UNITED STATES OF AMERICA
FEDERAL ENERGY REGULATORY COMMISSION

In the Matter of Order on Ten Year Fisheries Summary Report For the Don Pedro Hydroelectric Project	|	Project No. 2299-057

REQUEST FOR REHEARING OF CALIFORNIA DEPARTMENT OF FISH AND GAME

Pursuant to 18 C.F.R. ' 385.713 of the Rules of Practice and Procedure of the Federal Energy Regulatory Commission ("Commission" or "FERC"), California Department of Fish and Game (CDFG) respectfully requests rehearing of the Commission's September 6, 2007, *Order on Ten-Year Summary Report under Article 58* ("Order Approving Report") for the Don Pedro Hydroelectric Project, FERC Project No. 2118. Specifically, the Department of Fish and Game requests that the Commission reconsider their determination of compliance with regard to the Ten Year Summary Report submitted by the Modesto Irrigation District and Turlock Irrigation District (Districts) No. 2118 with regard to the Districts' monitoring efforts under Article 58, as well as data on non-flow mitigation and efforts and participation in other programs to improve fisheries in the San Joaquin River Basin.

I. STATEMENT OF ISSUE

The Commission should reconsider the Order Approving Report, based on further analysis of existing information, and new information regarding the continuing accelerated decline in the Tuolumne River salmon population. CDFG believes, based on information already provided to the Commission, and the accelerated decline of the Tuolumne River salmon population, that the primary limiting factor for salmon populations is the timing and magnitude of the instream flows currently released by the Districts below the above reference hydroelectric project. We request a re-evaluation of the effects of flow magnitude, timing and duration in the Tuolumne River as controllers of the salmon population, and the relationship of salmon production to water temperature. CDFG does not agree with the Commission's and Districts' evaluation of the extent of effects of out-of-tributary controlling factors on Tuolumne River salmon. Lastly, a preliminary United States Fish and Wildlife Service Report (USFWS) identifies the Tuolumne River fall-run Chinook salmon population to be at a high risk of extinction due to inadequate in-river conditions (e.g. insufficient instream flow releases) caused by Project operations.

II. REQUEST FOR REHEARING

A. Background

In a letter dated June 15, 2007, CDFG provided detailed comments regarding "*FERC Staff's Preliminary Analysis of the Tuolumne River Fisheries Study by Modesto and Turlock Irrigation Districts*" (FERC Project No. 2299). We requested requesting that the Commission consider additional information in their analysis, noting CDFG's strong concern with the Commission's preliminary determination that changes to the Tuolumne River spring instream requirements were unwarranted at that time. This concern was based on strong evidence that the Tuolumne River fall-run chinook salmon population has declined severely, and drastically below pre-project levels, which affects California significantly. As stated in that letter, this fall run was historically documented (U.S. Fish and Wildlife Service, 1940) to annually exceed 72,000 escaping (i.e., spawning) adults. In Ninth Circuit Court documents, prior to the onset of this power projects, several references to 40,000 salmon are documented. Today there are less than 1,000 fish, so this problem has become even worse. This reduction is severe and is, in part, caused by, water diversions and dams which were developed and are operated for power production on the Tuolumne River. The Tuolumne River is one of four major tributaries in the San Joaquin Basin. Hydrologically, it is among the two most significant sources of natural habitats and flows to protect public trust resources pursuant to License 2299.

a. Decline of Salmon Populations

Immediately prior to the operation of the New Don Pedro Project, fall-run salmon numbers annually reached 20,000 to 25,000 escaping adults, but the instream flow and other fishery protection measures included in the original Project 2299 license were inadequate to stem the continuing decline of salmon. By the time of the 1996 Fisheries Settlement Agreement, salmon numbers had progressively declined to less than 1,000 adults annually. This decline, both overall and when dissected into various life-stage survival components, very strongly correlates with Tuolumne River flow inadequacy during critical salmon life-stages.

b. San Joaquin River Watershed

CDFG believes that neither ocean harvest, nor ocean conditions, nor Delta exports, even though they are in fact minor sources of mortality, are strong controlling factors in the abundance, health and vitality of the Tuolumne River adult salmon population. Annual adult salmon escapement abundance in the Tuolumne River began its sharp decline well before the poor ocean condition phenomena experienced in summer of 2007 (Figure 9, Page 16, Marston[1] 2008 [Attachment 1]). Additionally, a new analysis of the

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[1] Marston, D. 2007. San Joaquin River Fall-run Chinook salmon and steelhead Rainbow Trout Historical Population Tred Summary . CDFG report to the Regional Water Quality controcl Board pursuant to CDFG's petition to list water temperatures in the Tuloumne, Stanislaus, Merced, and lower San Joaquin Rivers as impaired.

relationship between Delta smolt survival and Delta exports, and San Joaquin River inflow (i.e. Tuolumne River contributions along with other tributary flows (Newman 2008[2] [Attachment 2}) suggest that the Tuolumne River adult salmon population is primarily affected and controlled by in-tributary limiting factors, rather than oceanic or other downstream controlling features.

c. Tuolumne River Sub-Watershed

Within the Tuolumne River sub-watershed, there are substantial indications that factors limiting the salmon population in that river are directly associated with the instream flow amounts, duration, frequency and timing, associated with the Licensees' Project 2299 operations. We reiterate that this reflects a very consistent relationship between spring flow reduction and escapement reduction in the Tuolumne River between escapement years 2000 and 2006. Based on an investigation of the relationship between spring flow (magnitude, frequency/duration) and salmon escapement 2.5 years later, wherein spring flows for the period 2000- 2006, were categorized by both flow and frequency/duration of occurrence, a very clear trend in spring flow magnitude and duration was noted, which strongly correlates with Tuolumne River adult salmon production. This very important and revealing relationship prevails regardless of whether annual escapement or brood-year cohort production metrics are used.

d. Relationship of Salmon Production and Steelhead Habitat to Tuolumne River Water Temperature below the Project Dam

In addition to assessing Tuolumne River spring flow as a factor in Tuolumne River salmon production declines, spring Tuolumne River (Modesto measurement station) water temperature has been evaluated as a factor affecting Tuolumne River salmon brood year production. There is strong evidence that river water temperatures at the Modesto measurement station are driven primarily by minimum Tuolumne River instream flow releases from Project 2299 Dams. Substantial variation in spring water temperature frequency across the critical salmon thermal range occurred among spring Tuolumne River temperatures between 1998 and 2004. Years with colder spring water temperatures clearly produced higher adult escapement 2.5 years later, than was observed under warmer springtime conditions. We specifically noted that when spring water temperatures in the Tuolumne River at Modesto were below 15ºC (the U.S. Environmental Protection Agency (EPA) Region 10 Water Temperature Threshold Standard for Tributary Out-migrating Juvenile Chinook Salmon smolts), Tuolumne River adult salmon brood year production was at its highest. Due to the demonstrated influence of instream flow releases upon water temperatures on key reaches in the lower Tuolumne River, the spring and fall thermal regimes within the Tuolumne River downstream of New Don Pedro and La Grange Dam are controlled significantly by Project 2299 operations, and are therefore an important variable influencing and controlling adult

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[2] Newman, K. 2008. An Evaluation of Four Sacramento-San Joaquin River Delta Juvenile Salmon Survival Studies. FWS Service Report to CALFED for Project No. SCI-06-G06-299.

salmon production trends in the Tuolumne River. In addition, summer low flows in average or drier water years result in a longitudinal (along the river) and special (area) habitat constrictions, which confine steelhead rainbow trout distribution and likely their abundance.

e. Summary

As described above CDFG has provided substantial information that California's public trust resources are being severely impacted by this Project. . The primary factors controlling the salmon population to the Tuolumne River are occurring within the reach of the River which is directly operated in association with Project 2299. Districts have asserted that other downstream factors within the San Joaquin River and Delta are principally responsible for the observed salmon population declines. However, since Tuolumne River flow contributions from the project requirements are important in determining the fate of salmon and other species (e.g. Delta smelt, long fin smelt, steelhead), in the Delta this too is a direct affect of Project operations. We have observed a very dramatic decline in Tuolumne River salmon adult escapement between 2000 and 2007, while the Fishery Settlement Agreement flow regimes and other protective features have been in place. The strong relationship between this observed population decline and the conditions of reduced spring flow and elevated spring water temperature indicated needed changes in the operations of project 2299. Our analysis, only a part of which is provided above, shows fairly comprehensively, that out-of-tributary limiting factors are indeed in play, yet are not the most important determinants of Tuolumne River salmon production, by at least an order-of-magnitude.

