is most effective at increasing harvest opportunity if marked fish make up a large proportion of fish encountered in fisheries, but this runs counter to the conservation goals of increasing natural-origin fish abundance while reducing the effects of hatchery-origin fish on natural spawning populations. Similarly, MSF are unlikely to reduce impacts on listed stocks under the current management framework, since there is no requirement or incentive to reduce impacts on such stocks below the maximum allowable level set by ESA consultation standards. Also, unmarked DIT fish would violate the assumption that all hatchery fish are marked, compromising the capability to identify hatchery-origin fish in real-time and restrict their presence in natural spawning areas.

Conclusions

Although this report does not make an explicit recommendation for changes in marking and tagging practices, we note that CFM is the least expensive system considered. Given the PSC’s findings on PBT costs and the requirement for coordinated sampling coastwide, we would not recommend a switch to PBT at this time. Given uncertainty in the ability of MSF to achieve stated goals and the incompatibility of MSF with existing harvest management models and regulations, we would also not recommend consideration of MSF at this time for multi-stratum ocean or river fisheries. When comparing the remaining options, it is important to consider what added capabilities are desired and whether they justify the additional costs (and potentially sacrificed capabilities) of each option. It should be noted that although tagged natural-origin fish may pose challenges to real-time identification of hatchery-origin fish in some systems, currently there are no major, ongoing natural-origin tagging studies in California, and there are likely many escapement strata for which tagged natural-origin fish would be unlikely to make more than a negligible contribution. In addition, depending on the purposes of such studies, due to the cost of accessing and handling natural-origin fish, it may be cost-effective to use a more expensive but more data-rich tag (e.g., RFID tag) for natural-origin fish, which may not cause similar conflicts.

If it is desirable to be able to identify all hatchery-origin fish in real-time, either full marking and fractional tagging, fractional marking and full tagging plus ETD, or full marking and full tagging would suffice. If it is desirable to be able to identify stock of origin for all hatchery-origin fish, either fractional marking plus full tagging, fractional marking and fractional tagging plus PBT (CFM+PBT hybrid), or full marking and full tagging would suffice. Fully marking and fully tagging would increase sampling costs considerably (and require larger experimental release groups while rendering rare stock enrichment impossible), and so it would not be preferred over fractional marking plus full tagging unless it is essential to identify all hatchery-origin fish in real-time and ETD of tagged fish is not a viable way of doing so. Fractional marking plus full tagging is generally preferable over full marking and fractional tagging since it allows identification of all hatchery-origin fish back to stock of origin unless it is crucial that it be possible to identify all hatchery-origin fish in real-time in samples which may contain CWT-tagged natural-origin fish as well. If real-time identification of all hatchery-origin fish is important, the CFM+PBT hybrid is not a viable option, but if reliable post-hoc estimation of the proportion of hatchery-origin fish along with identification of all hatchery fish back to their stock of origin is sufficient, the choice between fractional marking plus full tagging or the CFM+PBT hybrid should depend on their relative costs and benefits, considering the potential future utility of both real-time identification of tagged fish (an advantage of full tagging) and the information provided by pedigree reconstruction (an advantage of the CFM+PBT hybrid).

This complexity defies any simple recommendation or ranking of systems, and emphasizes the importance of considering tradeoffs among what capacities are gained and lost under each alternative system. The value of any added capabilities should be weighed against a careful consideration of costs. Cost considerations include the obvious direct effects of increased marking or tagging, but also careful attention should be given to sampling costs and their implications for future sampling rates. Ultimately, different constituencies are likely to favor different marking/tagging systems and sampling regimes depending on their priorities, so it is important that decision makers are cognizant of the tradeoffs involved and aware of the unfortunate reality that there is no one option that is a true win-win for all parties.

1 Introduction

Mass marking of hatchery fish, as well as mark-selective Chinook salmon fisheries, remain controversial topics in California. In 2009, the Executive Committee of the Cal-Neva Chapter of the American Fisheries Society (Cal-Neva AFS EXCOM 2009) proposed mass marking all fall-run Chinook salmon produced at Central Valley (CV) [1] and Klamath-Trinity (KT) Basin anadromous fish hatcheries, and in spring 2009 the Cal-Neva Chapter (Cal-Neva AFS 2009) sponsored a mini-symposium on hatchery reform, mass marking (MM), and mark-selective fisheries (MSF). As practiced in Washington[2], under mass marking, 100% of hatchery salmon are adipose fin-clipped (ADC), but only a small proportion are also coded wire tagged (ADC+CWT). In ocean and/or freshwater mark-selective fisheries, only those fish with adipose fin clips can be retained. According to Cal-Neva AFS EXCOM (2009), mass marking would support improved hatchery management, including improved genetic fitness of hatchery broodstock and natural spawning populations, would increase probability of detecting and quantifying stray hatchery-origin fish in the spawning grounds of sensitive rivers, would allow more precise estimation of natural- and hatchery-origin salmon abundance, and would greatly simplify the monitoring of natural-origin and endangered stocks. Proponents of mark-selective fisheries argue that significantly increased overall harvest and fishing opportunities and decreased fishing mortality on ESA-listed and unmarked stocks would result. However, many questions and concerns have been raised about whether such fishery and natural population benefits would in fact be realized, the unintended consequences that could occur with implementation of MM & MSF, and the costs of maintaining a rigorous and reliable CWT marking and recovery program following implementation of MM & MSF (Zhou 2002, PSC 2005, Cal-Neva AFS 2009, NMFS SWFSC 2009, Satterthwaite et al. 2015a). Other marking/tagging system proposals have also been proposed that may produce benefits when compared with the current marking/tagging programs in California.

In June 2009, the National Marine Fisheries Service (NMFS) West Coast Regional Office[3], the California Department of Fish and Wildlife (CDFW), and the U.S. Fish and Wildlife Service (USFWS) jointly requested that the NMFS Southwest Fisheries Science Center (SWFSC) lead a scientific workgroup to thoroughly evaluate the costs, benefits, and risks of alternative marking/tagging systems for fall-run Chinook salmon, including the current marking/tagging (ADC+CWT) system, and the potential implications of mark-selective fisheries: "We request that the evaluation include, in particular, the implications of adopting MM/MSF in California for Chinook salmon harvest levels, protection of natural

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[1] A complete list of all acronyms used in this report is provided in Appendix A.
[2] Largely in response to legislation introduced by U.S. Representative Norm Dicks (see Section 4).
[3] The Southwest Regional Office merged with the Northwest Regional Office in 2013 to form the West Coast Regional Office. The original request came from the Southwest Regional Office.

and ESA-listed salmon, and addressing hatchery introgression" (NMFS CDFW USFWS 2009). The SWFSC accepted the request and charged the director of the Fisheries Ecology Division with organizing and executing the process. A Steering Committee was formed of designees from the requesting agencies and the American Fisheries Society (Churchill Grimes, NMFS-SWFSC; Tommy Williams, NMFS-SWFSC; Alice Low, CDFW; Jim Smith, USFWS; and Don Jackson, AFS). This Steering Committee developed a Terms of Reference for the scientific workgroup (WG), and selected a broad range of fishery scientists to serve on the WG. Scientists with specific knowledge of CV and KT salmon populations, salmon fishery assessment and management, freshwater and marine ecology of salmonids, and/or hatchery operations were selected from federal agencies (NMFS, USFWS, USFS), CDFW, academic institutions, tribal fisheries agencies, and private consultant groups (Table 1).

Table 1. Workgroup membership.

Member	*Affiliation*
Dr. Peter Bisson	U.S. Forest Service
Dr. Donald Campton	U.S. Fish and Wildlife Service
Mr. Scott Hamelberg	U.S. Fish and Wildlife Service
Dr. David Hankin	Humboldt State University
Mr. Dave Hillemeier	Yurok Tribal Fisheries
Dr. Steven Lindley	NMFS Southwest Fisheries Science Center
Ms. Alice Low	California Department of Fish and Wildlife
Mr. Michael Mohr (Chair)	NMFS Southwest Fisheries Science Center
Ms. Melodie Palmer-Zwahlen	California Department of Fish and Wildlife
Mr. James Smith	U.S. Fish and Wildlife Service

Note: Mr. Bradley Cavallo, Cramer Fish Sciences, was originally a member of the WG. He resigned from the WG on 15 April 2011. Dr. William Satterthwaite, NMFS Southwest Fisheries Science Center, was invited by the Chair in September 2016 to assist in bringing the report to completion.

This report provides a fairly detailed historical account of the use of marking/tagging in support of West Coast salmon management, and identifies the current and likely future needs to be addressed by a marking/tagging system. It then provides a qualitative assessment of the ability of the 11 different marking/tagging systems examined to meet certain specific needs regarding the conservation of CV and KT fall-run Chinook salmon, the conservation of certain other salmon stocks, and the management of salmon fisheries and hatcheries. The report concludes with a narrative description of the 11 marking/tagging systems examined. It describes a) what new capabilities each system would (or would not) support,, b) what marking/tagging and other related hatchery protocols would be needed to implement each system, c) what changes to the existing tag-recovery programs (including escapement surveys) would be required for each system, and d) what new infrastructure and/or personnel might be needed for each system.

2 Report goals

The WG's overall charge was to provide a technical evaluation of the attributes of various alternative marking/tagging systems and their potential value for conservation of CV and KT fall-run Chinook salmon, for conservation of other stocks such as Sacramento River (SR) winter-run Chinook salmon, for assessment and management of salmon fisheries, and for management of salmon hatcheries and other related programs. Six distinct marking/tagging systems were initially identified for evaluation and, following discussions at the first workshop meeting in November 2009, it became evident that five additional marking/tagging systems required evaluation. Because constant fractional marking (CFM) has been adopted by all CV and KT hatchery fall-run Chinook salmon programs, the WG was not asked to evaluate marking/tagging systems that proposed variable marking/tagging or an option that called for neither marking nor tagging.

For these hatchery marking/tagging systems, we define the term *mark* to mean an externally visible identifier of a hatchery-origin fish, and the term *tag* to mean an internal identifier of a hatchery-origin fish and/or its hatchery-of-origin and age. All of the marking/tagging systems evaluated use an adipose fin clip as the main external mark, although some options consider the use of electronic tag detection (ETD) without tag reading as an alternate means of externally identifying a hatchery-origin fish; and for the tag use either a CWT, an agency wire tag (AWT), and/or a genetic parentage-based tag (PBT). An agency wire tag is physically identical to a CWT except that the only information contained on the tag is the number of the agency that released the fish (Nandor et al. 2010, NMT 2012). An AWT can be used, for example, to identify a hatchery-origin fish. Parental-based tagging is a scheme in which all fish spawned (parents) at a hatchery are genotyped. Fish in subsequent generations returning to a hatchery, to natural spawning areas, or captured in fisheries are sampled and genotyped, and genetic parentage analysis is used to identify the specific parents of a sampled individual, provided the parents were among those spawned and genotyped at a hatchery (Anderson and Garza 2005, 2006). The complete set of alternative marking/tagging systems to be evaluated is presented in Table 2.

A brief overview of these marking/tagging systems follows. System 1 is CFM, the current marking/tagging program for fall-run Chinook salmon at CV and KT hatcheries. Systems 2 and 3 extend CFM by tagging all unmarked hatchery-produced fish with CWT or AWT, respectively, which allows for real-time (electronic) detection of all hatchery-origin fish. With System 2, CWT extraction and decoding from unmarked fish would also provide hatchery-of-origin and age of individuals. System 4 is like System 2 with PBT replacing CWT, except that unmarked hatchery-origin fish would not be detectable in real-time. System 5 is CFM+PBT which is most analogous to System 2 in terms of derivable information content, the difference being that unmarked hatchery-origin fish would not be detectable in real-time.

Table 2. Summary of marking/tagging systems examined. ADC denotes adipose fin clip; CWT denotes coded wire tag; AWT denotes agency wire tag; PBT denotes parental-based tag and 100% under PBT indicates that all parental broodstock are genotyped; MSF denotes mark-selective fisheries; F denotes a fraction (0<F<1) in a (constant) fractional marking and/or tagging scheme; 1-F denotes the remaining fraction of fish; "yes" indicates MSF would be associated with the marking/tagging system. If a system specifies F for ADC and CWT, it refers to the same group of fish. System 1 represents the current marking/tagging system for fall-run Chinook salmon at CV and KT hatcheries; System 6 is a typical system for MM & MSF, although in Washington the fraction receiving CWT may not be constant. Systems 1–5 are fractional ADC-marking, whereas Systems 6–11 are 100% ADC-marking. Systems 9–11 are the mass marking analogue to Systems 1, 2, and 4, respectively, and when coupled with MSF result in Systems 6–8, respectively. Systems 1, 2, 4, 6, 7, and 8 were initially presented for assessment; Systems 3, 5, 9, 10 and 11 were added following WG / Steering Committee discussions.

	Marking/tagging systems				
System	ADC	CWT	AWT	PBT	MSF
1	F	F			
2	F	100%			
3	F	F	1-F		
4	F			100%	
5	F	F		100%	
6	100%	F			yes
7	100%	100%			yes
8	100%			100%	yes
9	100%	F			
10	100%	100%			
11	100%			100%	

Systems 6–11 all include mass marking, and thus allow for real-time (visual) detection of all hatchery-origin fish. Systems 6–8 include mark-selective fisheries[4], otherwise they are equivalent to Systems 9–11, respectively. Systems 6 and 9 include fractional CWT, and are thus analogous to System 3 in terms of derivable information content and allowing for real-time identification of all hatchery-origin fish. Systems 7 and 10 include 100% CWT and are thus analogous to System 2 for these same reasons. Systems 8 and 11 are like Systems 7 and 10, respectively, with PBT replacing CWT, and are thus also analogous to System 2 for these same reasons.

The WG was asked to evaluate the benefits and risks of alternative marking/tagging systems with respect to the specific needs or concerns identified in Table 3 below (which has been supplemented by identification of further issues to consider). The WG made good progress on this assessment, contributing to the development of the findings reported in Section 7. The WG was also asked to evaluate the implementation costs of each of the marking/tagging systems, including the costs of the marking/tagging programs themselves, the costs of the associated fishery (ocean and river) surveys and spawner

[4] MSF itself is neither a form of marking or tagging, but for presentation convenience we label the designated type of marking and tagging in combination with the presence or absence of MSF as a "marking/tagging system".

Table 3. List of subject areas and criteria evaluated. HO denotes hatchery-origin; NO natural-origin. Fishery mortality rate (E-rate) is defined as rate of death due to landed and non-landed (e.g., hook-and-release) mortalities.

Criterion	*Definition*
Conservation of CV and KT fall-run Chinook salmon	
• Manipulate proportion HO in real-time	Ability to manipulate proportion of HO fish in natural spawning areas in real-time
• Restrict out-of-basin HO in real-time	Ability to restrict out-of-basin HO fish from natural spawning areas in real-time
• Estimate proportion HO	Ability to estimate proportion of hatchery-origin fish in natural spawning areas
• Estimate proportion out-of-basin HO	Ability to estimate proportion of out-of-basin hatchery-origin fish in natural spawning areas
• Estimate NO production	Ability to estimate natural-origin production (i.e., reconstructed pre-harvest ocean abundance of natural-origin fish)
• Achieve NO E-rate	Ability to achieve desired fishery mortality rate on natural-origin CV or KT fall-run Chinook salmon
Conservation of other salmon stocks	
• Restrict fall HO from spring spawning areas in real-time	Ability to restrict hatchery-origin fall-run Chinook salmon from entering CV and KT spring-run Chinook salmon spawning areas in real-time
• Compatible with other HO CWT studies	Compatibility with CWT tagging studies of other hatchery-origin indicators for stocks of concern (e.g., Livingston Stone National Fish Hatchery [LSNFH])
• Compatible with NO CWT studies	Compatibility with CWT tagging studies of natural-origin stocks
• Achieve non-fall E-rates	Ability to achieve desired fishery mortality rates on stocks other than CV or KT fall-run Chinook salmon
Management of salmon fisheries	
• Estimate/forecast HO E-rates, age x fishery	Ability to estimate/forecast age- and fishery-specific mortality rates on hatchery-origin CV fall-run (and potentially spring-run), SR winter-run, and KT fall-run (and potentially spring-run) Chinook salmon
• Estimate/forecast unmarked E-rates, age x fishery	Ability to estimate/forecast age- and fishery-specific mortality rates on unmarked fish (including natural-origin fish)
• Estimate NO & HO escapement at age	Ability to estimate natural-origin and hatchery-origin age-specific spawning escapement of specific stocks
• Compatible with existing CWT system	Compatibility with existing coast-wide CWT-based management system
• Support increased opportunity/harvest	Ability to support increased fishing opportunity and harvest
Management of salmon hatcheries	
• Manipulate proportion NO in hatchery matings	Ability to manipulate proportion of natural-origin fish used in hatchery matings
• Eliminate out-of-basin HO in hatchery matings	Ability to eliminate out-of-basin hatchery-origin fish in hatchery matings
• Assess performance of HO release groups	Ability to assess performance (survival and fishery contributions) of hatchery-origin release-groups

• Reduce over-escapement to hatcheries	Ability to reduce over-escapement to hatcheries
• Estimate hatchery-specific stray rates	Ability to estimate hatchery-specific stray rates
• Compatible with conservation hatcheries	Compatibility with operation and potential success of conservation hatcheries (e.g., LSNFH)
• Minimal changes to hatchery operations	Can be implemented without substantial changes in hatchery operations (e.g., without need for additional personnel, tagging equipment, etc.)

escapement (natural area and hatchery) surveys for mark/tag recovery, and the costs of equipment, personnel and infrastructure required to realize the possible benefits of each of the respective marking/tagging systems. The WG was unable to carry out a meaningful and timely assessment of the full costs of implementing the alternative marking/tagging systems, however, due to a very large number of uncertainties including at least: (1) unknown locations, designs and operations of segregation weirs, etc., that might be used to control the proportion of hatchery-origin fish in natural spawning areas if such devices were judged required or desirable, (2) the levels of precision with which various quantities (e.g., percent hatchery-origin [HO] in a natural spawning area) might need to be estimated and how these levels of precision depend not just on the marking/tagging system, but also on the extent of the associated freshwater mark/tag recovery programs and on the accuracy of the stream-specific estimates of spawning escapements, and (3) the projected costs of implementing PBT with regards to tag recovery in ocean and river fisheries and in spawning escapements (note however that some aspects of a PBT-CWT cost comparison are presented by Satterthwaite et al. 2015a and PSC CSC 2015), including the desired levels of precision for PBT-based estimates of harvests and spawning escapements of hatchery-origin fish, and the cost of developing a coast-wide PBT/genotype database to replace the coast-wide CWT database (RMIS). Therefore, our findings concerning the needs for new equipment, personnel, and infrastructure were limited to qualitative descriptions of the general needs associated with the respective marking/tagging systems, assuming their potential benefits were to be realized. These findings are reported in Section 8.

3 Workgroup process and subsequent report development

The WG's first meeting was a two-day workshop held at the NMFS SWFSC Fisheries Ecology Division in Santa Cruz, 2–3 November 2009, and this was followed by a public meeting held at the Moss Federal Building in Sacramento, 18 November 2009. The presentations received by the WG at these two events are listed in Table 4. Electronic copies of these presentations were provided to all members of the WG and are available from the WG Chair.

Table 4. Presentations received by the workgroup.

Speaker	*Affiliation*	*Date*	*Title / Brief Description*
Cavallo, Brad	Cramer Fish Sciences	2 Nov 2009	*A call for mass marking California salmon.* / Benefits from and needs for MM of hatchery-produced salmon.
Hankin, Dave	Humboldt State University	2 Nov 2009	*Report of the expert panel on the future of the coded wire tag recovery program for Pacific salmon.* / Serious negative impacts of MM & MSF on integrity and value of CWT tag-recovery system, especially regarding unmarked natural stocks of concern.
Low, Alice	California Department of Fish and Wildlife	2 Nov 2009	*Constant fractional marking program for fall-fun Chinook salmon in California.* / Description of recently implemented coordinated CFM program (approximately 25% ADC+CWT) at Central Valley salmon hatcheries.
Olson, Ron	Northwest Indian Fisheries Commission	2 Nov 2009	*Mass marking and electronic recovery of CWTs in the Pacific Northwest.* / Assessment of compliance, reliability, and cost of implementing electronic tag detection in response to the release of large numbers of hatchery-produced salmon with ADC but without CWT.
Palmer-Zwahlen, Melodie	California Department of Fish and Wildlife	2 Nov 2009	*California Ocean Salmon Project overview.* / Overview of current ocean fishery sampling, and calculation of hypothetical costs of increased staff and equipment needs were MM & MSF to be adopted in California.
Garza, John Carlos	NMFS Southwest Fisheries Science Center	2 Nov 2009	*Intergenerational genetic tagging for fishery management, hatchery evaluation, monitoring, and ecological investigation of salmonids.* / Description of PBT and its benefits relative to MM and CWT-based systems.
Lee, Dennis	Private Consultant	18 Nov 2009	*California's Central Valley steelhead fishery – a mark selective fishery.* / Review of California's implementation of MM & MSF for ESA-listed Central Valley steelhead.
Israel, Josh	University of California, Davis	18 Nov 2009	*Why fisheries management has become more complicated.* / Benefits and risks of marking and not marking. Argues that need to control numbers of hatchery-origin fish spawning in natural areas requires MM of hatchery-produced salmon.

Following the workshop and public meeting, several webinar work sessions were held by the WG and draft versions of this report were circulated for comment and approval by WG members. In addition, WG members were asked to develop cost data that might allow assessment of the potential costs of implementation of each of the alternative marking/tagging systems. As noted previously, this latter task proved to be a more ambitious and problematic undertaking than had been initially assumed, and little progress was made after more than 11 months' time. Therefore, on 1 February 2012, the WG Chair requested that the Steering Committee allow the WG to produce a report that provided an overall evaluation of the alternative marking/tagging systems, but that would not attempt to assess the costs of implementing these programs. Instead, new (relative to the existing CFM ADC+CWT system) infrastructure and/or personnel that would be needed to fully realize the potential benefits from the alternative marking/tagging systems would be briefly described in a narrative provided for each marking/tagging system.

Steering Committee approval for the preparation of a report without a cost assessment was given on 21 February 2012. The WG did not meet again after 2012, although the WG chair continued periodic work on the report with some input from other WG members. In September 2016, due to heightened interest on the part of the NMFS West Coast Regional Office and California Department of Fish and Wildlife, the WG Chair requested that Dr. William Satterthwaite (NMFS SWFSC) work on supplementing the report based on his experiences with a Pacific Salmon Commission (PSC)-funded project evaluating the potential for PBT-based systems to replace or supplement CWT-based systems, and to assist in bringing the report to completion. The completed report was then circulated among WG members for feedback and the option to join as coauthors. Feedback was received from all WG members. Although one WG member declined authorship, no objections to the report were raised.

4 History of marking/tagging for salmon management

Prior to the advent of the CWT in the early 1970s, researchers had relied principally on ocean tagging of adults or fin-clipping of juveniles to gain information about harvest patterns, ocean migrations, and possible stock composition in salmon fisheries. Fin clip studies of juveniles provided some information on patterns of exploitation of a few stocks, but marking, fishery sampling and reporting of recoveries were not coordinated across geographic and political boundaries and the number of fin clip combinations available was far too small to eliminate ambiguity in ocean recoveries of fish with a given fin clip or fin clip combination. Conventional fin-clipping technology did not provide the stock-, age-, and fishery-specific information needed by fishery managers.

Northwest Marine Technologies (NMT)[5] introduced the CWT in the early 1970s, providing a nearly limitless number of unique identifiable tag codes, and very rapidly leading to adoption of the CWT as the tag of choice in a highly coordinated coast-wide tag-recovery system[6]. Indeed, the 1985 Pacific Salmon Treaty (US and Canada) included an MOU specifically relating to the importance of the CWT

[5] Reference to trade names or manufacturers does not imply U. S. government endorsement of commercial products.
[6] CWTs are injected into the snout of juvenile fish. Recovery requires extracting the tag from the head, therefore recovery of tags requires only the heads of tagged fish.

which also motivated the highly coordinated coast-wide system: "The Parties agree to maintain a coded-wire tagging and recapture program designed to provide statistically reliable data for stock assessments and fishery evaluations." (PST 2013). The adipose fin clip was in 1977 *sequestered* as a fin clip that could be used only for purposes of identifying a fish that had been coded wire tagged. This greatly simplified the tag recovery process as field personnel could reliably assume that an ADC fish belonged to some CWT group released by some agency. Recoveries of CWTs in ocean and freshwater fisheries, in spawning escapements, and at hatcheries, allowed reconstruction of the fate of a cohort of fish throughout their life and soon generated some of the most critical information used for fishery management – stock-specific distributions of catch and stock-, age- and fishery-specific mortality rates. By 2004, more than 50 million CWT fish were released annually and more than 275,000 recoveries were made annually. In many cases, CWTs were applied to groups of hatchery fish that were assumed to be similar (juvenile migration timing and size, maturation schedule, ocean migration paths, run timing) to unmarked natural stocks of concern. Unmarked stocks of concern were assumed to share the fishery mortality rates of these *indicator* hatchery CWT release groups.

Among other things, CWT recovery data showed that many stocks of Chinook salmon were being seriously overharvested (fishery mortality rates were unsustainable) in ocean fisheries in the early 1980s. Fishery managers responded to these excess fishery mortality rates, and to legal rulings concerning sharing of allowable harvests between Tribal and non-Tribal users, by severely reducing levels of ocean fishing and by deliberately shifting fishery impacts away from the ocean and to terminal areas in those river systems or regions with recognized Tribal fishing rights (Olympic Peninsula, Puget Sound, Columbia River, Klamath River). Further reductions in ocean fisheries were required in some areas to protect stocks of concern that were listed under the U. S. Endangered Species Act (ESA) or the Canadian Species at Risk Act (SARA).

Faced with such severe curtailment of ocean fisheries, particularly in Washington, and by prohibition of directed take of natural-origin Oregon coastal coho salmon (*O. kisutch*, ESA-listed in 1998), mass marking (100% marking with ADC, but typically only a fraction receiving CWT) and mark-selective fisheries (in which only ADC fish may be retained) were first introduced for coho salmon off Oregon in 1998 and thereafter off Washington. The primary intention of mass marking was to provide fishing opportunities that might otherwise not be available and at the same time not exceed allowable fishery mortality rates on unmarked stocks of concern. The idea of MM & MSF was not new as California, Oregon and Washington had for many years marked all hatchery-produced steelhead (*O. mykiss*) with ADC (but without CWT) and adopted harvest regulations that were typically less restrictive for marked hatchery-origin fish than for unmarked natural-origin fish. Most recreational steelhead fishermen were well aware of the slogan: "If it's wild, let it go." It is important to note, however, that mark-selective ocean fisheries for Chinook salmon were only first adopted in Washington in 2010 (PFMC STT 2010) and remain of fairly limited extent, primarily due to concerns regarding accurate characterization of non-landed mortality on natural-origin stocks (Lawson and Sampson 1996, Yuen and Conrad 2010, Conrad et al. 2013).

For hatchery stocks which were 100% marked and subjected to mark-selective fisheries, however, it clearly could no longer be assumed that unmarked fish from stocks of concern experienced the same fishery mortality rates as the marked hatchery fish; i.e., marked hatchery stocks no longer served as appropriate indicators for unmarked stocks. Indeed, the express intent of MSF is to allow relatively high fishery mortality rates on hatchery stocks while at the same time not exceeding allowable fishery mortality rates on unmarked stocks of concern. Because recovery data generated from conventional CWT release groups could no longer generate direct estimates of fishery mortality rates on unmarked stocks, *double index tagging* (DIT) procedures were introduced as a potential method to circumvent this dilemma. In the DIT approach, two groups of fish are released at the same time and differ in only one respect: one group has ADC+CWT and the other has CWT-only. Theoretically, the fishery mortality rate on the DIT group with CWT-only should be the same as that on unmarked/untagged stocks for which the CWT-only DIT group would be a good indicator. Although the DIT approach has considerable conceptual appeal, there is little evidence that it is, in fact, a viable approach for estimation of fishery mortality rates on unmarked stocks of concern. In most cases, aggregate impacts of all MSF that might impact a stock can be estimated based on the ratio of marked versus unmarked members of DIT release groups in the escapement (PSC CTC 2014) but this does not yield the stratum-specific fishery mortality rates required by ocean harvest management models (Goldwasser et al. 2001, O'Farrell et al. 2012, Mohr and O'Farrell 2014). Methods have been proposed for more stratified estimates, but are highly uncertain (Zhou 2002) and/or over-parameterized without numerous simplifying assumptions (PSC 2005). Recent work confirms that these challenges to estimating MSF mortality rates remain (PSC SFEC 2016). Thus while the DIT concept might allow evaluation of the impacts of MSF in a single-stratum, terminal fishery, it would not allow for ocean harvest management based on time-, area-, and sector-specific effort controls or quotas as are currently practiced off California and Oregon.

Even if these estimation challenges could be overcome, the degree to which fishing opportunity and harvest might be increased under MSF management is difficult to gauge with any degree of confidence as it depends on a large number of variables, but it would likely vary substantially across years (Pyper et al. 2012). MSF is most effective at increasing harvest opportunity if marked fish make up a large proportion of fish encountered in fisheries (Lawson and Comstock 1995, Lawson and Sampson 1996), but this runs counter to the conservation goals of increasing natural-origin fish abundance while reducing the effects of hatchery-origin fish on natural spawning populations. Similarly, MSF are unlikely to reduce impacts on listed stocks under the current management framework, since there is no incentive to reduce impacts on such stocks below the maximum allowable level (PFMC 2016).

MSF pose the additional challenge that it would be inadvisable to use ADC to mark ESA-listed stocks because they might be specifically targeted in MSF. This could complicate natural stock tagging programs. For example, Livingstone Stone National Fish Hatchery (LSNFH) might discontinue use of ADC for SR winter-run Chinook salmon, which would greatly complicate the recovery of winter-run Chinook salmon CWTs (requiring representative sampling of unmarked fish and ETD in all sampling strata where winter-run Chinook salmon might be recovered) and require the use of ETD to exclude hatchery-origin broodstock. In addition, unmarked DIT fish would violate the assumption that all hatchery-origin fish are marked.

MM & MSF pose additional complications of a more practical nature. Because most MM fish are typically released without CWT, conventional ocean and freshwater recovery sampling programs must be modified by introduction of electronic detection devices (e.g., NMT wands, troughs, and tunnel detectors, NMT 2012) and hatcheries must invest in automated technologies (e.g., NMT AutoFish marking/tagging trailers, NMT 2012) so that 100% marking can be feasibly achieved within the relatively short period of time prior to release when juvenile Chinook salmon are large enough to be tagged using automated technologies. As noted by the PSC (2005) and in Ron Olson's presentation to the WG, electronic detection has not been adopted by all fisheries agencies charged with generating CWT recovery data. As a consequence, CWT recoveries from DIT groups have not been consistently collected. Despite these important issues surrounding MM & MSF, in 2003 MM became an essentially required activity at federally-funded hatcheries in Washington, Oregon, and Idaho[7] releasing coho salmon, Chinook salmon, or steelhead via legislation introduced by U.S. Congressional representative Norm Dicks (D-Washington) in an Interior Appropriations bill: "The United States Fish and Wildlife Service shall, in carrying out its responsibilities to protect threatened and endangered species of salmon, implement a system of mass marking of salmonid stocks, intended for harvest, that are released from Federally operated or Federally financed hatcheries including but not limited to fish releases of coho, chinook, and steelhead species. Marked fish must have a visible mark that can be readily identified by commercial and recreational fishers."