III. CONCLUSION

On the basis of the above discussion, and the extinction risk of the Tuolumne River salmon population raised by the FSW and due in part to Project operations, we respectfully request FERC to reconsider their determination on the Ten Year Summary Report, and require the Districts to conduct further and more comprehensive analysis related to the in river limiting factors. Further, based on the number of years remaining in the current license and the failure of the measures provided in the FSA to effect salmon population protection, we respectfully request your Commission to direct the Licensees to evaluate alternative approaches to provide higher magnitude and greater duration instream flows especially during the spring period of drier than average water years, to assure acceptable salmon smolt survival and other effective measures to assure that the now-critically-impaired salmon populations will remain intact and recover as a new power license is considered for Project 2299 as early as 2014. Additionally, CDFG respectfully requests FERC to direct the Licensees to begin working with our Department, the U.S. Fish and Wildlife Service, and the National Marine Fisheries Service to develop a conceptual and genetically sound salmon conservation style hatchery capability and a deployment plan, intended to help, in conjunction with increased spring pulse flows and other measures to boost juvenile and adult salmon production and to recover and sustain the Tuolumne River salmon and steelhead rainbow trout populations and restore these benefits to California..

Respectfully Submitted,

Original signed by W. E. Loudermilk

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William Loudermilk
Regional Manager

California Department of Fish and Game
Central Region
1234 East Shaw Avenue
Fresno, California 93710

Dated: __May 1___2008

FERC Service List
Attachments

San Joaquin River Fall-run Chinook Salmon and Steelhead Rainbow Trout Historical Population Trend Summary

Dean Marston
California Department of Fish & Game
September 2007

Acknowledgment

The author wishes to genuinely thank, and give due recognition to, the following individuals for their contributions to this report: Dr. Carl Mesick, Dr. Andy Gordus, and Mr. Dale Mitchell.

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Abstract

In response the continued declining trend of fall-run Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead rainbow trout (*Onchorhynchus mykiss*) in the San Joaquin River Basin[1] and the associated elevated water temperature trends during key life history phase time periods, the California Department of Fish and Game submitted a proposal to the California Central Valley Regional Water Quality Control Board to list water temperatures in the lower Stanislaus, Tuolumne, Merced, and San Joaquin Rivers as water temperature impaired. The Central Valley Regional Board asked the Department to submit information regarding the historical trends of salmon and steelhead in the San Joaquin River Basin (excluding the Mokelumne and Cosumnes Rivers). Substantial declines in fall-run Chinook salmon in the San Joaquin, Stanislaus, Tuolumne, and Merced Rivers has occurred since the 1940's and 1950's. Since the year 2000, when the most recent salmon escapement abundance high occurred, escapement has substantially declined in the Stanislaus, Tuolumne and Merced Rivers between the years 2000 and 2006. Consistent with this decline has been the associated reduction in spring flow magnitude and duration which has resulted in an increase in water temperature in the lower reaches of the San Joaquin east-side tributaries, during the later part of the spring smolt out-migration season. The salmon and steelhead populations that once existed in the mainstem San Joaquin River upstream of Friant were extirpated by the early 1950's. Little is known regarding steelhead abundance, and trends, in the San Joaquin River basin. Anecdotal reports from anglers and guides suggest that steelhead catch increases consistent with good, instream flow related, habitat quality (e.g. cool water temperature) exists.

Introduction

The purpose of this paper is to afford the California Department of Fish and Game (CDFG) the opportunity to document for the California Central Valley Regional Water Quality Control Board (CVRWQCB) a summary of the present, and historical, status of salmon and steelhead in the Stanislaus, Tuolumne, and Merced Rivers (i.e. principal east-side tributaries to the San Joaquin River). The CVRWQCB is presently considering, based upon a proposal by the California Department of Fish & Game, whether to list the lower reach of the San Joaquin River (e.g. Vernalis) and the lower reaches of the major east side tributaries (e.g. Stanislaus, Tuolumne, and Merced Rivers) as water temperature impaired for fall-run chinook salmon (*Oncorhynchus tshawytscha*) and steelhead rainbow trout (*Onchorhynchus mykiss*). The CDFG asserts that current water temperature regimes in the Stanislaus, Tuolumne, and Merced Rivers are not protecting the fall-run chinook salmon and steelhead beneficial uses in these rivers. The CDFG is providing this documentation to the CVRWQCB as a line of evidence to support a water temperature impairment designation for the lower San Joaquin, Stanislaus, Tuolumne, and Merced Rivers. Excessive water temperature is associated with the recent (e.g. since year 2000) substantial decline in abundance of fall-run chinook salmon and is believed to be likewise responsible for steelhead rainbow trout abundance trends as well.

The material provided herein is not intended to be an exhaustive account of the historical salmon and steelhead resources of the San Joaquin River (SJR) and its three southern

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[1] Excluding the Cosumnes and Mokelumne Rivers.

most east-side tributaries (e.g. Stanislaus, Tuolumne, and Merced Rivers) rather, it is a summary of the historical trends of the fall-run chinook salmon populations in each of these rivers providing a partial documentation of the declining trend of both salmon and steelhead in these rivers.

Physiologically speaking, water temperature has the capacity to control every aspect of a an anadroumous fishes life. Water temperature determines: i) whether or not adults successfully migrate into nursery areas to spawn, ii) where and when adults spawn, iii) whether or not eggs will be fertile (e.g. are viable) at time they are spawned and once, deposited, when they will hatch; iv) where juveniles will take up residence; and v) the on-set and duration of smoltification (e.g. release of hormones enabling salt water transition). Water temperature influences disease prevalence within salmonids, and both predation, and growth rates, of salmonids. Water temperature has the ability to be a population controlling (e.g. limiting) factor. In short, water temperature is an extremely important parameter in the production of anadromous salmonids within the SJR basin.

Historically speaking, salmon and steelhead populations once thrived in the San Joaquin River basin to a level of abundance that it has been said that San Joaquin River salmon abundance once rivaled that of the Klamath River at its salmon production apex. Today the once mighty San Joaquin, and its vast salmon and steelhead resources, are but a shadow of its once mighty stature. Where once salmon were so numerous one could walk across the river on the backs of salmon, today they are extinct in the mainstem San Joaquin and are in relatively poor condition in the Merced, Tuolumne, and Stanislaus Rivers.