As documented in Ron Olson's presentation, about 90% of the total annual hatchery coho salmon released throughout the Pacific Northwest (southern British Columbia, Washington, Oregon) are now mass marked with ADC. In Washington and Oregon, about 70% of the approximately 140 million hatchery Chinook salmon released annually are now mass marked with ADC. Representative groups are

[7] Congress has not funded MM In California. Consequently, USFWS believes that the MM requirement at federally-funded hatcheries does not apply to California.

also tagged (CWT). In California's Central Valley, hatchery release groups of winter-run, spring-run, and late fall-run Chinook salmon are 100% ADC+CWT for monitoring and broodstock management purposes. Experimental release groups of fall-run Chinook salmon are also 100% ADC+CWT. For large production release groups of fall-run Chinook salmon from hatcheries in California's CV and KT, fish are 25% ADC+CWT as part of the CFM Program (Alice Low's presentation). The CFM program is designed to provide reliable estimates of contribution rates of hatchery fish to fall-run Chinook salmon populations, to allow evaluation of the propagation program's genetic and ecological effects on natural Chinook salmon populations, to allow estimation of exploitation rates of hatchery and natural CV Chinook salmon in ocean and river fisheries, and to allow assessment of the success of restoration actions designed to increase natural production. Throughout California, CWT recovery does not require electronic detection because all CWT fish are marked (ADC). California's CFM programs have not been designed to support mark-selective fisheries.

Beginning in the early 2000s, increasing numbers of studies, relying on use of genetic technologies, have provided compelling evidence, primarily for steelhead, that reproductive performance of hatchery-origin fish that stray to natural spawning areas may be less than that of natural-origin fish and that reproductive performance of hatchery x natural matings may be intermediate to hatchery x hatchery and natural x natural matings (Araki et al. 2008, Araki et al. 2007, 2009, Williamson et al. 2010, Chilcote et al. 2011). About the same time, the Hatchery Scientific Review Group (HSRG) in Washington (HSRG 2004) developed new criteria for hatchery operations that distinguished between *segregated* and *integrated* hatchery and natural populations. In *segregated hatchery populations*, the goal is to manage hatchery fish as a distinct population (gene pool) separate from a natural population (two gene pools). Any natural area spawning by hatchery-origin fish is considered high risk because they are managed as a separate stock. In *integrated hatchery populations***,** the goal is to manage hatchery fish as an artificially produced component of a natural population (one gene pool) where natural selection associated with the natural environment and natural reproduction has a greater genetic influence on the population than does domestication selection and artificial propagation in the hatchery environment. The integrated approach requires the systematic inclusion of natural-origin fish into the hatchery broodstock, but does not require natural area spawning by hatchery fish. For integrated hatchery operations, the HSRG (2004) proposed guidelines for the percentage of hatchery brood stock that should consist of natural-origin adults and for the percentage of hatchery-origin fish that should be allowed to spawn in natural areas. More recently, the California HSRG (2012) recommended that all California hatchery programs be of the integrated type because it was impossible to ensure that some returning adults from segregated hatchery programs would not spawn in natural areas where they would pose risks. Although CFM programs allow for estimation of these percentages, deliberate manipulation of fish to ensure that desired percentages are achieved, at hatcheries and in natural spawning areas, requires real-time identification (visual or electronic) of all[8] hatchery-origin fish, at locations such as weirs or other facilities that could allow control of hatchery-origin fish migrating into natural spawning areas.

Advances in genetic technologies have also led to proposals to use parentage-based tagging (PBT) as an alternative to CWT. PBT involves genotyping parental broodstock (typically in a hatchery setting) and then assigning fish genotyped during later sampling events back to their parent pair and thus, given proper separation and tracking of offspring throughout hatchery rearing, back to the release group of origin. Because genotyping a single pair of parents effectively tags thousands of offspring, PBT is a very cost-effective means of deploying tags (Satterthwaite et al. 2015a), however this cost savings at one stage must be considered in the context of an overall marking, tagging, and sampling scheme. Unless tagged fish are also marked (e.g., via ADC), recovering genetic tags would also require the genotyping of many fish whose parents would not be known (although the genetically defined stock or stock-group of origin could still be determined for such fish through genetic stock identification, GSI). At 2015 genotyping costs, a coastwide system for PBT is estimated to be more expensive than one based on CWT (Satterthwaite et al. 2015a). Thus, the PSC's Committee on Scientific Cooperation (PSC CSC 2015) found that a coastwide PBT-based system was not currently cost-competitive with CWT, especially after accounting for transitional costs, but recommended that this comparison be updated periodically as genotyping costs are expected to decline. Additionally, much of the cost disadvantage for PBT in coastwide scenarios is the great expense of applying PBT to natural-origin indicator stocks used in the PSC management process. Since natural-origin indicator stocks are not currently used in California, the cost comparison would likely be more favorable if restricted to California. However, ocean recovery data must be shared among regions (e.g., CV and KT fall-run fish are harvested in significant numbers off Oregon), and so it is important that marking, tagging, and sampling practices be compatible across regions.

Satterthwaite et al. (2015a) noted the potential for additional alternative marks (e.g., ventral fin clips) to allow for more cost-effective sampling in either a PBT-based or CWT-based marking, tagging, and sampling regime. However, the PSC CSC (2015) deemed near-term adoption of any alternative mark unlikely, so we do not explore alternative marks further in this report.

[8] With CFM some reduction in the proportion hatchery-origin would be possible by culling marked fish, (assuming large numbers of marked natural-origin fish are not present) but this would only be a subset of all hatchery-origin fish present.

5 Current and future requirements for marking/tagging

5.1 Present – required now

Current management uses of marked/tagged CV and KT fall-run Chinook salmon include providing the required inputs for harvest management models, evaluating the performance of these models, and quantifying hatchery- versus natural-origin contributions to harvest and escapement. Sampling of marked and tagged fish also enables ecological investigations, including comparisons among individual release groups or treatments applied to hatchery fish differing in key aspects of their rearing or release strategy, and hatchery evaluations of program and release group performance.

Current fishery management in California requires assessment of the demographic performance of, and fishery impacts on, hatchery-origin fish (PFMC 2016). Stock-specific exploitation rate limits are developed based on forecasts or other information about the abundance of key stocks and then fishing seasons (consisting primarily of time-area constraints, minimum size-limits, and some quotas in northern California) are constructed which are expected to remain within these limits based on the outputs of models relying on CWT data (Goldwasser et al. 2001, O'Farrell et al. 2012, Mohr and O'Farrell 2014).

Current recoveries of CWT are regarded as sufficient for parameterizing the models used for harvest management of CV and KT fall-run Chinook salmon, although concerns have been raised about the limited number of SR winter-run Chinook salmon tag recoveries (PFMC SSC 2015). Because the mark-selective ocean fisheries conducted off Washington and Oregon have thus far largely been limited to coho salmon, MM & MSF have not yet substantively impacted the integrity of CWT recovery data for California hatchery-produced Chinook salmon (but see Kormos et al. 2012 for apparent evidence of increased proportions of ADC Chinook salmon found without CWT in 2010 California ocean fishery sampling). If in the future mark-selective ocean fisheries for Chinook salmon are expanded off Washington, this too would not seriously compromise the integrity of CWT recovery data for California Chinook salmon because these stocks are distributed primarily south of Cape Falcon, Oregon. The current level of tag recoveries appears sufficient to support increased stratification of CV fall-run Chinook salmon management models if desired, but not KT fall-run Chinook salmon (PFMC SSC 2015), because the new strata would be would not be expected to meet a goal of 10 tag recoveries per age/stratum sufficiently often.

The suitability of these models for ocean harvest management partially relies on the assumption that ocean exploitation rates for hatchery-origin fish also apply to untagged natural-origin fish of the same origin and run timing. This assumption has not been fully tested (PSC 2005, PSC CWTW 2008), however numerous lines of evidence suggest similarity in ocean distribution of appropriately paired natural- and hatchery-origin fish (e.g., Weitkamp and Neely 2002, Weitkamp 2010, Sharma and Quinn 2012, Satterthwaite et al. 2015b), although other factors may also affect exposure to the fishery.

The CFM programs (25% ADC+CWT) also allow for routine estimation of the proportion of hatchery-origin fish in ocean and river harvest, hatchery returns, and natural-area escapement along with the contribution of individual hatchery programs (Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, 2015). Although initial planning of the CV CFM program identified an optimal mark/tagging rate of 33% (Hicks et al. 2005), subsequent review of these recommendations and consultations with salmon managers elsewhere led to the adoption of a 25% rate (Palmer-Zwahlen and Kormos 2015).

CV and KT hatcheries typically produce several types of fall-run Chinook salmon, including fingerlings, yearlings, and various kinds of experimental/treatment groups. At a given hatchery, for each type, there typically are several groups of fish released (e.g., grouped by size or age), and often these groups are released on separate dates over an extended period, typically with some fraction of each group receiving ADC+CWT. The performances of, and fishery mortality rates on, these different type/group combinations often vary dramatically, and it is critically important that a marking/tagging system allow for performance and fishery mortality rate assessment at the type/group level. The current CFM program allows for this, with each tagged fish receiving a CWT implant that identifies its hatchery/year/type/group. Thus unique CWT codes associated with individual hatchery release groups have allowed management-relevant research including comparisons of survival and maturation rates of fingerling versus yearling release groups (Hankin and Logan 2010), comparing straying and recovery rates for fish released at different locations (Kormos et al. 2012, Palmer-Zwahlen and Kormos 2013, 2015), and investigating the effects of release timing on survival (Satterthwaite et al. 2014).

5.2 Near future (2–10 years) – likely additional requirements

Although compelling evidence of negative impacts of hatchery-origin fish on reproductive performance is not yet available for fall-run Chinook salmon (but see Williamson et al. 2010 re. spring-run Chinook salmon), there is good reason to believe that results from recent studies of the reproductive performance of natural- and hatchery-origin steelhead should apply generally to Chinook salmon as well. If so, then it is reasonable to assume that it will become necessary to be able to identify hatchery-origin fish in real-time as they encounter weirs en route to natural spawning areas (to minimize spawning of hatchery-origin fish in natural spawning areas), where such weirs exist, and at hatcheries to ensure that natural-origin fish are incorporated into hatchery matings for integrated hatchery programs. Although an adipose fin clip (visual detection) could be used for this purpose, a CWT or AWT (electronic detection) could be used as well. Radio-frequency identification (RFID) tags may also become a cost-effective option in the near future (PSC CSC 2015). Continuing research on PBT, coupled with increasingly rapid throughput of genotyping, may enable its use to ensure inclusion of natural-origin fish in hatchery broodstock, although it is unlikely that PBT (without accompanying marks or physical tags) could be used for real-time identification of hatchery-origin fish.

If there are to be serious efforts to control the proportions of hatchery- and natural-origin fish in both natural spawning areas and hatcheries, then considerable new infrastructure (e.g., weirs) will be required to allow physical capture, identification, diversion[9], and mating of hatchery- and/or natural-origin fish, and presumably an associated increase in personnel required to operate these infrastructure assets and programs.

5.3 Near future (2–10 years) – possible additional requirements

Continuing poor performance of SR fall-run Chinook salmon, increased efforts to conserve remaining natural stocks of concern in California, and associated further curtailment of fishing opportunities for Chinook salmon, could together build support for MM & MSF in California ocean and/or river fisheries. Implementation of 100% ADC-marking at all CV and KT hatcheries would require substantial investments in new tagging equipment, in recovery technologies needed to identify marked hatchery-origin fish that are also tagged with CWT (unless 100% CWT), and in personnel needed to sample ocean and river fisheries and spawning escapements. If mark-selective fisheries were implemented, they would need to be structured to have minimal impact on the integrity of the existing CWT program and its use for management of natural stocks of concern, and have little or no impact on the current ADC+CWT marking programs used to support restoration of SR winter-run Chinook salmon or on any other natural-origin tagging programs that currently rely on ADC+CWT.

Although the ADC mark may be the most obvious choice to permit visual identification of hatchery-origin fish in mark-selective fisheries, other identifying fin clips might also be considered for this purpose. However, despite considerable interest over a long period of time (PSC 2005, Satterthwaite et al. 2015a), no suitable alternative mark has yet been proposed for widespread adoption due to concerns over mark-induced mortality, potential for errors recognizing marks at recovery, and suspected difficulties in developing automated procedures for applying asymmetric marks (PSC CSC 2015).

6 Evaluation of marking/tagging systems: assumptions and uncertainties

In the evaluation, we assume that the intent would be to realize the full benefits of new capabilities yielded by any given marking/tagging system. Thus, we assume willingness and ability to pay for the construction, maintenance, and operation of weirs to exclude hatchery-origin fish from select spawning areas for systems that could in theory provide this capability. We also assume willingness and ability to

[9] Electronic detection of hatchery-origin fish might also allow for electronically-activated diversion/routing devices.

pay for the establishment of hatchery infrastructure and record-keeping processes that would allow for post-hoc culling of eggs produced by undesirable matings. Further, we assume hatcheries would be willing and able to pay for increased marking and/or tagging costs; and for options based on PBT we assume willingness and ability to pay for genotyping costs and the infrastructure required to maintain discrete release groups based on distinct sets of parents.

Reflecting the basis for current harvest management models, we assume that exploitation rates calculated for carefully chosen hatchery-origin indicator stocks also apply to similar natural-origin stocks, unless regulations are in place which would cause unmarked fish to be treated differently from marked fish (i.e., MSF). For marking/tagging systems which would be associated with MSF, we assume that the DIT concept could be relied upon to generate meaningful estimates of total fishery mortality rates on unmarked fish subjected to MSF, although we recognize that DIT could not generate estimates of fishery mortality rates at the age-, month-, area-, and sector-specific level that is currently needed for fisheries management purposes (PSC 2005).

For tagging systems relying on PBT, we assume that progeny from different groups of matings are tracked and segregated throughout hatchery rearing from the time of spawning to the time of release. Identification of release groups among hatchery-origin fish using PBT requires that a specific parent-pair contribute offspring to one and only one release group (which might otherwise confound the effects of experimental treatment with parental genotype), and that the parent genotypes of each release group are known. The latter two requirements together enable release group identification of recovered hatchery-origin PBT fish. The hatchery infrastructure requirements for individual release groups using PBT are described in more detail elsewhere (e.g., Satterthwaite et al. 2015a) and we assume that these challenges can be met. Note that, with PBT, the fish comprising a release group must be designated as such from the beginning, reared and released in the same fashion, and released as a single group. This precludes last minute creation of new release groups in response to unanticipated needs.

For systems where some unmarked fish receive CWT or AWT, we assume widespread adoption of ETD in all relevant sampling strata and that ETD is reliable and effective. In systems where some fish are marked but not tagged, we assume adoption of ETD rather than collection of heads from all marked fish, tagged or not, based on practices adopted in the Pacific Northwest.

We note that some of the proposed systems would substantially increase the costs of existing sampling programs. We assume that the costs of ETD to avoid the processing of marked but untagged fish could and would be borne by existing sampling programs, based on largely successful adoption of ETD in the Pacific Northwest (PSC SFEC 2016). However, under some systems the number of tags recovered could increase almost four-fold. We note major concern about the willingness and ability of existing sampling programs to accept this increased cost, deeming it highly likely that sampling rates would be decreased in response. However, we lacked adequate information on fixed versus variable costs of sampling programs, and relevant policy drivers, to generate a defensible assumption for an alternative sampling rate.