Many factors have been suggested for the decline of San Joaquin River salmon and steelhead such as dams, water diversion, mining, and harvest. Around 1870 the California Fish Commission, in response to declining salmon population abundance, introduced fishing seasons, take limits, and gear restrictions in an effort to reduce the population decline. However as water development and mining continued unabated, San Joaquin River salmon abundance fell precipitously so much so that by the 1950's salmon became extinct in the mainstem San Joaquin River and populations of less than 500 were an all too common an occurrence in the Merced, Tuolumne, and Stanislaus Rivers (Figure 1). Since the 1950s, the trend in the abundance of adult salmon in all three tributaries has been highly correlated with the magnitude and duration of streamflow during the winter and spring when the juvenile fish rear and then migrate toward the ocean (Mesick & Marston)[2]. During dry and normal years, when flows are highly regulated during the winter and spring, very few salmon smolts outmigrate from the rivers and few adults from that cohort return over the next few years. However during wet years when high flows occur over several months, numerous salmon smolts outmigrate and many adults return over the next few years. The gradual decline in salmon abundance is clearly a result of increased water diversions that has led to unsuitably high water temperatures and a lack of floodplain inundation, which augments

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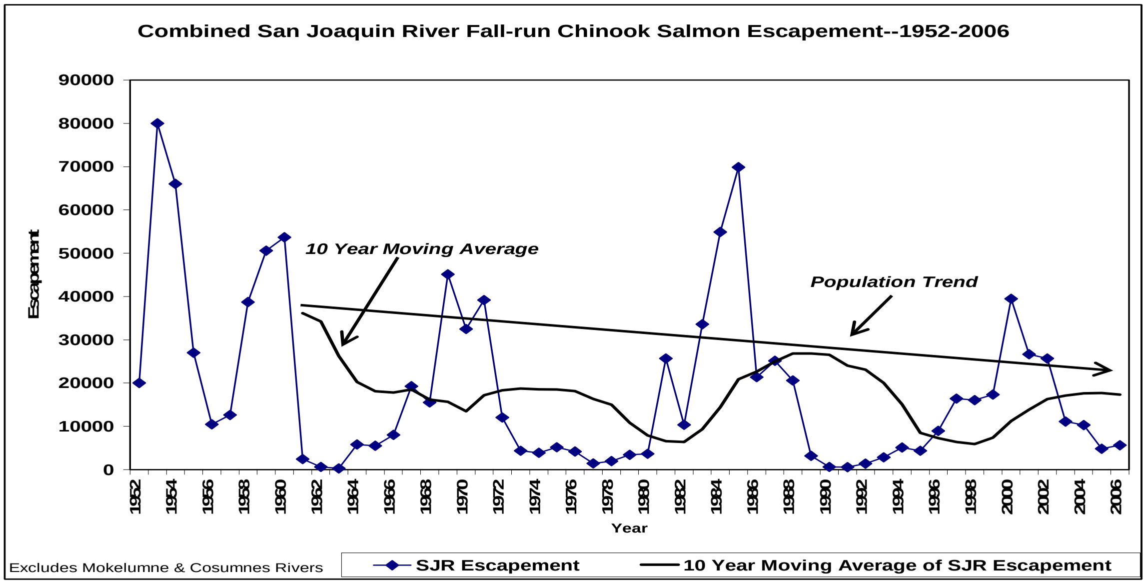
[2] Mesick, C. and D. Marston. 2007. Relationships Between Fall-run Chinook Salmon Recruitment to the Major San Joaquin River Tributaries and Streamflow, Delta Exports, the Head of the Old River Barrier, and Tributary Restoration Projects From the Early 1980's to 2003. Provisional Draft.

food resources and provides refuge from predation, during the rearing and outmigration periods. It is likely that high water temperatures have direct impacts as well as indirect impacts on juvenile survival. For example, high water temperatures increase the susceptibility of the juveniles to disease, predation, and contaminants increases (Myrick and Cech 2001[3]).

Figure 1. San Joaquin River Fall-run Chinook Salmon Annual Escapement Trends—1952 to 2006



The blue dotted line represents the combined annual San Joaquin River fall-run Chinook salmon escapement (e.g. for the Stanislaus, Tuolumne, and Merced Rivers). Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since 1952 there have been several peak escapement periods. The 10 year moving average[4] of escapement trends has the overall affect of reducing individual escapement peak amplitude and allowing visual determination of overall escapement trend over time (e.g. is trend increasing or declining). Overall San Joaquin River annual escapement is declining over time.

It should be noted that both steelhead and various runs of salmon were once abundant in the San Joaquin River basin. However, now: i) all runs of salmon and steelhead are extinct in the mainstem San Joaquin River[5]; ii) spring, winter, and late-fall run salmon are rare in the SJR east-side tributaries; iii) fall-run salmon in the Stanislaus, Tuolumne, and Merced Rivers are so low in abundance that they are considered to be in poor condition; and iv) steelhead are listed as a Federally Threatened species. Consistent with these declines has been the substantial reduction, over time, of spawning and rearing habitat

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[3] Myrick, C.A. and J.J. Cech, Jr. 2001. Temperature effects on Chinook salmon and steelhead: a review focusing on California's Central Valley populations. Published electronically by the Bay-Delta Modeling Forum at http://www.sfei.org/modelingforum/. Technical Publication 01-1.

[4] The 10 year moving average is a continuous moving average of 10 year blocks over the period of record. The first average (e.g. point along the line depicted) is the 1952 to 1962 annual escapement average. The second average is the 1953 to 1963 annual escapement average. The 20 year annual escapement averages continue up to the 1996 to 2006 time period.

[5] Occasionally in very wet years, salmon produced in other rivers stray into the mainstem SJR reach above the confluence with the Merced River.

quantity and quality caused primarily by water development (e.g. construction of dams and diversion of water). However, despite this substantial reduction one race of salmon (e.g. fall-run chinook) have shown the resiliency, as a population, to be able to rebound to, comparatively speaking, larger runs when favorable water quantity and quality conditions exist. Because water quality (e.g. temperature level) is largely dependent upon reservoir storage and release levels[6], managing water quantity is a necessary precursor to managing water quality. It is imperative that adequate water quality (e.g. temperature) exist to protect the beneficial use of both salmon and steelhead in the Stanislaus, Tuolumne, and Merced Rivers.

It should also be noted that the CDFG and the Oakdale, South San Joaquin, and Stockton East Water Districts, the U.S. Bureau of Reclamation, and the CALFED Ecosystem Restoration Program (collectively referred to as Stanislaus River Stakeholders) has funded and constructed a water temperature model for the lower Stanislaus River in response to substantial concerns regarding elevated water temperatures in the Stanislaus Rivers. The primary result of this effort has been to gain a better understanding of how reservoir storage and release volume influence water temperture trends in the lower Stanislaus River. A completed model and report are available upon request. Additionally, the U.S. Fish and Wildlife Service, the National Marine Fisheries Service, the Modesto and Turlock Irrigation Districts, and the Merced Irrigation District, in response to elevated water temperature and declining salmon and steelhead trends in both the Tuolumne and Merced Rivers, have joined the Stanislaus River Stakeholders in the construction of a water temperature model for the lower SJR basin[7]. This model will allow resource managers the opportunity to understand how the systems parts can be operated dependently to reduce water temperature impairment in the SJR basin. This model, and documentation, will be available this fall.

It is also noted that there is comprehensive restoration project recently initiated for the Friant reach of the mainstem San Joaquin River. How this project will influence water temperature impairment (e.g. improve or worsen) in the lower SJR remains to be seen. The CDFG recognizes that the SJR is a system comprised of dependent parts (e.g. mainstem and tributaries) that collectively have the capacity to exacerbate or ameliorate water temperature impairment in the SJR basin.

A summarized description of the decline of salmon and steelhead resources in the mainstem San Joaquin River and its three east-side tributataries the Stanislaus, Tuolumne, and Merced Rivers is now provided.

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[6] Meteorological conditions also influence water temperature response. However, both reservoir storage volume and reservoir release volume level can substantially delay water warming as water flows downstream of the reservoir.

[7] This Army Corp of Engineer based model (HEC5Q) simulates reservoir storage and lower river release for the Stanislaus, Tuolumne, and Merced Rivers. This model includes the SJR reach from SJR at Stevinson to the SJR at Mossdale.