We also note major concerns regarding the costs associated with a genetic sampling program required if PBT replaces CWT. Per-fish genotyping costs are higher than per-fish CWT recovery costs (Satterthwaite et al. 2015a). Although these costs may be largely offset by reduced costs of tagging (Satterthwaite et al. 2015a), it is highly uncertain whether the savings at one stage could be passed on to pay for increased costs at another, because sampling versus tagging costs may be paid by different agencies or out of different budgets. In addition, maintaining the ocean harvest data stream using PBT requires tissue sampling of ocean fishery landings in Oregon (south of Cape Falcon) as well as California, which cannot be assured based on changes in California marking/tagging practices alone. Thus we deem it highly uncertain whether coastwide genetic sampling of the harvest of CV and KT fall-run Chinook salmon is possible. There are multiple Oregon stocks managed under the Pacific salmon treaty, and so Oregon must maintain marking, tagging, and sampling programs compatible with areas further north. A centralized database for genetic tag recoveries similar to RMIS would be required, but no such database currently exists. We also note major uncertainty in the willingness and ability of agencies to pay for parallel sampling programs that could recover both PBT and CWT.

7 Ability of marking/tagging systems to meet identified criteria

In this section we provide tables that summarize a qualitative assessment of the degree to which each of the proposed marking/tagging systems meets the criteria stated in Table 3 under the topics of "*Conservation of CV and KT fall-run Chinook salmon*" (Table 5), "*Conservation of other salmon stocks*" (Table 6), "*Management of salmon fisheries*" (Table 7), and "*Management of salmon hatcheries*" (Table 8). For each criterion, the qualitative ratings were assigned as follows:

Rating	*Definition*
+	System fully meets criterion under Section 6 assumptions.
≈	System partially meets criterion, meets it only under substantially increased sampling costs deemed unlikely in Section 6, and/or meets criterion at substantially higher costs than another system receiving a "+" for the same criterion.
–	System clearly does not meet criterion.
?	Unclear if system would meet criterion, since it would depend on unproven technologies and/or the development of new models.

We provide the rationale and/or qualification of these ratings in footnoted tables provided in Appendix B. We have rephrased some of the needs or impacts from the original terms of reference so that the scale of qualitative assessment is essentially the same for all criteria (i.e., "+" always indicates favorable assessment whereas "–" always indicates unfavorable assessment). This allows readers to scan tables quickly to determine which marking/tagging systems generally have the greatest proportion of "+" entries as compared to "–" entries, or to examine specific criteria that are of special interest or may be regarded as essential requirements for salmon fishery management.

Table 5. Conservation of CV and KT fall-run Chinook salmon. Qualitative assessment of degree to which proposed marking/tagging systems can meet criteria. Marking/tagging systems: ADC denotes adipose fin clip; CWT denotes coded wire tag; AWT denotes agency wire tag; PBT denotes parental-based tag; MSF denotes mark-selective fisheries; F denotes a fraction (0<F<1) in a (constant) fractional marking and/or tagging scheme; 1-F denotes the remaining fraction of fish; "yes" indicates that MSF would be associated with the marking/tagging system. If a system specifies F for ADC and CWT, it refers to the same group of fish. Criteria are defined in Table 3; "HO" denotes "hatchery-origin"; "NO" denotes "natural-origin"; "E-rate" denotes "fishery mortality rate"; "+" denotes "clearly meets criterion"; "≈" denotes "partially meets the criterion, or requires a major increase in costs compared to other fully capable systems"; "–" denotes "clearly does not meet criterion"; "?" denotes "unclear if would meet criterion".

Marking/tagging system						Criterion					
System	ADC	CWT	AWT	PBT	MSF	Manipulate proportion HO in real-time	Restrict out-of-basin HO in real-time	Estimate proportion HO	Est. prop. out-of-basin HO	Est. NO production	Achieve NO E-rate
1	F	F				–	–	+	+	+	+
2	F	100%				+	–	+	+	+	+
3	F	F	1-F			+	–	+	+	+	+
4	F			100%		–	–	+	+	?	?
5	F	F		100%		–	–	+	+	+	+
6	100%	F			yes	+	–	+	+	–	?
7	100%	100%			yes	+	–	+	+	–	?
8	100%			100%	yes	+	–	+	+	–	?
9	100%	F				+	–	+	+	+	+
10	100%	100%				+	–	+	+	+	+
11	100%			100%		+	–	+	+	?	?

Table 6. Conservation of other salmon stocks. Qualitative assessment of degree to which proposed marking/tagging systems can meet criteria. Marking/tagging systems: ADC denotes adipose fin clip; CWT denotes coded wire tag; AWT denotes agency wire tag; PBT denotes parental-based tag; MSF denotes mark-selective fisheries; F denotes a fraction (0<F<1) in a (constant) fractional marking and/or tagging scheme; 1-F denotes the remaining fraction of fish; "yes" indicates that MSF would be associated with the marking/tagging system. If a system specifies F for ADC and CWT, it refers to the same group of fish. Criteria are defined in Table 3; "HO" denotes "hatchery-origin"; "E-rates" denotes "fishery mortality rates"; "+" denotes "clearly meets criterion"; "≈" denotes "partially meets the criterion, or requires a major increase in costs compared to other fully capable systems"; "–" denotes "clearly does not meet criterion"; "?" denotes "unclear if would meet criterion".

Marking/tagging system						Criterion			
System	ADC	CWT	AWT	PBT	MSF	Restrict fall HO from spring spawning areas in real-time	Compatible with other HO CWT studies	Compatible with NO CWT studies	Achieve non-fall E-rates
1	F	F				–	+	+	+
2	F	100%				–	+	≈	+
3	F	F	1-F			–	+	≈	+
4	F			100%		–	?	?	?
5	F	F		100%		–	+	+	+
6	100%	F			yes	–	+	–	?
7	100%	100%			yes	–	≈	–	?
8	100%			100%	yes	–	?	–	?
9	100%	F				–	+	≈/+	+
10	100%	100%				–	≈	≈/+	≈
11	100%			100%		–	?	?	?

Table 7. Management of salmon fisheries. Qualitative assessment of degree to which proposed marking/tagging systems can meet criteria. Marking/tagging systems: ADC denotes adipose fin clip; CWT denotes coded wire tag; AWT denotes agency wire tag; PBT denotes parental-based tag; MSF denotes mark-selective fisheries; F denotes a fraction (0<F<1) in a (constant) fractional marking and/or tagging scheme; 1-F denotes the remaining fraction of fish; "yes" indicates that MSF would be associated with the marking/tagging system. If a system specifies F for ADC and CWT, it refers to the same group of fish. Criteria are defined in Table 3; "HO" denotes "hatchery-origin"; "NO" denotes "natural-origin"; "E-rates" denotes "fishery mortality rates"; "+" denotes "clearly meets criterion", "≈" denotes "partially meets the criterion, or requires a major increase in costs compared to other fully capable systems"; "–" denotes "clearly does not meet criterion"; "?" denotes "unclear if would meet criterion".

Marking/tagging system						Criterion				
System	ADC	CWT	AWT	PBT	MSF	Estimate/forecast HO E-rates, age x fishery	Estimate/forecast unmarked E-rates, age x fishery	Estimate NO & HO escapement at age	Compatible with existing CWT system	Support increased opportunity/harvest
1	F	F				+	+	+	+	–
2	F	100%				+	+	+	+	–
3	F	F	1-F			+	+	+	+	–
4	F			100%		?	?	?	–	–
5	F	F		100%		+	+	+	+	–
6	100%	F			yes	+	–	+	≈	?
7	100%	100%			yes	≈	–	+	≈	?
8	100%			100%	yes	?	–	+	–	?
9	100%	F				+	+	+	≈	–
10	100%	100%				≈	≈	+	≈	–
11	100%			100%		?	?	+	–	–

Table 8. Management of salmon hatcheries. Qualitative assessment of degree to which proposed marking/tagging systems can meet criteria. Marking/tagging systems: ADC denotes adipose fin clip; CWT denotes coded wire tag; AWT denotes agency wire tag; PBT denotes parental-based tag; MSF denotes mark-selective fisheries; F denotes a fraction (0<F<1) in a (constant) fractional marking and/or tagging scheme; 1-F denotes the remaining fraction of fish; "yes" indicates that MSF would be associated with the marking/tagging system. If a system specifies F for ADC and CWT, it refers to the same group of fish. Criteria are defined in Table 3; "HO" denotes "hatchery-origin"; "+" denotes "clearly meets criterion"; "≈" denotes "partially meets the criterion, or requires a major increase in costs compared to other fully capable systems"; "–" denotes "clearly does not meet criterion"; "?" denotes "unclear if would meet criterion".

Marking/tagging system						Criterion						
System	ADC	CWT	AWT	PBT	MSF	Manipulate proportion NO in hatchery matings	Eliminate out-of-basin HO in hatchery matings	Assess performance of HO release groups	Reduce over-escapement to hatcheries	Estimate hatchery-specific stray rates	Compatible with conserv. hatcheries	Minimal changes to hatchery operations
1	F	F				–	–	+	–	+	+	+
2	F	100%				+	+	+	–	+	+	–
3	F	F	1-F			+	–	+	–	+	+	–
4	F			100%		≈	+	?	–	+	+	–
5	F	F		100%		≈	+	+	–	+	+	–
6	100%	F			yes	+	–	+	?	+	–	–
7	100%	100%			yes	+	+	≈	?	+	–	–
8	100%			100%	yes	+	+	?	?	+	–	–
9	100%	F				+	–	+	–	+	+	–
10	100%	100%				+	+	≈	–	+	≈	–
11	100%			100%		+	+	?	–	+	≈	–

8 Implementation requirements for alternative marking/tagging systems

In this section we provide brief narrative summaries of the 11 marking/tagging systems with respect to the following issues: (a) What capabilities would the system support? (b) What marking/tagging and other related hatchery protocols would be needed? (c) What changes to existing tag-recovery programs (including escapement surveys) would be required? and (d) What new infrastructure and/or personnel might be needed? In all cases, we address these questions assuming that the intent would be to realize the full benefits of any given marking/tagging scheme, and that the assumptions in Section 6 are met.

8.1 System 1: CFM (fractional ADC+CWT)

8.1.1 What capabilities would the system support?

CFM is the status quo marking system for Chinook salmon at CV and KT hatcheries, although it is important to note that CFM was only recently adopted in the CV (2006 brood year) and at Iron Gate hatchery (2009 brood year). Adoption of the CFM system with 25% ADC+CWT (Hankin 1982, Kormos et al. 2012) throughout California reflects a relatively new consensus regarding the importance of coordinated and consistent hatchery marking/tagging programs, with special focus on the need for unbiased and accurate estimation of the proportion of hatchery-origin fish in natural spawning areas.

The current CFM system supports estimation of hatchery release group survival and associated fishery mortality and maturation rates that are essential for current fisheries management. It also allows for estimation of stray rates and the proportion of hatchery-origin fish in natural spawning areas and hatcheries, and is compatible with efforts to mark and tag natural-origin fish. CFM does not enable identification of all hatchery-origin fish and thus does not allow for the manipulation of hatchery- and natural-origin fish in natural spawning areas and hatcheries[10], or for the exclusion of out-of-basin hatchery-origin fish in hatchery matings.

Under the current CFM system, all fish with ADC can be assumed to contain CWT and vice versa. Thus, sample collection can be targeted toward only fish with ADC. While large production hatcheries mark and tag only a fraction of their released fish, smaller hatcheries, or individual release groups, can be marked and tagged at a higher rate to increase the probability of tag recovery from such groups. Targeting ADC fish in sampling programs therefore provides for enrichment of stocks (or release groups) that might otherwise have exceptionally low presence (encounter probability) in completely random samples of ocean and river catches (see PSC 2005).

[10] Strictly speaking, some reduction in the proportion hatchery-origin would be possible by culling marked fish (assuming no marked natural-origin fish are present) but this would only be a subset of all hatchery-origin fish present.

8.1.2 What marking/tagging and other related hatchery protocols would be needed?

Achieving the current CFM rate of 25% ADC+CWT requires the use of automated fish marking and tagging equipment at most facilities, and requires that ADC+CWT are applied to representative (random) 25% samples of fish reared and released in any specific way that may differ from other groups. Although there are important exceptions to this marking/tagging system (e.g., 100% of winter-run Chinook salmon reared at Livingstone Stone National Fish Hatchery are ADC+CWT), current hatchery mating and rearing protocols do not generally require that parents associated with particular matings are tracked through incubation and rearing; incubators are generally loaded with eggs from an unknown number of matings that are carried out on any particular day.

8.1.3 What changes to existing tag-recovery programs (including escapement surveys) would be required?

Existing ocean and river fishery sampling programs, and much of natural area escapement and hatchery return sampling programs are focused on fish that are ADC+CWT. In ocean fisheries sampling, the target is to sample a minimum 20% of the catch. Heads are collected for later extraction of CWTs from all heads collected from fish with adipose fin clips. Similar sampling takes place in freshwater, although there is greater variability in sampling rates. All fish returning to hatcheries are sampled for presence of CWT.

8.1.4 What new infrastructure and/or personnel might be needed?

No new infrastructure or personnel are associated with this status quo system. While this is the status quo system, substantial recent investments have already been made to implement this system. These investments have included increased costs for tagging, recovery of tags in freshwater, and purchase of fully automated tagging trailers.

8.2 System 2: Fractional ADC; 100% CWT

8.2.1 What capabilities would the system support?

This system would allow for real-time (electronic) identification of all hatchery-origin fish, thereby allowing for estimation of the proportion of hatchery-origin fish in natural spawning areas and hatcheries, for manipulation of hatchery- and natural-origin fish in natural spawning areas and hatcheries, and for post-hoc exclusion of out-of-basin hatchery-origin fish in hatchery matings (based on CWT decoding). This system would support estimation of hatchery release group survival and associated fishery mortality and maturation rates that are essential for current fisheries management. The California HSRG (2012) recommended that System 2 be adopted at all Chinook salmon hatcheries in the CV and KT that produce fish for mitigation/harvest purposes. This system would not be fully compatible with deploying CWT in natural-origin fish, or at least not in natural-origin fish likely to be recovered in sampling strata where real-time identification of hatchery-origin fish was desired, because tagging natural-origin fish would violate the assumption that all tagged fish are hatchery-origin.

8.2.2 What marking/tagging and other related hatchery protocols would be needed?

As the status quo CFM program requires that approximately 25% of all fall-run Chinook salmon in a hatchery release group receive ADC+CWT, System 2 would require increased equipment and personnel to tag the remaining 75% with CWT. A 100% tagging rate could likely only be achieved using NMT AutoFish tagging technologies or similar devices.

Manipulation of the proportion of natural-origin fish used in hatchery matings would require all unmarked prospective broodstock entering the hatchery to pass through an electronic detection device.

Post-hoc elimination of out-of-basin hatchery fish from spawnings would require that (a) CWTs were extracted from all spawners and linked to individual 1:1 spawnings and (b) eggs from just one (or two) pairwise matings are trayed in a single incubator. Eggs from matings with out-of-basin hatchery parents would be culled from hatchery production.

8.2.3 What changes to existing tag-recovery programs (including escapement surveys) would be required?

Because all ADC-marked fish contain a CWT for this system, there would be no required changes in ocean fishery, river fishery, natural area escapement, or hatchery return sampling programs (although some proposed methods for dealing with uncertain ADC status of decomposed carcasses require the assumption that all CWT fish must have been ADC, Mohr and Satterthwaite 2013). If identification of unmarked, hatchery-origin fish were desired, ETD would be required. If identification of hatchery-of-origin were desired for all hatchery-origin fish, additional CWT head collection, extraction, and decoding would be required.

8.2.4 What new infrastructure and/or personnel might be needed?

Manipulation of the proportion of hatchery-origin fish in natural spawning areas would require weirs on spawning tributaries where the composition of hatchery/natural fish is a management priority, electronic detection devices to identify unmarked hatchery-origin fish, and additional personnel to staff these weirs during spawning runs.

Electronic detection devices would be required at hatcheries to allow manipulation of the proportion of natural-origin fish used in brood stock.

Increased numbers of incubators and increased numbers of hatchery staff would be required for manipulation of the proportion of natural-origin fish used in hatchery matings, and to eliminate out-of-basin hatchery-origin fish from hatchery matings. (These issues received substantial consideration by the California HSRG (2012).)