Stanislaus

The California Fish Commission, in 1886, stated the Stanislaus River mirrored the Tuolumne River as a preeminent salmon stream, but that by 1886 only an occasional salmon was seen trying to get over its numerous dams. Damming and diversion of water for hydraulic gold mining and agricultural use of Stanislaus River water began soon after the gold rush circa 1850. At this time there was approximately 124 miles of the Stanislaus River available to salmon for use. In 1913 Goodwin Dam, at 20 feet in height, was built. In 1926 Old Melones Dam, a 200 foot high dam was built.[8]

In 1929 G.H. Clark noted: "The Stanislaus has a good spring and fall-run of salmon. The spawning grounds extend from the marsh lands above Oakdale to Knights Ferry, a distance of 10 miles. The Stanislaus like the other rivers, has dams which hinder and block the salmon. There was a small power dam built in 1910 at Knight's Ferry but it was replaced in 1913 by the Goodwin Dam, situated 18 miles above Oakdale. The dam is 20 feet high and has a fishway so that the salmon can spawn between the dame and the Melones Dam, which is a short distance above the old town of Melones in Iron Canyon. It is 210 feet high and was dedicated in 1926. The dam of course is an impassable barrier to salmon. It is a combination power and irrigation project. The abundance of salmon in the Stanislaus is about the same as in the Tuolumne. The rivers are very nearly alike and what is true in one is true in the other." [9]

In 1958 present Day Tulloch Dam was built. New Melones Dam construction was completed in the late 1970's, with Melones Reservoir filling for the first time in 1984. Prior to the dams, spring-run was the predominate race of salmon in the Stanislaus River. After the dams were built, fall-run became the predominate race of salmon. Today 58 miles of the Stanislaus River are available to salmon use, a 53% loss from historical levels. When only spawning and rearing habitat miles are considered, the loss is even greater (80% loss) as approximately 25 miles are left for salmon spawning and rearing today.[10]

Per Figure 2, prior to the construction of present day Tulloch Dam (1958) the average annual fall-run Chinook salmon escapement averaged 10,300 spawners[11]. Post Tulloch Dam Stanislaus River escapement declined to an average of 4,300 spawners. Post New Melones Reservoir operation annual escapement has further dropped to an average of 3,600 spawners. There continues to be a decline in the amplitude of annual escapement as water impoundment and diversion capability has increased on the Stanislaus River.

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[8] Material primarily from Yoshiyama, Ronald M., Eric R. Gerstung, Frank W. Fisher, and Peter. B. Moyle. 2001. Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California. Fish Bulletin 179. California Department of Fish & Game Publication.

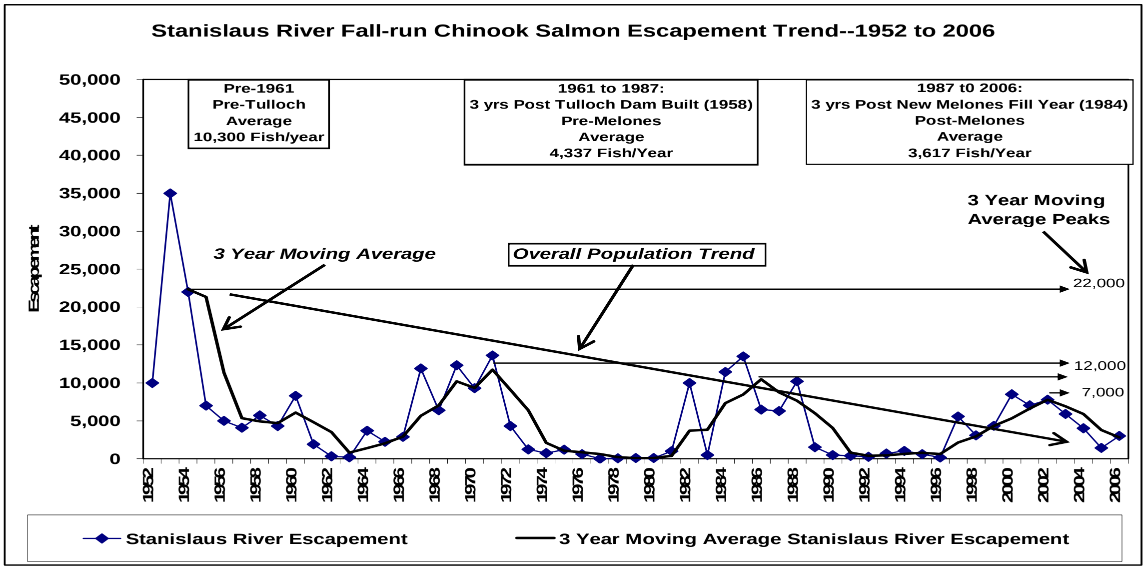
[9] From G.H. Clark. 1929. Sacramento-San Joaquin Salmon (*Onchorhynchus tschawytscha*) Fishery of California. Fish Bulletin No. 17. Division of Fish and Game of California.

[10] Material primarily from Yoshiyama, Ronald M., Eric R. Gerstung, Frank W. Fisher, and Peter. B. Moyle. 2001. Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California. Fish Bulletin 179. California Department of Fish & Game Publication.

[11] Escapement Data from California Department of Fish & Game's Central Valley Fall-run Salmon Escapement Estimate GrandTab Table dated August 2007.

Between 1952 and 2006 the Stanislaus River fall-run escapement population has oscillated over time and has dropped to levels less than 1,000 on several occasions. The average escapement of fall-run salmon in the Stanislaus River declined post New Melones time frame (Figure 2). Since 2000, the Stanislaus River escapement population has steadily declined and by 2006 (3,000 salmon) had dropped to about 65% percent below the year 2000 peak abundance of 8,500 salmon (Figure 3). It is important to note that this salmon production decrease in the Stanislaus River occurred at the same time both Delta exports and ocean harvest was reduced for the same time period (CDFG July 2007 Letter to the Federal Energy Regulatory Commission) which, strongly suggests that in-tributary factors, rather than out-side or downstream factors, are controlling salmon production in the Stanislaus River.

Figure 2. Stanislaus Fall-run Chinook Salmon Escapement Trend 1952 to 2006



The blue dotted line represents the annual historical Stanislaus River fall-run Chinook salmon escapement. Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since 1952 there have been several peak escapement periods. The 3 year moving average[12] of escapement trend is intended to account for the various ages of salmon that comprise an annual escapement. Juvenile salmon produced in one year (e.g. brood year) typically return as adults to spawn as age 2, 3, or four year old salmon. The three year moving average is intended to cover the three year period that salmon return to spawn post brood production year. The three year moving average indicates that the overall Stanislaus annual escapement is declining over time. This declining trend is consistent with the overall declining trend observed in Figure 1 for the SJR salmon escapement trend.

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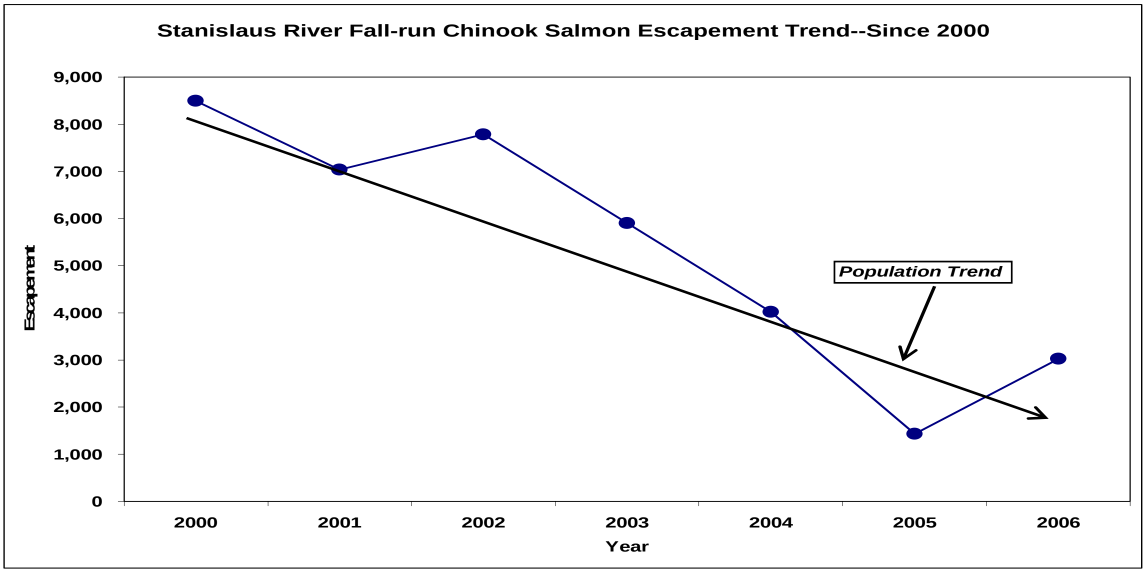
[12] The 3 year moving average is a continuous moving average of 3 year blocks over the period of record. The first average is the 1952 to 1954 annual escapement average. The second average is the 1953 to 1955 annual escapement average. The 3 year annual escapement average continues up to the 2004 to 2006 year time period.

Figure 3. Stanislaus River Annual Salmon Escapement Trend Since 2000



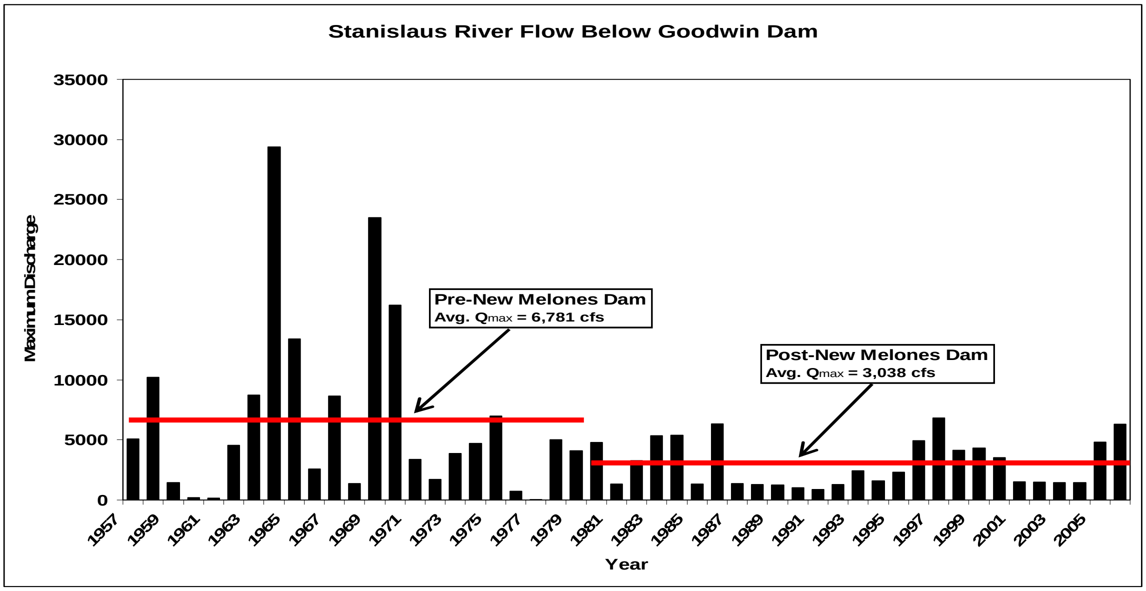
This graph shows the Stanislaus annual escapement trend for the years 2000 through 2006. Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since the peak escapement in the year 2000 (over 8,000 spawners), stemming from environmental conditions two to three years earlier (e.g. reference to water years 1997-98 and 1998-99) that would have contributed the year 2000 annual escapement (e.g. reference to two and three year old salmon which typically comprise the bulk of any one escapement year's abundance) has dropped sharply by the year 2006.

Annual flow releases into the lower Stanislaus River has lessened over time as water development has occurred (Figure 4). As water development has occurred, the magnitude, duration, and frequency of elevated spring flows has diminished. This reduction in annual maximum flow has resulted in substantial geomorphological impacts (reduced channel scouring) and fishery impacts (reduced salmonid production) in the Stanislaus River. There is a strong correlation between annual spring flow magnitude and the production of smolt outmigrants from the tributary, survival of smolts in the Delta, and the production of adults in the escapement and ocean harvest (Mesick and Marston 2007).

There is a strong relationship between flow volume, as represented by Goodwin Dam flows into the lower Stanislaus River, and the longitudinal river reach water temperature trend (Figure 5). In the spring when Goodwin Dam release flows are reduced (less than 700 cfs) much warmer water temperature results (21ºC/69ºF), in comparison to when Goodwin Dam release flows are increased (about 1500 cfs) water temperature during the spring is reduced substantially (17ºC /63ºF). This longitudinal temperature trend reduction, for both low and higher flows, occurred at similar meteorological conditions and approximate release temperature strongly suggesting that Goodwin Dam release flow level is important in conveying adequate water temperatures downstream. Consistent with reduction in spring flow, is an associated increase in water temperature during the later spring time period when a substantial fraction of smolts are leaving the Stanislaus River. Figure 6 shows the Stanislaus River smolt outmigration trend timing for the years 1996 through 2006 and indicates that 25% of smolts outmigrate by April 20th, 50% by

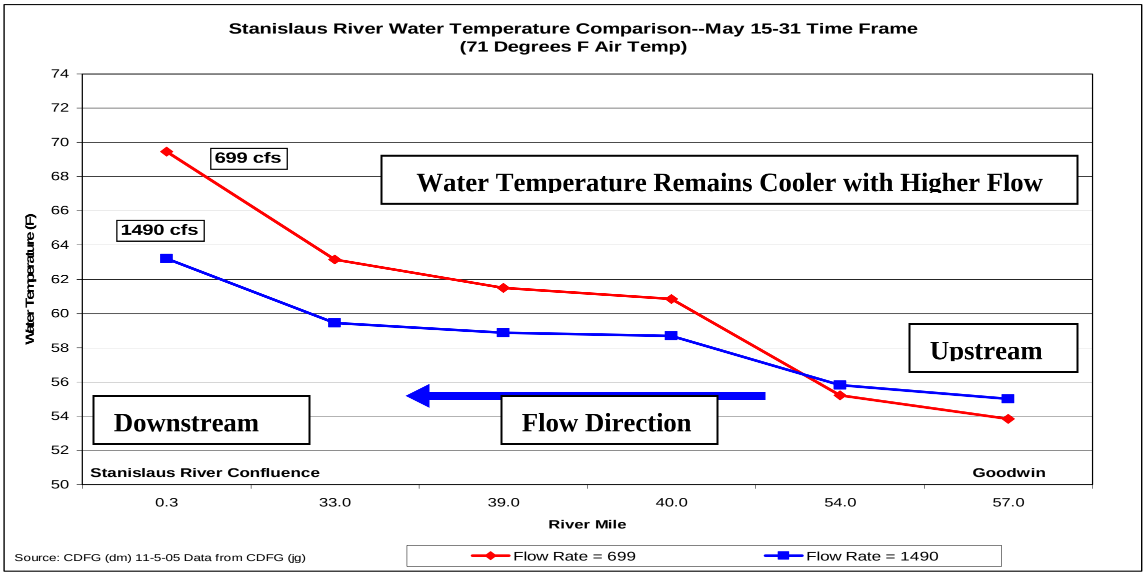
May 4th, and 70% by May 15th. Approximately 30% of smolts outmigrating from the Stanislaus River leave after May 15th.

Figure 4. Stanislaus Flow at Goodwin by Time Period



This figure compares the both annual maximum flow level in the Stanislaus River at Goodwin and the average annual maximum flow level for the pre and post-New Melones Dam time periods (data from U.S. Geological Survey Gage No. 11302000). Prior to New Melones the annual maximum flow level (3,038 cfs) was substantially higher than the post-New Melones Dam time period maximum flow level (6,781 cfs).