8.3 System 3: Fractional ADC+CWT; remainder AWT

8.3.1 What capabilities would the system support?

This system would allow for real-time (electronic) identification of all hatchery-origin fish, thereby allowing for estimation of the proportion of hatchery-origin fish in natural spawning areas and hatcheries, and for the manipulation of hatchery- and natural-origin fish in natural spawning areas and hatcheries. It would not allow for the exclusion of out-of-basin hatchery-origin fish in hatchery matings[11]. This system would support estimation of hatchery release group survival and associated fishery mortality and maturation rates that are essential for current fisheries management. Alternative tagging and sampling schemes would be required for natural-origin tagging programs, as the operating assumption under System 3 is that all fish with wire tags (CWT or AWT) are hatchery-origin.

8.3.2 What marking/tagging and other related hatchery protocols would be needed?

As the status quo CFM program requires that approximately 25% of all fall-run Chinook salmon in a hatchery release group receive ADC+CWT, System 3 would require increased equipment and personnel to tag the remaining 75% with AWT. This increased tagging rate could only be achieved using NMT AutoFish tagging technologies or similar devices.

Electronic detection devices would need to be used to allow manipulation of the proportion of natural origin fish among hatchery spawners.

8.3.3 What changes to existing tag-recovery programs (including escapement surveys) would be required?

Because all ADC-marked fish contain a CWT for this system, there would be no required changes in ocean fishery, river fishery, natural area escapement, or hatchery return sampling programs. If identification of unmarked, hatchery-origin fish were desired, then electronic detection of AWT would be required.

8.3.4 What new infrastructure and/or personnel might be needed?

Manipulation of the proportion of hatchery-origin fish in natural spawning areas would require construction, operation and maintenance of weirs on spawning tributaries where the composition of

[11] Except in special cases where all within-basin tagging is done by one agency while all likely sources of out-of-basin strays are tagged by different agencies, in which case reading of AWT codes would allow detection of out-of-basin strays.

hatchery/natural fish is a management priority, electronic detection devices to identify unmarked hatchery-origin fish, and additional personnel to staff these weirs during spawning runs.

Electronic detection devices would be needed to allow control of the proportion of natural-origin fish among hatchery spawners.

8.4 System 4: Fractional ADC; 100% PBT

8.4.1 What capabilities would the system support?

This system would not allow for real-time identification of all hatchery-origin fish, but would permit this post-hoc based on genotyping of individuals. This system would therefore allow for potential manipulation of hatchery- and natural-origin fish in hatchery matings, but would not permit manipulation of hatchery-and natural-origin proportions in natural spawning areas. Post-hoc elimination of out-of-basin hatchery fish from spawnings would require that (a) genotypes were sequenced from all spawners and linked to individual 1:1 spawnings and (b) eggs from just one (or two) pairwise matings are trayed in a single incubator, but (a) is required for 100% PBT by definition and some level of segregation of offspring from different matings (approaching b) would be necessary to establish discrete release groups. Tagging of natural-origin fish in a PBT-based system would likely be very expensive (Satterthwaite et al. 2015a).

Because this system does not call for application of CWT to any fall-run Chinook salmon hatchery release groups, a PBT-based program would have to generate data sets suitable for the kinds of cohort reconstructions that can be generated from recoveries of status quo ADC+CWT release groups and which allow for estimation of survival, maturation, and fishery mortality rates. To allow development of such PBT-based cohort reconstructions, large-scale and costly changes would need to be made in ocean fishery, river fishery, natural area escapement, and hatchery return sampling programs, and in hatchery operations. In particular, a coordinated coast-wide genotype-recovery database would need to be developed to exchange information (as for CWTs) and algorithms used for parentage analysis would need to be standardized across all fishery jurisdictions. Satterthwaite et al. (2015a) describes many of the steps required for such a transition, which the PSC CSC (2015) deemed not yet feasible but worthy of continued consideration as technologies mature.

8.4.2 What marking/tagging and other related hatchery protocols would be needed?

CV and KT hatcheries typically produce several types of fall-run Chinook salmon, including fingerlings, yearlings, and various types of experimental release groups. At a given hatchery, for each type, there typically are several groups of fish released (e.g., grouped by size or age), and often these groups are released on separate dates over an extended period, typically with some fraction of each group receiving

ADC+CWT. The performances of, and fishery mortality rates on, these different type/group combinations often varies dramatically, and it is critically important that a marking/tagging system allow for performance and fishery mortality rate assessment at the type/group level. The status quo (System 1) allows for this, with each tagged fish receiving a CWT implant that identifies its hatchery/year/type/group.

To achieve the hatchery/year/type/group tagging requirement with PBT, the parental tag must be associated with one, and only one, hatchery/year/type/group so that returns from any particular parental pair can be associated only with this group and not also with some other group as well. Thus, for example, progeny from matings made on a given day could not be used for eventual release as both fingerlings and yearlings nor could they be released in different months or at significantly different sizes. Ensuring that parental tags are associated with one, and only one, release group would require that all of the progeny originating from a known set of parents are reared and released in identical fashion so that they all belong to a single group. Just exactly how this might be accomplished would likely vary according to production facility, but it would certainly require a great deal more tracking of parental matings (e.g., all of those made on a particular day) than has been customary in production type facilities. Adipose fin clips would be applied to a random fraction, F, of progeny associated with each specific group, assuming that the CWT-based tradition of targeting sampling toward such visually-marked individuals were maintained in ocean fishery, river fishery, natural area escapement, and hatchery return sampling programs. This approach would necessarily confound parental genotype with experimental treatments applied to specific release groups, although this could be addressed through increased release group size (implying more parents) and statistical models including both fixed treatment effects and random family effects (Satterthwaite et al. 2015a, p.63).

This system would allow for manipulation of the proportion of natural-origin fish used in hatchery matings. Natural-origin fish would be identified as such, post-hoc (i.e., after matings take place), if their genotype did not originate from any PBT parents at any West Coast hatchery (assuming all West Coast hatcheries PBT all parents every year) or at least not from any PBT parents associated with nearby hatcheries (assuming that no stray hatchery fish from other than nearby hatcheries enter a particular facility). Note that if other hatcheries (non-fall-run Chinook salmon in California, and/or out-of-state hatcheries) producing fish that could stray into relevant strata still use CWT, a parallel sampling for both CWT and genetic samples would be required. If some of these other hatcheries fractionally marked and tagged, there would be no way to fully exclude hatchery-origin fish.

Out-of-basin hatchery-origin fish could be identified as such, post-hoc, if their genotype originated from PBT parents spawned at another hatchery (assuming that (a) all west coast hatcheries

PBT all parents every year, or (b) all nearby hatcheries are PBT and no strays came from other hatcheries). Eggs from identified out-of-basin matings would be destroyed.

8.4.3 What changes to existing tag-recovery programs (including escapement surveys) would be required?

To generate the kind of geographically coordinated data currently provided by the status quo CWT tag-recovery program, a coast-wide network and program would need to be developed and established for the reporting of all PBT parent genotypes, release group identifying characteristics, catch- and escapement-sample information, and the genotypes of random samples of fish encountered in ocean fishery sampling, river fishery sampling, natural area escapement surveys, and hatchery return sampling (100% sampling). Recovery sampling could continue to target ADC fish, with enrichment benefits described above. Participation of all hatcheries and sampling programs would be necessary if such a PBT-based system were to completely supplant the existing CWT-based system, otherwise parallel sampling programs for both CWT and genetics would need to be maintained.

Ocean fishery, river fishery, natural area escapement, and hatchery return samplers would need to collect tissues or scales from all ADC-marked fish encountered, store the material appropriately, ascribe a unique number to the sampled fish (so that once the genotype is determined it can be associated back to the individual sample and fish information), and ship samples to a genotyping facility using agreed upon analytic methods for parentage analysis.

8.4.4 What new infrastructure and/or personnel might be needed?

Industrial-scale genotyping facilities would be required to implement this PBT-based marking/tagging system. Increased numbers of incubators and increased numbers of hatchery staff would be required to manipulate the proportion of natural-origin fish used in hatchery matings, and to eliminate out-of-basin hatchery-origin fish from hatchery matings. Additional hatchery infrastructure (e.g. tanks and raceways) and protocols would be required to keep genetically-identifiable release groups from distinct sets of parents isolated from fertilization through release.

8.5 System 5: Fractional ADC+CWT; 100% PBT

8.5.1 What capabilities would the system support?

Because this system retains status quo CFM marking/tagging, there would be a need to collect tissues for genotyping only if suitable information could not be generated from the status quo marking/tagging program. This system would not allow for real-time identification of all hatchery-origin fish, but would permit this post-hoc following genotyping of individuals. The system would therefore allow for potential manipulation of hatchery- and natural-origin fish in hatchery matings, but would not permit manipulation of hatchery- and natural-origin proportions in natural spawning areas. This system would allow for current marking/tagging practices for natural-origin fish and for rare stock enrichment.

8.5.2 What marking/tagging and other related hatchery protocols would be needed?

At minimum, this would require all the protocols in System 1 along with genotyping of all of the parental broodstock in relevant hatcheries. If PBT rather than CWT were used for performance and fishery mortality rate assessment purposes, then the protocols necessary to maintain association of a PBT with one, and only one, type/group would also need to be followed as in System 4 (see Section 8.4.2).

8.5.3 What changes to existing tag-recovery programs (including escapement surveys) would be required?

If CWT rather than PBT were used for performance and fishery mortality rate assessment purposes, then tag-recovery sampling programs would be unaffected relative to the status quo. If PBT rather than CWT were used for performance and fishery mortality rate assessment purposes, then representative genetic sampling, analysis, and reporting would need to expand to all strata of catch and escapement as in System 4 (see Section 8.4.3).

PBT would allow for post-hoc estimation of hatchery-origin contributions to harvest and escapement if tissue or scale samples were collected for this purpose, although parallel collection of genetic and CWT samples would be required if other hatcheries still used CWT.

8.5.4 What new infrastructure and/or personnel might be needed?

Large-scale genotyping facilities would be required (with the exact scale depending on whether genetic sampling was limited to hatcheries or encompassed harvest and/or natural area escapement as well). Increased numbers of incubators and increased numbers of hatchery staff would be required to manipulate the proportion of natural-origin fish used in hatchery matings, to eliminate out-of-basin hatchery-origin fish from hatchery matings, and to collect tissues for genetic sequencing. Additional hatchery infrastructure (e.g. tanks and raceways) and protocols would be required to keep genetically identifiable release groups from distinct sets of parents isolated from fertilization through release, however since some fish receive CWT in this system it may be acceptable for genetically-identifiable release groups to be more coarsely defined.

8.6 System 6: 100% ADC; fractional CWT; MSF

8.6.1 What capabilities would the system support?

This system would allow for real-time (visual) identification of all hatchery-origin fish, which would allow for potential manipulation of hatchery- and natural-origin fish in natural spawning areas and hatcheries. However, unmarked DIT fish used to evaluate MSF impacts would violate the assumption that all hatchery fish are marked. Because the ADC mark does not identify hatchery-of-origin, it would not be possible to exclude out-of-basin hatchery-origin fish in hatchery matings. Marking of natural-origin fish would violate the assumption that all marked fish are hatchery-origin, although unmarked but tagged natural-origin fish could be recovered using ETD. Marking of listed stocks would be problematic since marked fish are targeted by MSF.

The visible ADC mark is conducive to MSF. The degree to which fishing opportunity and harvest might be increased under MSF management is difficult to gauge with any degree of confidence as it depends on a large number of variables, but it would likely vary substantially across years (Pyper et al. 2012). MSF would be a marked departure from current Chinook salmon fishery management in California, and would require development of new assessment methods and models for managing the fisheries intercepting California Chinook salmon stocks, as well as the establishment of new reference points specific to hatchery- versus natural-origin fish. It is currently doubtful whether the required models can be adequately parameterized (PSC CSC 2015, PSC SFEC 2016).

With this system, large numbers of hatchery fish would be released with an ADC mark, but without CWT, and some (DIT) fish would be released with CWT, but without an ADC mark. Significant changes would be required to the current ocean fishery, river fishery, natural area escapement, and hatchery return sampling programs.

8.6.2 What marking/tagging and other related hatchery protocols would be needed?

One hundred percent marking with ADC of all hatchery-produced fish could only be achieved using NMT AutoFish marking/tagging technologies or similar devices. DIT groups would need to be released to allow for estimation of the total fishery mortality rate on unmarked (natural-origin) fish. DIT groups would have to be large enough to achieve adequate statistical precision in resulting estimates. It would be problematic to use ADC to indicate the presence of CWT in listed stocks (e.g. SR winter-run Chinook salmon) because marked fish would be directly targeted in MSF fisheries.

8.6.3 What changes to existing tag-recovery programs (including escapement surveys) would be required?

For MSF fisheries, random samples of ADC-fish would need to be taken and electronic devices used to detect CWT fish. If some fisheries were not managed by MSF[12], random samples from all fish (ADC-marked and unmarked) would need to be taken and electronic devices used to detect CWT fish.

In natural spawning area surveys and at hatcheries, random samples from all fish (ADC-marked and unmarked) would need to be taken and electronic devices used to detect CWT fish.

[12] This may occur, for example, when the marked-to-unmarked ratio is anticipated to be low.

Sampling fractions of unmarked fish may need to be high to generate sufficient CWT recoveries in the unmarked DIT component to yield reliable estimates of fishery mortality rates for these unmarked fish.

8.6.4 What new infrastructure and/or personnel might be needed?

Manipulation of the proportion of hatchery-origin fish in natural spawning areas would require construction, operation and maintenance of weirs on spawning tributaries where manipulation of the composition of hatchery/natural fish is a management priority, additional personnel to staff these weirs during spawning runs, and ETD applied to fish handled at these weirs.

8.7 System 7: 100% ADC+CWT; MSF

8.7.1 What capabilities would the system support?

This system would allow for real-time (visual and electronic) identification of all hatchery-origin fish, which would allow for potential manipulation of hatchery- and natural-origin fish in natural spawning areas and hatcheries. Unmarked DIT fish used to evaluate MSF impacts would violate the assumption that all hatchery fish are marked, but not the assumption that all hatchery fish are tagged. Hatchery-of-origin could be determined for all hatchery fish (via CWT), which would allow post-hoc exclusion of out-of-basin hatchery-origin fish in hatchery matings. Marking of natural-origin fish would violate the assumption that all marked fish are hatchery-origin, although tags could be recovered from unmarked natural-origin fish using ETD (but unmarked, tagged natural-origin fish could not be distinguished from unmarked DIT fish based on ETD). One hundred percent marking and tagging of fish from production hatcheries would eliminate the possibility of rare stock enrichment, and any decrease in the overall sampling rate in response to greatly increased fall-run tag recoveries would reduce the already worryingly low SR winter-run Chinook salmon tag recoveries (PFMC SSC 2015), and require larger release groups for evaluating the performance of experimental releases. Marking of listed stocks with ADC would be problematic since ADC-marked fish are targeted by MSF

The visible ADC mark is conducive to MSF. The degree to which fishing opportunity and harvest might be increased under MSF management is difficult to gauge with any degree of confidence as it depends on a large number of variables, but it would likely vary substantially across years (Pyper et al. 2012). MSF would be a marked departure from current Chinook salmon fishery management in California, and would require development of new assessment methods and models for managing the fisheries intercepting California Chinook salmon stocks, as well as the establishment of new reference points specific to hatchery- versus natural-origin fish. It is currently doubtful whether the required models can be adequately parameterized (PSC CSC 2015, PSC SFEC 2016).

With this system, some (DIT) fish would be released with CWT, but without an ADC mark. Significant changes would be required to the current ocean fishery, river fishery, natural area escapement, and hatchery return sampling programs.

8.7.2 What marking/tagging and other related hatchery protocols would be needed?

One hundred percent marking and tagging with ADC and CWT of all hatchery-produced fish could only be achieved using NMT AutoFish marking/tagging technologies or similar devices.