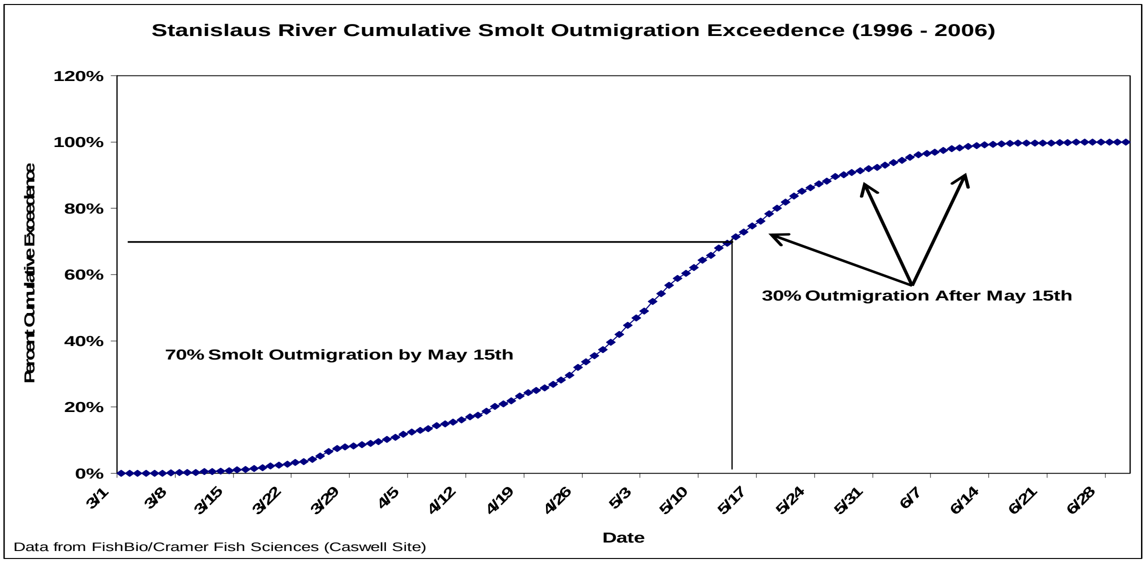
Figure 5. Goodwin Dam Flow Release Level and Downstream Water Temperature Response



Source: CDFG (dm) 11-5-05 Data from CDFG (jg)

This figure shows that Goodwin Dam release volume and release water temperature level determine the longitudinal (downstream) water temperature level (at the mouth) during the late spring time period when salmon smolts are migrating out of the Stanislaus River. Both the reduced, and elevated, flow levels depicted in this figure occurred during similar meteorological conditions (approximately 71ºF). Elevated flows have the ability to withstand meteorologically induced thermal warming of the water as it moves downstream in the Stanislaus River.

Figure 6. Stanislaus River Cumulative Smolt Outmigraton Exceedence (1996-2006)



Data from FishBio/Cramer Fish Sciences (Caswell Site)

This graph combines the smolt outmigration from the Stanislaus River (Caswell Rotary Screw Trap expanded catch data) for each year by date and shows the outmigration abundance time trend over a 10 year period from 1996 to 2006.

In addition to excessively warm spring time period water temperatures, the Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present the lower San Joaquin and lower Stanislaus Rivers during the fall adult upstream migration seasons for the years 1999 thru 2006 (Tables 7 and 10 in CDFG's Letter to the RWQCB dated February 2007). Also, the Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present in the lower Stanislaus River spawning habitat reaches, during the first half of the spawning season for years 1999 thru 2005 (Table 11 in CDFG's Letter to the RWQCB dated February 2007). An example of the relationship between spawning activity, as measured by spawning redd density, and water temperature is provided in Figure 7[13].

Steelhead, the anadromous form of rainbow trout, is a highly sought game fish in the Stanislaus River. Little is known regarding overall population abundance and trends over time. Adult steelhead have been recently captured while migrating upstream at the fish counting weir located near Riverbank[14]. Juvenile rainbow trout (smolts) out-migrating the Stanislaus River are caught annually in rotary screw traps. Steelhead in the Stanislaus River are considered winter run. Anecdotal reports by anglers suggest that steelhead abundance is greatest following years where summer rearing conditions are good (e.g. number of river miles possessing cold water temperatures). State and Federal fish agency biologists believe that steelhead abundance trends over time have followed that of salmon, only more so precipitating the need to list Steelhead in the Central Valley as

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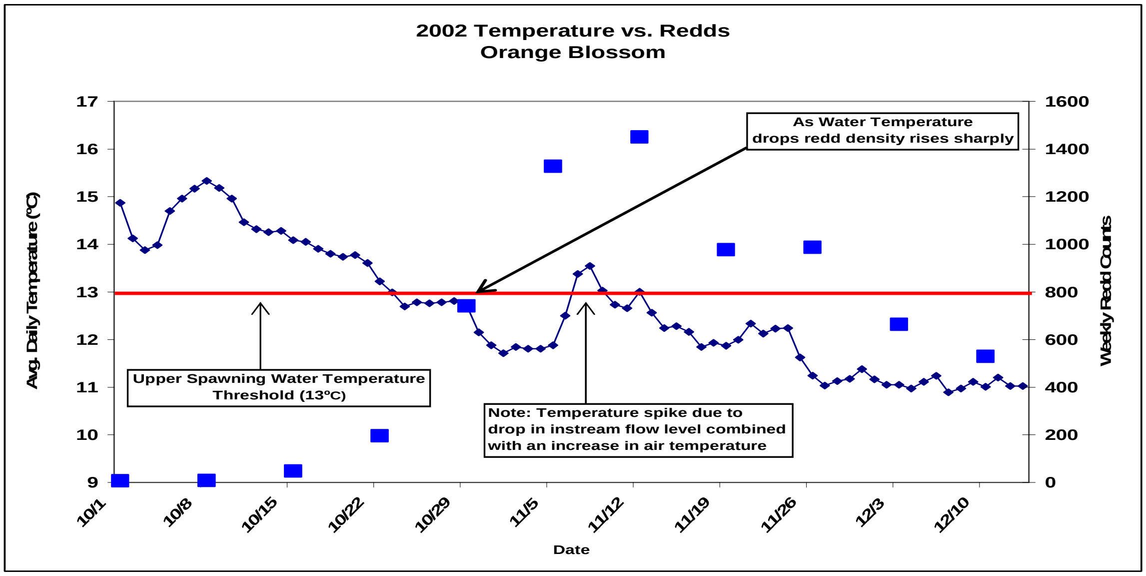
[13] Data provided by Jason Guignard (California Department of Fish Game Fishery Biologist)
[14] From weir data collected by Cramer Fish Sciences.

threatened. The Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present in the lower Stanislaus River juvenile steelhead rearing reach, during the summer for years 1999 thru 2006 (Table 11 in CDFG's Letter to the RWQCB dated February 2007). It should be noted that of the three primary San Joaquin River east-side tributaries the Stanislaus has the most abundant steelhead population (e.g. not in good condition but most abundant). This may be attributable to the New Melones being required to meet winter and summer Vernalis flow objectives that require elevated flows to be released into the lower Stanislaus River during the winter and summer time periods.[15]

Figure 7. 2002 Stanislaus River Fall Spawning Season—Orange Blossom Bridge



This figure shows the relationship between salmon spawning activity in the Stanislaus River, at Orange Blossom Bridge, and water temperature level. As water temperature decreases to a level less than 13ºC (59ºF) spawning activity, as measured by weekly spawning redd counts, rises markedly. The water temperature spike occurring during the first week of November is associated with a rise in air temperature level and also with a reduction in Goodwin Dam release flow into the lower Stanislaus River. Typically a fall pulse flow is provided during the month of October to attract salmon into the Stanislaus River. In 2002, the Stanislaus River fall pulse flow occurred between October 21st and October 29th and ranged between 250 to 700 cubic feet per second. The purpose of the fall pulse (e.g. attraction flow) is threefold: i) lower water temperature in the lower Stanislaus River and lower San Joaquin River; ii) improve dissolved oxygen conditions (e.g. raise DO) in the San Joaquin River at the Stockton Deep Water Ship Channel; and iii) attract upstream migrating salmon into the Stanislaus River. The rise in spawning redd counts occurs concurrent with increased Goodwin Dam release flow levels (e.g. fall attraction or pulse flow) and associated decrease in water temperature level.

Tuolumne River

Both spring and fall-runs occurred in the Tuolumne River historically and were able to ascend a considerable distance. Both adult steelhead and salmon probably had access all the way to Preston Falls, which is about 50 miles upstream of New Don Pedro Dam. The occurrence of salmon in the Tuolumne River in the early years was noted by John Marsh

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[15] The State Water Resources Control Board Decision D-1641 requiring New Melones releases to achieve summer San Joaquin River at Vernalis water quality flow objectives went into effect in the year 2000.

who had arrived in California in 1830. John Marsh stated that the Tuolumne River "particularly abounds with Salmon." In 1849, in his memoirs of the Gold Rush, Samuel Ward recalled "a plenteous fish supper of salmon, caught by rifle shot in the lower Tuolumne River." A later historical account noted the local native people "Every spring, when the salmon were running up the river, enough salmon were caught and dried to last nearly all the year" and "The waters of the Tuolumne, Stanislaus, Merced, and San Joaquin generally furnish them with good fishing."

Significant blockage of salmon runs in the Tuolumne River began in the 1870's when various dams and irrigation projects were constructed, although dams and water diversions associated with mining had been present as early as 1852 and undoubtedly had some effect. Wheaton Dam, built in 1871 at the site of present day La Grange Dam, may have blocked the salmon run. By 1884, both the Tuolumne and Stanislaus Rivers were dammed in such a way as to prevent the fish from ascending. In 1894 La Grange Dam was built and permanently cut-off the spring-run spawning areas upstream of La Grange Dam. In 1896 the California Fish Commission declared that a proposed fish ladder on the Tuolumne River was not warranted because the fish ladder would not be of much benefit due to the small size of the Tuolumne River the salmon population which would likely continue to decline due to the waters being taken out of the river for irrigation purposes. It should be noted that John Muir recorded in his journal, 1877, that when he passes the mouth of the Tuolumne that the river was brown with mining mud and that the San Joaquin River water was clear. It is possible that mining, in combination with dam building and water diversion, affected the salmon runs in the late 1800s.[16]

In 1929 G. H. Clark stated: "The spawning run of the salmon in the Tuolumne is during the spring and fall. The fall run is the only one of any consequence. The spawning grounds extend from the town of Waterford to La Grange, a distance of twenty miles of good gravel river. The Tuolumne River, like the other rivers of the San Joaquin system, is used for irrigation. Two dams on the river affect the salmon. The lower is the La Grange Dam near the town by that name. It is an irrigation diversion dam which supplies water for the ranches in the lower country. The dam is 120 feet high and has no fish ladder. Thirteen miles above this is the Don Pedro Dam, which is about 300 feet high and was built in 1923. It forms a large storage reservoir for irrigation and also generates some power. Salmon in the Tuolumne River are scarce. The spring run amounts to almost nothing, but there are some fish that come up the stream in the fall. The river, like the rest in years past, used to abound with salmon. Three years ago (1925) a good run was reported in the stream that surpassed anything that had appeared in several years."[17]

When looking at San Joaquin River hydrology records between 1902 and 2005, a period of 105 years, it is not surprising that the 1925 year escapement was notable. In the years 1921 to 1923, the juvenile production time periods contributing the 1925 year

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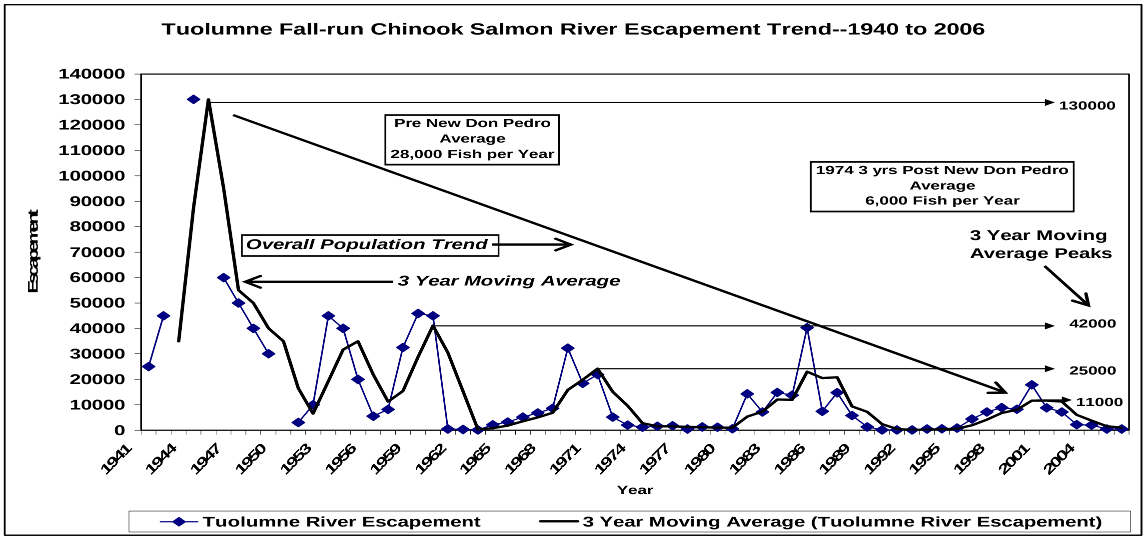
[16] Material primarily from Yoshiyama, Ronald M., Eric R. Gerstung, Frank W. Fisher, and Peter. B. Moyle. 2001. Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California. Fish Bulletin 179. California Department of Fish & Game Publication.

[17] From G.H. Clark. 1929. Sacramento-San Joaquin Salmon (Onchorhynchus tschawytscha) Fishery of California. Fish Bulletin No. 17. Division of Fish and Game of California.

escapement, the spring run-off in Tuolumne River for these years was one of the higher three year spring run-off periods on record. This suggests that the San Joaquin River east-side tributary boom and near bust fall-run salmon population cycle has been in existence for at least the last 80+ years (Figure 5). The current reduction in peak abundance over time is very disturbing and suggests that overall population resiliency (e.g. production over time) is steadily decreasing and may reach a point where given enough successive dry years the population could become extinct. In 2007, the estimated abundance of out-migrating salmon smolts, the life-history phase which is strongly correlated with adult production, was extremely low[18] (less than 1,000 smolts). From 1998 to 2006, the estimated number of smolt outmigrants was much higher ranging from 9,960 smolts in 2003 to about 350,000 smolts in 2005.

Between 1940 and 2006 the Tuolumne River fall-run escapement population has oscillated over time and has dropped to levels less than 1,000 on several occasions. The average escapement of fall-run salmon in the Tuolumne River seriously declined post New Don Pedro time frame (Figure 8). By 2000, the Tuolumne River fall-run salmon escapement population had steadily declined and by 2006 (500 salmon) had dropped to about 97% percent below the year 2000 peak abundance of 17,875 salmon (Figure 9).

Figure 8. Historical Annual Tuolumne River Salmon Escapement Trend



The blue dotted line represents the historical Tuolumne River salmon escapement for the years 1941 to 2006 (note: escapement data not available for years 1943, 1945 and 1950). Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since 1941 there have been several peak escapement periods. The 3 year moving average[19] of escapement trend is intended to account for the various ages of salmon that comprise an annual escapement. Juvenile salmon produced in one year (e.g. brood year) typically return as adults to spawn as age 2, 3, or four year old salmon. The three year moving average is intended to cover the three year period that salmon return to spawn post brood production year. The three year moving average indicates that the overall Tuolumne annual escapement is