DIT groups would need to be released to allow for estimation of the total fishery mortality rate on unmarked (natural-origin) fish. DIT groups would have to be large enough to achieve adequate statistical precision in resulting estimates. It would be problematic to use ADC to indicate the presence of CWT in listed stocks (e.g., SR winter-run Chinook salmon) because marked fish would be directly targeted in MSF fisheries.

Post-hoc elimination of out-of-basin hatchery fish from matings could be achieved if (a) CWTs were extracted and decoding from all hatchery-origin fish involved in matings, (b) matings were 1:1, and (c) all eggs from one (or two) parental pairs were incubated in single incubators. Eggs from unacceptable out-of-basin matings would be culled whenever out-of-basin parents were identified.

8.7.3 What changes to existing tag-recovery programs (including escapement surveys) would be required?

For MSF fisheries, random samples of ADC-fish would need to be taken and electronic devices used to detect CWT fish. If some fisheries were not managed by MSF[13], random samples from all fish (ADC-marked and unmarked) would need to be taken and electronic devices used to detect CWT fish.

In natural spawning area surveys and at hatcheries, random samples from *unmarked* fish would need to be taken and ETD used to detect CWT fish belonging to DIT groups. Sampling fractions of unmarked fish might need to be high to generate sufficient CWT recoveries in the unmarked DIT component to yield reliable estimates of fishery mortality rates for these unmarked fish.

Subsampling protocols may need to be revised for all survey settings to cope with the four-fold increase in the number of CWT heads/extractions/decodings that would otherwise occur under current sampling designs.

8.7.4 What new infrastructure and/or personnel might be needed?

Increased numbers of incubators and increased numbers of hatchery staff would be required to restrict out-of-basin matings and to control the proportion of natural origin fish in brood stock.

[13] This may occur, for example, when the marked-to-unmarked ratio is anticipated to be low.

Manipulation of the proportion of hatchery-origin fish in natural spawning areas would require construction, operation and maintenance of weirs on spawning tributaries where manipulation of the composition of hatchery/natural fish is a management priority, additional personnel to staff these weirs during spawning runs, and ETD applied to fish handled at these weirs.

8.8 System 8: 100% ADC; 100% PBT; MSF

8.8.1 What capabilities would the system support?

This system would allow for real-time (visual) identification of all hatchery-origin fish, which would allow for potential manipulation of hatchery- and natural-origin fish in natural spawning areas and hatcheries. Hatchery-of-origin could be determined by PBT, which would allow post-hoc exclusion of out-of-basin hatchery-origin fish in hatchery matings. Marking of natural-origin fish would violate the assumption that all marked fish are hatchery-origin, while tagging of natural-origin fish via PBT is likely to be very expensive and recovering such tags from unmarked fish would require genotyping many more fish during sampling. One hundred percent marking and tagging of fish from production hatcheries would eliminate the possibility of rare stock enrichment and any decrease in the overall sampling rate would reduce the already worryingly low SR winter-run Chinook salmon tag recoveries (PFMC SSC 2015), and require larger release groups for evaluating the performance of experimental releases. Marking of listed stocks would be problematic since marked fish are targeted by MSF.

The visible ADC mark is conducive to MSF. The degree to which fishing opportunity and harvest might be increased under MSF management is difficult to gauge with any degree of confidence as it depends on a large number of variables, but it would likely vary substantially across years (Pyper et al. 2012). MSF would be a marked departure from current Chinook salmon fishery management in California, and would require development of new assessment methods and models for managing the fisheries intercepting California Chinook salmon stocks, as well as the establishment of new reference points specific to hatchery- versus natural-origin fish. It is currently doubtful whether the required models can be adequately parameterized (PSC CSC 2015, PSC SFEC 2016).

This system would need to rely on PBT to allow estimation of fishery mortality rates on unmarked stocks because no fall-run Chinook salmon would be released with CWT.

8.8.2 What marking/tagging and other related hatchery protocols would be needed?

Use of PBT rather than CWT for performance and fishery mortality rate assessment purposes would require the spawning and rearing protocols necessary to maintain association of a PBT with one, and only one, type/group as described in System 4 (see Section 8.4.2). All hatchery-origin fish would be adipose fin clipped. One hundred percent marking with ADC of all hatchery-produced fish could only be achieved using NMT AutoFish marking/tagging technologies or similar devices. It would be problematic to use ADC to indicate the presence of PBT in listed stocks (e.g., SR winter-run Chinook salmon) because marked fish would be directly targeted by fisheries.

This system would allow for manipulation of the proportion of natural-origin fish used in hatchery matings. Out-of-basin hatchery-origin fish could be identified as such, post-hoc, if their genotype originated from PBT parents spawned at another hatchery (assuming that (a) all West Coast hatcheries PBT all parents every year, or (b) all nearby hatcheries are PBT and no strays came from other hatcheries). Eggs from identified out-of-basin matings would be culled. Note that if other hatcheries (non-fall-run Chinook salmon in California, and/or out-of-state hatcheries) producing fish that could stray into relevant strata still use CWT, a parallel sampling for both CWT and genetic samples would be required. If some of these other hatcheries fractionally marked and tagged, there would be no way to fully exclude hatchery-origin fish.

8.8.3 What changes to existing tag-recovery programs (including escapement surveys) would be required?

Representative genetic sampling, analysis, and reporting would need to expand to all strata of catch and escapement as in System 4 (see Section 8.4.3). In addition, DIT and recovery of tagged natural-origin fish would require sampling of unmarked fish in addition to marked fish. Parallel genetic and CWT sampling programs would need to be maintained if other hatcheries still used CWT.

8.8.4 What new infrastructure and/or personnel might be needed?

Industrial-scale genotyping facilities would be required to implement this PBT-based marking/tagging system.

Increased numbers of incubators and increased numbers of hatchery staff would be required to manipulate the proportion of natural-origin fish used in hatchery matings, and to eliminate out-of-basin hatchery-origin fish from hatchery matings. Additional hatchery infrastructure (e.g. tanks and raceways) and protocols would be required to keep genetically-identifiable release groups from distinct sets of parents isolated from fertilization through release.

8.9 System 9: 100% ADC; fractional CWT; no MSF

8.9.1 What capabilities would the system support?

This system would allow for real-time (visual) identification of all hatchery-origin fish, which would allow for potential manipulation of hatchery- and natural-origin fish in natural spawning areas and hatcheries. Because the ADC mark does not identify hatchery-of-origin, it would not be possible to exclude out-of-basin hatchery-origin fish in hatchery matings. This system would be incompatible with marking of natural-origin fish, although tagged but unmarked natural-origin fish could be recovered using ETD in all relevant strata (although otherwise ETD would only be used on marked fish in this system).

8.9.2 What marking/tagging and other related hatchery protocols would be needed?

One hundred percent marking with ADC of all hatchery-produced fish could only be achieved using NMT AutoFish marking/tagging technologies or similar devices. Marking natural-origin fish would violate the assumption that all marked fish are of hatchery-origin required for real-time identification, although tagged but unmarked natural-origin fish could be recovered using ETD.

8.9.3 What changes to existing tag-recovery programs (including escapement surveys) would be required?

Electronic detection devices would be required in all sample survey settings in order to detect which ADC sampled fish contain a CWT. Fishery and escapement surveys would be similar to those currently used, although the number of ADC-marked fish encountered by samplers would be increased by a factor of four relative to the status quo. However, the number of heads that would need to be collected would not change from the status quo. ETD applied to unmarked fish might be required to recover tagged but unmarked natural-origin fish.

8.9.4 What new infrastructure and/or personnel might be needed?

Manipulation of the proportion of hatchery-origin fish in natural spawning areas would require construction, operation and maintenance of weirs on spawning tributaries where manipulation of the composition of hatchery/natural fish is a management priority, and additional personnel to staff these weirs during spawning runs. ETD would be required for CWT recovery from sampling programs and at hatcheries (but not for identifying hatchery-origin fish at weirs).

8.10 System 10: 100% ADC+CWT; no MSF

8.10.1 What capabilities would the system support?

This system would allow for real-time (visual or electronic) identification of all hatchery-origin fish, which would allow for potential manipulation of hatchery- and natural-origin fish in natural spawning areas and hatcheries. Marking natural-origin fish would violate the assumption that all marked fish are of hatchery-origin required for real-time identification, although tagged but unmarked natural-origin fish could be recovered using ETD (despite ETD being otherwise unnecessary under this system). One hundred percent marking and tagging of fish from production hatcheries would eliminate the possibility of rare stock enrichment and any decrease in the overall sampling rate would reduce the already worryingly low SR winter-run Chinook salmon tag recoveries (PFMC SSC 2015), and require larger release groups for evaluating the performance of experimental releases.

8.10.2 What marking/tagging and other related hatchery protocols would be needed?

One hundred percent marking with ADC of all hatchery-produced fish could only be achieved using NMT AutoFish marking/tagging technologies or similar devices.

Visual methods (presence of ADC) could be used to control proportion of natural-origin fish among brood stock. Marking natural-origin fish would violate the assumption that all marked fish are of hatchery-origin required for real-time identification, although tagged but unmarked natural-origin fish could be recovered using ETD.

Post-hoc elimination of out-of-basin hatchery fish from matings could be achieved if (a) CWTs were extracted and decoding from all hatchery-origin fish involved in matings, (b) matings were 1:1, and (c) all eggs from one (or two) parental pairs were incubated in single incubators. Eggs from unacceptable out-of-basin matings would be culled whenever out-of-basin parents were identified.

8.10.3 What changes to existing tag-recovery programs (including escapement surveys) would be required?

Electronic detection devices would <u>not</u> be required in any sample survey setting, (unless tagging was performed on unmarked natural-origin stocks) since in this system all hatchery-origin fish are ADC+CWT.

Subsampling protocols may need to be developed for all survey settings to cope with the four-fold increase in the number of CWT heads/extractions/decodings that would otherwise occur under current sampling designs.

8.10.4 What new infrastructure and/or personnel might be needed?

Increased numbers of incubators and increased numbers of hatchery staff would be required to restrict out-of-basin matings.

Manipulation of the proportion of hatchery-origin fish in natural spawning areas would require construction, operation and maintenance of weirs on spawning tributaries where manipulation of the composition of hatchery/natural fish is a management priority, and additional personnel to staff these weirs during spawning runs.

8.11 System 11: 100% ADC; 100% PBT; no MSF

8.11.1 What capabilities would the system support?

This system would allow for real-time (visual) identification of all hatchery-origin fish, which would allow for potential manipulation of hatchery- and natural-origin fish in natural spawning areas and hatcheries. Hatchery-of-origin could be determined by PBT, which would allow post-hoc exclusion of out-of-basin hatchery-origin fish in hatchery matings. Marking of natural-origin fish would violate the assumption that all marked fish are hatchery-origin, while tagging of natural-origin fish via PBT is likely to be very expensive and recovering such tags from unmarked fish would require genotyping many more fish during sampling. One hundred percent marking and tagging of fish from production hatcheries would eliminate the possibility of rare stock enrichment and any decrease in the overall sampling rate would reduce the already worryingly low SR winter-run Chinook salmon tag recoveries (PFMC SSC 2015), and require larger release groups for evaluating the performance of experimental releases.

8.11.2 What marking/tagging and other related hatchery protocols would be needed?

Use of PBT rather than CWT for performance and fishery mortality rate assessment purposes would require the spawning and rearing protocols necessary to maintain association of a PBT with one, and only one, type/group as described in System 4 (see Section 8.4.2). One hundred percent marking with ADC of all hatchery-produced fish could only be achieved using NMT AutoFish marking/tagging technologies or similar devices.

Out-of-basin hatchery-origin fish could be identified as such, post-hoc, if their genotype originated from PBT parents spawned at another hatchery (assuming that (a) all west coast hatcheries PBT all parents every year, or (b) all nearby hatcheries are PBT and no strays came from other hatcheries). Eggs from identified out-of-basin matings would be destroyed. Note that if other hatcheries (non-fall-run in Chinook salmon California, and/or out of state hatcheries) producing fish that could stray into relevant strata still use CWT, a parallel sampling for both CWT and genetic samples would be required. If some of these other hatcheries fractionally marked and tagged, there would be no way to fully exclude hatchery-origin fish.

8.11.3 What changes to existing tag-recovery programs (including escapement surveys) would be required?

Representative genetic sampling, analysis, and reporting would need to expand to all strata of catch and escapement as in System 4 (see Section 8.4.3). In addition, recovery of tagged natural-origin fish would require sampling of unmarked fish in addition to marked fish. Parallel genetic and CWT sampling programs would need to be maintained if other hatcheries still used CWT.

8.11.4 What new infrastructure and/or personnel might be needed?

Industrial-scale genotyping facilities would be required to implement this PBT-based marking/tagging system.

Increased numbers of incubators and increased numbers of hatchery staff would be required to manipulate the proportion of natural-origin fish used in hatchery matings, and to eliminate out-of-basin hatchery-origin fish from hatchery matings. Additional hatchery infrastructure (e.g. tanks and raceways) and protocols would be required to keep genetically-identifiable release groups from distinct sets of parents isolated from fertilization through release.

Manipulation of the proportion of hatchery-origin fish in natural spawning areas would require construction, operation and maintenance of weirs on spawning tributaries where manipulation of the composition of hatchery/natural fish is a management priority, and additional personnel to staff these weirs during spawning runs.

9 Synthesis

Although the aim of this report is not to recommend any specific system or rank the alternatives, an analysis of the 11 systems developed here illustrates important points about the tradeoffs associated with any changes in marking, tagging, or sampling schemes. All of the alternative systems described here are likely to increase costs relative to System 1, CFM (although as genotyping costs fall, System 4 might be cost-competitive, see Satterthwaite et al. 2015a and PSC CSC 2015), and while all proposed alternative systems offer at least one additional capability over System 1, many also sacrifice capabilities relative to System 1 as well. In addition to concerns with costs, reliance on ADC or ETD for real-time identification of hatchery-origin fish would then preclude the use of ADC or wire tags in natural-origin fish. MSF are incompatible with existing harvest management models, would pose problems for marking (and thus easily sampling) listed stocks, and may not yield the desired increase in harvest opportunity nor decrease impacts on unmarked fish.

The status quo (System 1, CFM) allows for cost-effective estimation of the quantities required for harvest management models, evaluation of hatchery performance, rare stock enrichment, experimental release groups of moderate size, post-hoc estimation of the contribution and proportion of hatchery-origin fish in harvest, hatchery broodstock, and natural area escapement (and this proportion can be approximated in real-time if mark rates for dominant contributing stocks are known), and is compatible with marking and tagging (ADC+CWT) of natural-origin fish. Weaknesses of System 1 are (a) its reliance on the assumption that exploitation rates estimated for hatchery-origin fish apply to similar natural-origin fish as well, (b) the inability to identify all hatchery-origin fish in real-time, (c) the inability to post-hoc identify all hatchery-origin fish, (d) the inability to identify all hatchery-origin fish back to stock of origin, and (e) limited tag recoveries for SR winter-run Chinook salmon. System 1 is also (f) not conducive to MSF.

None of the alternative systems proposed here circumvent weakness (a), and most alternative systems (with the exception of System 5) either complicate or preclude straightforward tagging of natural-origin stocks that could address this weakness. Similarly, none of the proposed systems circumvent weakness (e) and, with the exception of Systems 2–5 (and possibly 6 and 9 with widespread ETD), the proposed alternative systems are likely to exacerbate this weakness by increasing sampling costs which may lead to lower sampling rates.

However, all of the alternative systems address weakness (c), although unmarked DIT fish could compromise this in systems using MSF. All but Systems 4 and 5 address weakness (b) as well. Systems 2, 4, 5, 7, 8, 10, and 11 address weakness (d). Systems 6–8 address issue (f).

Although this report does not make an explicit recommendation for changes in marking and tagging practices, we note that CFM is the least expensive system considered. Given the PSC's findings on PBT costs and the requirement for coordinated sampling coastwide, we would not recommend a switch to PBT at this time. Given uncertainty in the ability of MSF to achieve stated goals and the incompatibility of MSF with existing harvest management models and regulations, we would also not recommend consideration of MSF at this time for multi-stratum ocean or river fisheries. When comparing the remaining options, it is important to consider what added capabilities are desired and whether they justify the additional costs (and potentially sacrificed capabilities) of each option. It should be noted that although tagged natural-origin fish may pose challenges to real-time identification of hatchery-origin fish in some systems, currently there are no major, ongoing natural-origin tagging studies in California, and there are likely many escapement strata for which tagged natural-origin fish would be unlikely to make more than a negligible contribution. In addition, depending on the purposes of such studies, due to the cost of accessing and handling natural-origin fish, it may be cost-effective to use a more expensive but more data-rich tag (e.g., RFID tag) for natural-origin fish, which may not cause similar conflicts.

If it is desirable to be able to identify all hatchery-origin fish in real-time, either full marking and fractional tagging, fractional marking and full tagging plus ETD, or full marking and full tagging would suffice. If it is desirable to be able to identify stock of origin for all hatchery-origin fish, either fractional marking plus full tagging, fractional marking and fractional tagging plus PBT (CFM+PBT hybrid), or full marking and full tagging would suffice. Fully marking and fully tagging would increase sampling costs considerably (and require larger experimental release groups while rendering rare stock enrichment impossible), and so it would not be preferred over fractional marking plus full tagging unless it is essential to identify all hatchery-origin fish in real-time and ETD of tagged fish is not a viable way of doing so. Fractional marking plus full tagging is generally preferable over full marking and fractional tagging since it allows identification of all hatchery-origin fish back to stock of origin unless it is crucial that it be possible to identify all hatchery-origin fish in real-time in samples which may contain CWT-tagged natural-origin fish as well. If real-time identification of all hatchery-origin fish is important, the CFM+PBT hybrid is not a viable option, but if reliable post-hoc estimation of the proportion of hatchery-origin fish along with identification of all hatchery-origin fish back to their stock of origin is sufficient, the choice between fractional marking plus full tagging or the CFM+PBT hybrid should depend on their relative costs and benefits, considering the potential future utility of both real-time identification of tagged fish (an advantage of full tagging) and the information provided by pedigree reconstruction (an advantage of the CFM+PBT hybrid).

This complexity defies any simple recommendation or ranking of systems, and emphasizes the importance of considering tradeoffs among what capacities are gained and lost under each alternative system. The value of any added capabilities should be weighed against a careful consideration of costs. Cost considerations include the obvious direct effects of increased marking or tagging, but also careful attention should be given to sampling costs and their implications for future sampling rates. Ultimately, different constituencies are likely to favor different marking/tagging systems and sampling regimes depending on their priorities, so it is important that decision makers are cognizant of the tradeoffs involved and aware of the unfortunate reality that there is no one option that is a true win-win for all parties.

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Appendix A: Acronyms and abbreviations

ADC	adipose fin clip, or adipose fin-clipped
AFS	American Fisheries Society
AWT	agency wire tag
Cal-Neva	California-Nevada (Chapter of AFS)
CDFW	California Department of Fish and Wildlife
CFM	constant fractional marking/tagging
CSC	Committee on Scientific Cooperation (PSC)
CTC	Chinook Technical Committee (PSC)
CV	Central Valley (California)
CWT	coded wire tag
CWTW	Coded Wire Tag Workgroup (PSC)
DIT	double index tag
E-rate	fishery mortality (exploitation) rate
ESA	Endangered Species Act (U.S.)
ETD	electronic tag detection
EXCOM	Executive Committee (Cal-Neva)
F	a fraction ($0 < F < 1$)
GSI	genetic stock identification
HO	hatchery-origin
HSRG	Hatchery Scientific Review Group
KT	Klamath-Trinity
LSNFH	Livingston Stone National Fish Hatchery
MM	mass marking
MOU	Memorandum of Understanding
MSF	mark-selective fisheries
NMFS	National Marine Fisheries Service
NMT	Northwest Marine Technologies
NO	natural-origin
PBT	parental-based tag
PFMC	Pacific Fishery Management Council
PSC	Pacific Salmon Commission
RFID	radio-frequency identification
RMIS	Regional Mark Information System
SARA	Species at Risk Act (Canada)
SR	Sacramento River
SSC	Scientific and Statistical Committee (PFMC)
STT	Salmon Technical Team (PFMC)
SWFSC	Southwest Fisheries Science Center (NMFS)
USFS	United States Forest Service
USFWS	United States Fish and Wildlife Service
WG	Workgroup

Appendix B: Tables describing system capabilities, with accompanying justifications

The tables in this appendix (Tables B5, B6, B7, B8) are a reproduction of Section 7 Tables 5, 6, 7, 8, respectively, except that each table entry (rating) includes a footnote that provides the rationale and/or qualification of that rating. (There are no such Tables B1–B4.)

Table B5. Conservation of CV and KT fall-run Chinook salmon. Qualitative assessment of degree to which proposed marking/tagging systems can meet criteria. Marking/tagging systems: ADC denotes adipose fin clip; CWT denotes coded wire tag; AWT denotes agency wire tag; PBT denotes parental-based tag; MSF denotes mark-selective fisheries; F denotes a fraction (0<F<1) in a (constant) fractional marking and/or tagging scheme; 1-F denotes the remaining fraction of fish; "yes" indicates that MSF would be associated with the marking/tagging system. If a system specifies F for ADC and CWT, it refers to the same group of fish. Criteria are defined in Table 3; "HO" denotes "hatchery-origin"; "NO" denotes "natural-origin"; "E-rate" denotes "fishery mortality rate"; "+" denotes "clearly meets criterion"; "≈" denotes "partially meets the criterion, or requires a major increase in costs compared to other fully capable systems"; "–" denotes "clearly does not meet criterion"; "?" denotes "unclear if would meet criterion". Footnotes provide rationale and/or qualification for rating assessments.

Marking/tagging system						Criterion					
System	ADC	CWT	AWT	PBT	MSF	Manipulate proportion HO in real-time	Restrict out-of-basin HO in real-time	Estimate proportion HO	Est. prop. out-of-basin HO	Est. NO production	Achieve NO E-rate
1	F	F				–[1]	–[4]	+[5]	+[5]	+[10]	+[13]
2	F	100%				+[2]	–[4]	+[6]	+[6]	+[10]	+[13]
3	F	F	1-F			+[2]	–[4]	+[7]	+[5]	+[10]	+[13]
4	F			100%		–[3]	–[4]	+[6]	+[6]	?[11]	?[14]
5	F	F		100%		–[3]	–[4]	+[6]	+[6]	+[10]	+[13]
6	100%	F			yes	+[2]	–[4]	+[8]	+[8]	–[12]	?[15]
7	100%	100%			yes	+[2]	–[4]	+[9]	+[9]	–[12]	?[15]
8	100%			100%	yes	+[2]	–[4]	+[9]	+[9]	–[12]	?[15]
9	100%	F				+[2]	–[4]	+[8]	+[8]	+[10]	+[13]
10	100%	100%				+[2]	–[4]	+[9]	+[9]	+[10]	+[13]
11	100%			100%		+[2]	–[4]	+[9]	+[9]	?[11]	?[14]

[1] Since some HO fish are both unmarked and untagged, it would not be possible to identify all HO fish in a sample and thus it would not be possible to eliminate all HO fish or reduce their contribution by more than the hatchery marking fraction, F. Limited reduction in HO proportion would be possible by removing marked fish, but not if substantial numbers of marked NO fish are also present.

[2] Conceptually feasible if weirs are installed and continuously and successfully operated downstream of all spawning areas, with HO fish identified using ETD in Systems 2 and 3, ADC in Systems 6, 8, 9, and 11; and either ETD or ADC in Systems 7 and 10. May not be feasible in all streams, and weir operation and fish control in years of high abundance would be problematic. Assumes that there would not be significant straying of marked (or tagged in Systems 2 and 3) NO fish into manipulated areas, or at

least that marked (or tagged in Systems 2 and 3) HO fish greatly outnumber marked (or tagged in Systems 2 and 3) NO fish. Similarly, assumes that unmarked DIT fish required to evaluate MSF impacts (Systems 6–8) would not significantly compromise this goal.

[3] Real-time identification of all hatchery-origin fish would not be possible (genotyping required), although partial manipulations as in System 1 would be possible.

[4] Identification to hatchery of origin in real-time not possible (extraction and reading of CWTs or sequencing of genetic samples and comparison against a database would be required).

[5] Proportion HO [or out-of-basin HO] could be estimated by summing marked fish expanded (for mark rate) tag recoveries across all HO [or out-of-basin HO] release groups present in samples. Accurate estimates may not be possible for hatchery-specific contributions in very small populations (where the total number sampled is less than 50 fish) when the hatchery marking fraction, F, is no more than the current 25%.

[6] Proportion HO [or out-of-basin HO] could be estimated by summing marked fish expanded (for mark rate) tag (CWT or genotype) recoveries across all HO [or out-of-basin HO] release groups present in samples. Accurate estimates may not be possible for hatchery-specific contributions in very small populations (where the total number sampled is less than 50 fish) when the hatchery marking fraction, F, is no more than the current 25%. Expanding for mark rate would not be required if ETD was used to recover tags from unmarked fish, and if no tagged NO fish were present, proportion HO [or out-of-basin HO] could be estimated directly from the number of tagged fish (not an option for System 5 unless all fish, marked or unmarked, are genotyped).

[7] Proportion HO [or out-of-basin HO] could be estimated by summing marked fish expanded (for mark rate) tag recoveries across all HO [or out-of-basin HO] release groups present in samples. Accurate estimates may not be possible for hatchery-specific contributions from very small populations (where the total number sampled is less than 50 fish) when the hatchery marking fraction, F, is no more than the current 25%. If no tagged NO fish were present and ETD was used to recover AWT from unmarked fish, proportion HO (not separated by basin of origin) could be estimated directly from the number of tagged (CWT or AWT) fish.

[8] Proportion HO [or out-of-basin HO] could be estimated by summing expanded (for tag rate) tag recoveries across all HO [or out-of-basin HO] release groups present in samples. If no tagged NO fish were present, proportion HO (not separated by basin of origin) could be estimated directly from the number of marked fish. Unmarked DIT fish required to evaluate MSF impacts (System 6) would require ETD applied to unmarked fish.

[9] Proportion HO [or out-of-basin HO] could be estimated by summing tag recoveries (no expansion required) across all HO [or out-of-basin HO] release groups present in samples. If no tagged NO fish were present, proportion HO (not separated by basin of origin) could be estimated directly from the number of marked fish, although this would miss the contributions of unmarked DIT fish required to evaluate MSF impacts (Systems 7 and 8). Unmarked DIT fish required to evaluate MSF impacts (System 6) would require ETD applied to unmarked fish.

[10] Estimating NO production requires an estimate of proportion HO to estimate NO escapement from total escapement, and a cohort reconstruction (based on representative fish) to scale NO escapement to production. Cohort reconstructions could be performed for marked and tagged (CWT) fish under this system, and marked fish are assumed representative of unmarked NO fish in the absence of MSF.

[11] Estimating NO production requires an estimate of proportion HO to estimate NO escapement from total escapement, and a cohort reconstruction (based on representative fish) to scale NO escapement to production. Cohort reconstruction under PBT could in principle achieve this, but it would require coastwide genetic sampling, the development of a new coastwide database for genetic tag recoveries, and sufficient hatchery infrastructure to segregate/track the required number of discrete release groups from spawning until release. Whether all of these requirements could be met is uncertain.

[12] Estimating NO production requires an estimate of proportion HO to estimate NO escapement from total escapement, and a cohort reconstruction (based on representative fish) to scale NO escapement to production. With MSF, cohort reconstructions performed on marked and tagged fish would not be representative of unmarked NO fish, therefore NO production could not be estimated.

[13] Systems that allow for cohort reconstructions of marked and tagged fish that are assumed to be representative of unmarked NO fish would allow for continued use of current harvest management models to achieve anticipated exploitation rates.

[14] Systems that allow for cohort reconstructions of marked and tagged fish that are assumed to be representative of unmarked NO fish would allow for continued use of current harvest management models to achieve anticipated exploitation rates. Cohort reconstruction under PBT could in principle achieve this, but it would require coastwide genetic sampling, the development of a new coastwide database for genetic tag recoveries, and sufficient hatchery infrastructure to segregate/track the required number of discrete release groups from spawning until release. Whether all of these requirements could be met is uncertain.

[15] With MSF, fisheries would in principle be managed to achieve higher fishery mortality rates on ADC HO fish. The realized total fishery mortality rate on NO fish thus may, or may not achieve the NO target fishery mortality rate depending on numerous factors (fishery mortality rate on ADC HO fish; hook-and-release mortality rate; probability of repeat encounters of unmarked fish, etc.). Current harvest management models for CV and KT Chinook salmon are incapable of modeling MSF mortality rates on unmarked fish.

Table B6. Conservation of other salmon stocks. Qualitative assessment of degree to which proposed marking/tagging systems can meet criteria. Marking/tagging systems: ADC denotes adipose fin clip; CWT denotes coded wire tag; AWT denotes agency wire tag; PBT denotes parental-based tag; MSF denotes mark-selective fisheries; F denotes a fraction (0<F<1) in a (constant) fractional marking and/or tagging scheme; 1-F denotes the remaining fraction of fish; "yes" indicates that MSF would be associated with the marking/tagging system. If a system specifies F for ADC and CWT, it refers to the same group of fish. Criteria are defined in Table 3; "HO" denotes "hatchery-origin"; "E-rates" denotes "fishery mortality rates"; "+" denotes "clearly meets criterion"; "≈" denotes "partially meets the criterion, or requires a major increase in costs compared to other fully capable systems"; "–" denotes "clearly does not meet criterion"; "?" denotes "unclear if would meet criterion". Footnotes provide rationale and/or qualification for rating assessments.

Marking/tagging system						Criterion			
System	ADC	CWT	AWT	PBT	MSF	Restrict fall HO from spring spawning areas in real-time	Compatible with other HO CWT studies	Compatible with NO CWT studies	Achieve non-fall E-rates
1	F	F				–[1]	+[4]	+[4]	+[12,4]
2	F	100%				–[2]	+[5]	≈[5,9]	+[12,5]
3	F	F	1-F			–[2]	+[5]	≈[5,9]	+[12,5]
4	F			100%		–[3]	?[6]	?[6]	?[12,6]
5	F	F		100%		–[3]	+[5]	+[5]	+[12,5]
6	100%	F			yes	–[2]	+[7]	–[10]	?[13]
7	100%	100%			yes	–[2]	≈[8]	–[10]	?[13]
8	100%			100%	yes	–[2]	?[6,8]	–[10]	?[13]
9	100%	F				–[2]	+[7]	≈/+[7,9,11]	+[12,7]
10	100%	100%				–[2]	≈[8]	≈/+[8,9,11]	≈[12,8]
11	100%			100%		–[2]	?[6,8]	?[6,8,9,11]	?[12,6,8]

[1] This system could not identify all HO fall-run Chinook salmon.

[2] This system could identify HO fish in real-time, but could not differentiate HO fall-run from HO spring-run fish.

[3] Real-time identification of all HO fish would not be possible (genotyping required).

[4] This is the system under which other HO and NO CWT studies were developed. Under this system ADC assures the presence of CWT, thus ADC fish from other stocks would be sampled for CWT, at similar rates to the status quo.

[5] Under this system ADC assures the presence of CWT, thus ADC fish from other stocks would be sampled for CWT, at similar rates to the status quo.

[6] Under this system ADC denotes PBT but not CWT for the numerically dominant fall-run stocks. ETD would be required on all ADC recoveries to differentiate ADC+CWT fish from ADC+PBT fish, and subsequent collection of head or tissue sample. Would require coastwide genetic sampling and a coastwide database for genetic tag recoveries, and whether these requirements could be met is uncertain. Recovering CWT from non-fall HO stocks would require an inefficient parallel system, or a switch of non-fall hatcheries to PBT as well, and it is unclear whether such system costs would be borne just to recover a small number of tags.

7 With 100% ADC but fractional CWT, ETD would be required on all ADC recoveries to identify ADC+CWT fish. Rare stock enrichment could be achieved by fully tagging less abundant stocks.

[8] With 100% ADC+CWT [or ADC+PBT], the recovery rate of CWTs from relatively small release groups would likely be substantially reduced due to dilution (unless substantial increases in sampling costs were tolerated), which would increase the statistical uncertainty associated with all relatively small tagging studies.

[9] Although ADC+CWT NO fish would be sampled under this system, their presence in areas where real-time manipulation of proportion HO via EDT [or presence of ADC] was desired would violate the assumption that only HO fish are tagged (CWT or AWT) [or marked with ADC] required to manipulate the proportion HO in real-time, thus defeating a major motivation for proposing this system.

[10] Under this system, tags recovered from marked NO fish would not be representative of exploitation rates on unmarked NO fish. Additionally, marking of NO fish may be incompatible with the goals of MSF, because it would make those NO fish targets of the fishery. It might be possible to tag but not mark NO fish, however such fish would not be recovered in fisheries sampling and so no information on NO ocean ecology, or NO ocean or river fishing mortality, would be provided.

[11] NO fish could be tagged but not marked, thus they would not interfere with identification of HO fish in real-time on the basis of ADC, however recovering the tags would require applying ETD to all unmarked fish in samples. This could be a substantial expense, but NO tagging studies are already expensive.

[12] We assume non-fall-run Chinook salmon E-rates can be achieved if cohort reconstructions can be performed for the current set of non-fall indicator stocks, all of which are HO in California. Thus we assume these E-rates can be achieved by systems compatible with non-fall HO CWT studies, and HO stocks remain suitable as indicators.

[13] With MSF, fisheries would in principle be managed to achieve higher fishery mortality rates on ADC HO fish. The realized total fishery mortality rates on non-fall stocks thus may, or may not achieve the target fishery mortality rates for those stocks depending on numerous factors (fishery mortality rate on ADC HO fish; hook-and-release mortality rate; probability of repeat encounters of unmarked fish, etc.). Current harvest management models for CV and KT Chinook salmon are incapable of modeling MSF mortality rates on unmarked fish.

Table B7. Management of salmon fisheries. Qualitative assessment of degree to which proposed marking/tagging systems can meet criteria. Marking/tagging systems: ADC denotes adipose fin clip; CWT denotes coded wire tag; AWT denotes agency wire tag; PBT denotes parental-based tag; MSF denotes mark-selective fisheries; F denotes a fraction (0<F<1) in a (constant) fractional marking and/or tagging scheme; 1-F denotes the remaining fraction of fish; "yes" indicates that MSF would be associated with the marking/tagging system. If a system specifies F for ADC and CWT, it refers to the same group of fish. Criteria are defined in Table 3; "HO" denotes "hatchery-origin"; "NO" denotes "natural-origin"; "E-rates" denotes "fishery mortality rates"; "+" denotes "clearly meets criterion", "≈" denotes "partially meets the criterion, or requires a major increase in costs compared to other fully capable systems"; "–" denotes "clearly does not meet criterion"; "?" denotes "unclear if would meet criterion". Footnotes provide rationale and/or qualification for rating assessments.

Marking/tagging system						Criterion				
System	ADC	CWT	AWT	PBT	MSF	Estimate/forecast HO E-rates, age x fishery	Estimate/forecast unmarked E-rates, age x fishery	Estimate NO & HO escapement at age	Compatible with existing CWT system	Support increased opportunity/harvest
1	F	F				+[1]	+[5]	+[7]	+[13]	–[17]
2	F	100%				+[1]	+[5]	+[8 or 7]	+[13]	–[17]
3	F	F	1-F			+[1]	+[5]	+[8 or 7]	+[13]	–[17]
4	F			100%		?[2]	?[2,5]	?[9]	–[14]	–[17]
5	F	F		100%		+[1]	+[5]	+[7 or 9]	+[13]	–[17]
6	100%	F			yes	+[3]	–[6]	+[10]	≈[15]	?[18]
7	100%	100%			yes	≈[4]	–[6]	+[11]	≈[16]	?[18]
8	100%			100%	yes	?[2,4]	–[6]	+[11]	–[14]	?[18]
9	100%	F				+[3]	+[3,5]	+[10]	≈[15]	–[17]
10	100%	100%				≈[4]	≈[4,5]	+[11]	≈[16]	–[17]
11	100%			100%		?[2,4]	?[2,4,5]	+[11]	–[14]	–[17]

[1] Under this system, ADC assures the presence of CWT, thus CWT from all stocks would be expected to be recovered at similar rates given the current sampling scheme, allowing continued use of existing harvest models to estimate and forecast HO E-rates.

[2] E-rate calculation and forecasting requires the ability to perform cohort reconstructions for PBT fish. Would require coastwide genetic sampling, a coastwide genetic database, and sufficient hatchery infrastructure to segregate/track the required number of discrete release groups from spawning until release, and whether all of these requirements could be met is uncertain.

[3] Under this system, ETD would be required on all ADC recoveries to identify ADC+CWT fish, but we would not anticipate significant reductions in sampling rates and tag recoveries from rare stocks.

[4] Under this system, the recovery rate of CWTs from relatively small release groups would likely be substantially reduced due to dilution (unless substantial increases in sampling costs were tolerated), compromising the SR winter-run Chinook salmon cohort reconstruction and harvest models (and limiting the ability to develop a similar set of models for spring-run stocks if desired).

[5] Assumes tagged HO stock serves as adequate indicator for untagged stock.

[6] DIT does not allow for estimation of fishery-specific mortality rates on the unmarked component, and current harvest management models for CV and KT Chinook salmon are incapable of modeling MSF mortality rates on unmarked fish.

[7] Hatchery-origin: CWT-decode and expand marked fish. Natural-origin: Scale age unmarked fish. Given total escapement at age, subtract unmarked HO contribution (expanded from CWT).

[8] Hatchery-origin: CWT-decode and expand marked fish (or for System 2 only: CWT-decode tagged fish, detected electronically). Natural-origin: scale-age untagged fish (detected electronically). Assumes negligible contribution of tagged but unmarked NO fish.

[9] Hatchery-origin: Use ETD on recovered ADC fish to determine whether any CWT fish are present. Extract those tags and expand for mark and tag rates. Genotype remaining ADC fish and expand those which identify back to known parents for mark rate (this assumes all non-assigning fish did not have genotyped HO parents, so some correction may be necessary if some hatcheries using PBT fail to achieve 100% broodstock genotyping, as well as an accounting for false negatives in parental assignments). Natural-origin: scale-age unmarked fish to estimate cumulative age structure of unmarked fish, and subtract off the estimated unmarked contribution of HO fish to each age class based on the expansions performed for HO. ETD and reading of CWT would not be needed if all hatcheries likely to contribute to escapement in relevant strata used PBT rather than CWT. It may be difficult to obtain usable genotypes from significantly decomposed carcasses, and models need to be developed to characterize the probability of false negatives.

[10] Hatchery-origin: CWT-decode and expand tagged fish (detected electronically). Natural-origin: scale-age unmarked fish. Assumes negligible contribution of marked NO fish.

[11] Hatchery-origin: decode marked fish tags (CWT or PBT). Natural-origin: scale-age unmarked fish. Assumes negligible contribution of marked NO fish and unmarked DIT fish.

[13] ADC assures the presence of CWT, providing compatibility with the existing coastwide CWT sampling scheme. ETD is not required and tag recoveries would not increase substantially, so sampling costs for existing programs would not be affected.

[14] A system in which no HO fall-run fish have CWT is not compatible with the existing coastwide CWT sampling scheme.

[15] CWT would still be recovered in this system, but ETD would be required to prevent the costly processing of many marked but untagged fish.

[16] CWT would still be recovered in this system, but substantial increases in personnel and infrastructure would be needed to cope with the large increase in numbers of fish with ADC+CWT.

[17] There is nothing inherent to this system designed to increase or decrease fishing opportunity.

[18] The degree to which fishing opportunities and harvest might be increased is difficult to gauge with any degree of confidence as it depends on a large number of variables, but it would likely vary substantially across years.

Table B8. Management of salmon hatcheries. Qualitative assessment of degree to which proposed marking/tagging systems can meet criteria. Marking/tagging systems: ADC denotes adipose fin clip; CWT denotes coded wire tag; AWT denotes agency wire tag; PBT denotes parental-based tag; MSF denotes mark-selective fisheries; F denotes a fraction (0<F<1) in a (constant) fractional marking and/or tagging scheme; 1-F denotes the remaining fraction of fish; "yes" indicates that MSF would be associated with the marking/tagging system. If a system specifies F for ADC and CWT, it refers to the same group of fish. Criteria are defined in Table 3; "HO" denotes "hatchery-origin"; "+" denotes "clearly meets criterion"; "≈" denotes "partially meets the criterion, or requires a major increase in costs compared to other fully capable systems"; "–" denotes "clearly does not meet criterion"; "?" denotes "unclear if would meet criterion". Footnotes provide rationale and/or qualification for rating assessments.

Marking/tagging system						Criterion						
System	ADC	CWT	AWT	PBT	MSF	Manipulate proportion NO in hatchery matings	Eliminate out-of-basin HO in hatchery matings	Assess performance of HO release groups	Reduce over-escapement to hatcheries	Estimate hatchery-specific stray rates	Compatible with conserv. hatcheries	Minimal changes to hatchery operations
1	F	F				–[1]	–[6]	+[7]	–[9]	+[11]	+[12]	+[15]
2	F	100%				+[2]	+[3]	+[7]	–[9]	+[11]	+[12]	–[16]
3	F	F	1-F			+[2]	–[6]	+[7]	–[9]	+[11]	+[12]	–[16]
4	F			100%		≈[3]	+[3]	?[7]	–[9]	+[11]	+[12]	–[17]
5	F	F		100%		≈[3]	+[3]	+[7]	–[9]	+[11]	+[12]	–[17]
6	100%	F			yes	+[4]	–[6]	+[7]	?[10]	+[11]	–[13]	–[16]
7	100%	100%			yes	+[4,5]	+[3]	≈[7,8]	?[10]	+[11]	–[13]	–[16]
8	100%			100%	yes	+[4,5]	+[3]	?[7]	?[10]	+[11]	–[13]	–[16,17]
9	100%	F				+[4]	–[6]	+[7]	–[9]	+[11]	+[12]	–[16]
10	100%	100%				+[4,5]	+[3]	≈[7,8]	–[9]	+[11]	≈[14]	–[16]
11	100%			100%		+[4,5]	+[3]	?[7]	–[9]	+[11]	≈[14]	–[16,17]

[1] Note that if some marked (or tagged in Systems 2 and 3) NO fish stray to hatcheries, manipulations of the proportion HO will be imprecise (some NO fish may be inadvertently eliminated, and the proportion HO in the retained broodstock may be lower than estimated based just on the proportion of broodstock that was marked or tagged. For Systems 2, 7, and 9, post-hoc reading of tags would allow correctly identifying NO fish that might have initially been mischaracterized as HO. For Systems 4, 5, 8, and 11, post-hoc genotyping and identification of parents would allow correctly identifying NO fish that might have initially been mischaracterized as HO, assuming that all contributing hatcheries fully genotyped their broodstock.

[1] A large fraction of HO fish could not be identified as such. It would be possible to reduce HO contribution somewhat by culling marked fish.

[2] All HO fish could be identified as such in real-time using ETD. If some tagged NO fish stray to hatcheries, manipulations of the proportion HO based on unread tags would be imprecise, although post-hoc reading of tags would allow correctly identifying NO fish that might have initially been mischaracterized as HO.

[3] Could be accomplished post-hoc based on decoded tags, but would require pairwise matings, individual traying, and identification of eggs from specific matings, to allow destruction of excess eggs with HO parents (or out-of-basin parents). For simply manipulating proportion HO, this is less cost-effective than systems allowing real-time identification.

[4] All HO fish could be identified on the basis of ADC (except for unmarked DIT fish in systems with MSF). If some ADC NO fish stray to hatcheries, manipulations of the proportion HO based on ADC would be imprecise.

[5] Although manipulations of the proportion HO in real-time based on ADC would be imprecise if some ADC NO fish stray to hatcheries, post-hoc reading of CWT (Systems 7 and 10) or genotyping and parental assignment (Systems 8 and 11) would allow correctly identifying NO fish that might have initially been mischaracterized as HO.

[6] Under this system, not all HO fish could be identified back to their hatchery of origin.

[7] Evaluating performance requires a system capable of performing cohort reconstructions (to calculate survival from release to pre-fishery recruitment) and estimating the number of fish harvested in (contributing to) a fishery by release group, which can be derived from the harvest proportion HO (release-specific). All systems are capable of estimating contributions by release group (Table 5, "Est. out-of-basin proportion HO"), so the score in this column is driven by "Estimate/forecast E-rates HO" in Table 7, since cohort reconstructions are required to do this. System-specific explanations are therefore in Table 7.

[8] While the ability to perform cohort reconstructions for small stocks (e.g., SR winter-run Chinook salmon) is uncertain under Systems 7 and 10 due to pressures for reduced sampling rates following increased fall-run recoveries, fall-run cohort reconstructions would still be possible at reduced sampling rates and therefore so would performance evaluation for fall-run Chinook salmon hatcheries. However performance of individual release groups could be difficult to estimate even for fall run, unless the minimum size of experimental release groups was increased sufficiently to accommodate any change in sample rates.

[9] These systems are not designed for harvest to target HO fish over NO fish (manipulations addressed in earlier tables are considered to occur post-escapement).

[10] To meet this criterion, MSF would have to achieve a substantial increase in the fishery mortality rate on hatchery-origin fish. However, the degree to which this would be possible is difficult to gauge with any degree of confidence as it depends on a large number of variables, but it would likely vary substantially across years.

[11] Estimating stray rates would require the ability to estimate, by release group, total escapement to all relevant areas. Assuming all relevant areas are sampled, all of these systems are capable of doing this as described under "Est. out-of-basin prop. HO" in Table 5.

[12] Under these systems, HO fish are not particularly targeted for increased fishing mortality, so there is no conflict with conservation hatchery goals.

[13] LSNFH winter Chinook salmon are 100% ADC+CWT, with the offspring of parental-pairs receiving a unique CWT. The information generated from the CWT recoveries are used for many purposes, including providing for direct estimates of the realized incidental fishery mortality rates on ESA-listed SR winter-run Chinook salmon. With MSF, LSNFH may stop ADC-marking their fish so that they are not targeted on by the MSF, but lacking an ADC-mark might complicate other aspects of the LSNFH program (e.g., broodstock selection). Establishing DIT groups (to estimate cumulative, but not stratum-specific, mortality from MSF) would not be possible because the total number of fish released from LSNFH are already only minimally sufficient to provide adequate tag recoveries with 100% of the fish tagged, without subdividing these tags among multiple groups for which independent inferences are required.

[14] This system would not pose problems for the use of ADC in conservation hatcheries. However, under this system, the recovery rate of CWTs from relatively small release groups would likely be substantially reduced due to dilution (unless substantial increases in sampling costs were tolerated). Thus while conservation hatcheries could continue to operate, and exclude HO broodstock if desired, they would have limited ability to assess their performance through cohort reconstructions.

[15] This is the current system, so no changes would be needed.

[16] Substantial increases in marking and/or tagging levels would be required for these systems.

[17] Facilities and methodologies to keep offspring from different parental groups segregated for their entire rearing period would be required for discrete release groups under a PBT-based system. Uniquely tagging unplanned release groups would be essentially impossible (it would be possible to genetically fingerprint every individual in the unplanned release group, but at substantial cost).