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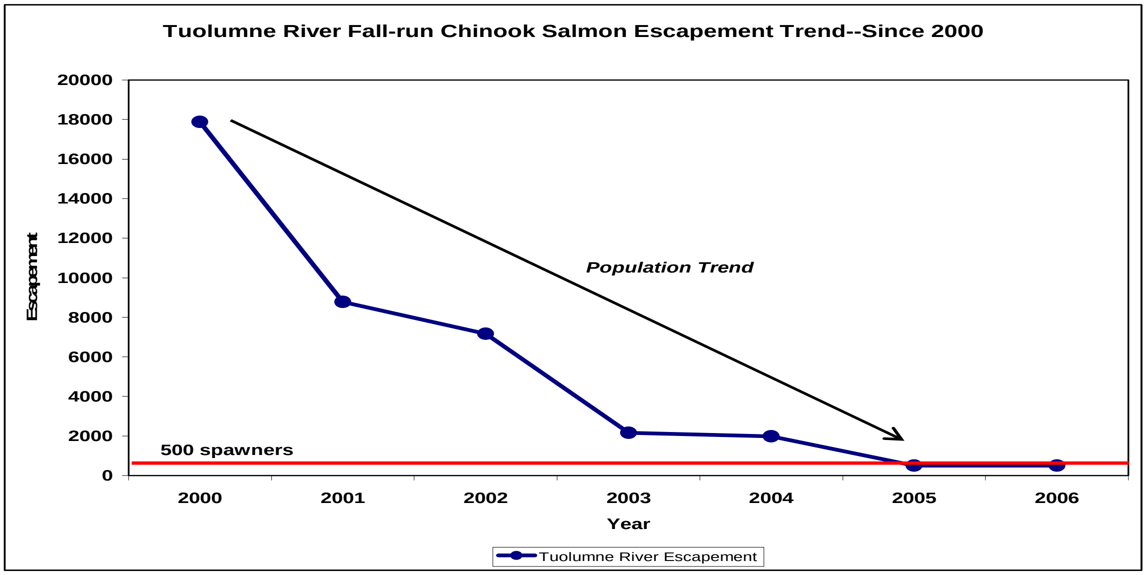
[18] Estimate provided by FishBio in August of 2007.

[19] The 3 year moving average is a continuous moving average for a 3 year period. The first average is the 1952 to 1954 annual escapement average. The second average is the 1953 to 1955 annual escapement average. The 3 year annual escapement averages continue up to the 2004 to 2006 time period.

declining over time. This declining trend is consistent with the overall declining trend observed in Figure 1 for the SJR salmon escapement trend.

Figure 9. Tuolumne River Annual Salmon Escapement Trend 2000 to 2006



This graph shows the Tuolumne annual escapement trend for the years 2000 through 2006. Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since the peak escapement in the year 2000 (over 17,000 spawners), escapement has dropped sharply to 500 spawners for both the 2005 and 2006 escapement years.

Figure 10 shows how annual flow releases into the lower Tuolumne River has lessened over time as water development has occurred. As water development increased, the magnitude, duration, and frequency of elevated spring flows has diminished. There is a strong correlation between annual spring flow magnitude and future year adult production (Mesick and Marston 2007). Also, as spring flow increases smolt survival increases (TID/MID Annual Report to FERC 2005)[20]. As a consequence of reduced spring flows, when smolts are out-migrating, water temperatures are increased. There is a strong relationship between flow volume, as represented by La Grange Dam flows into the lower Tuolumne River, and the longitudinal river reach water temperature trend (Figure 11). In the spring when La Grange Dam release flows are reduced (less than 569 cfs) much warmer water temperature results (22ºC/71ºF), in comparison to when La Grange Dam release flows are increased (about 4500 cfs) water temperature during the spring is reduced substantially (15ºC /59ºF). This longitudinal temperature trend reduction, for both low and higher flows, occurred at similar meteorological conditions and approximate release temperature strongly suggesting that La Grange Dam release flow level is important in conveying adequate water temperatures downstream. Excessively warm water temperatures in the lower reach during the spring have occurred at a time when juvenile salmon are still present in the upper reach of the Tuolumne River (Table 1).

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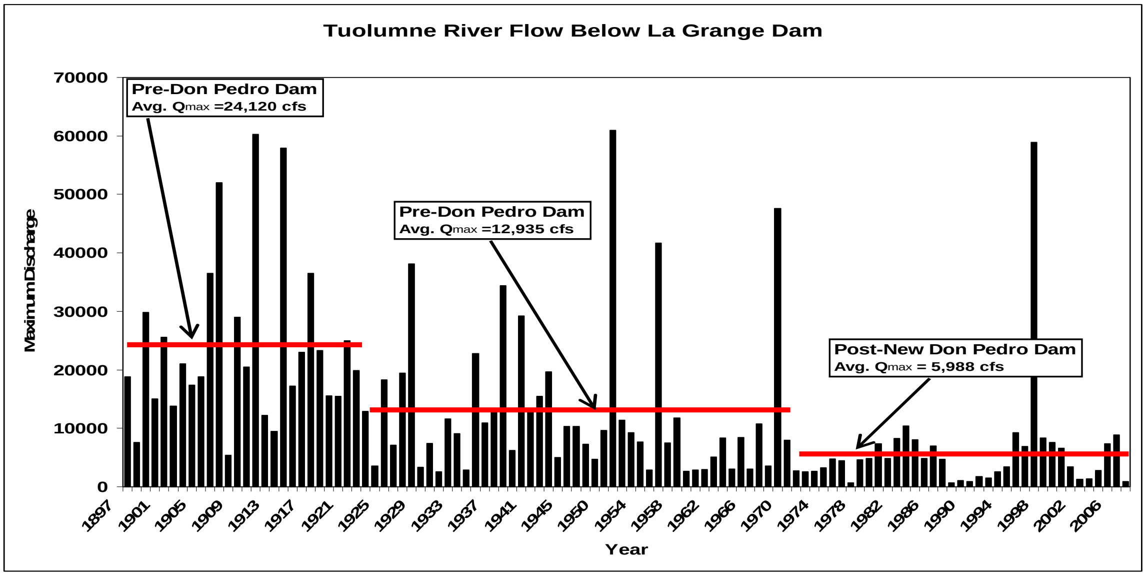
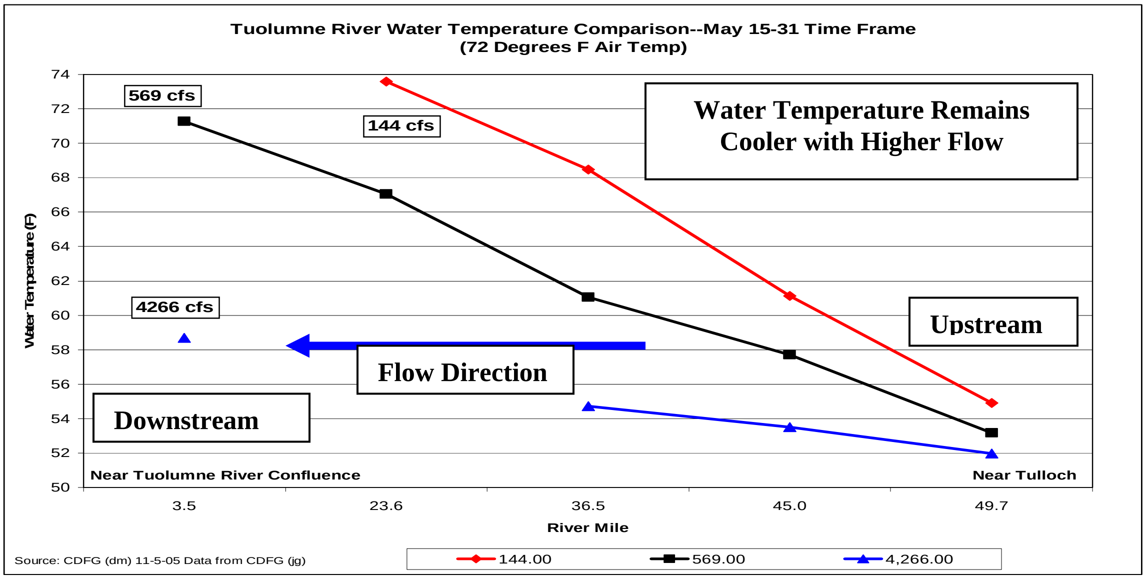
[20] 2005 Turlock and Modesto Irrigation District Annual Report to the Federal Energy Regulatory Commission.

Figure 10. Historical Tuolumne River Flow at La Grange (Annual Peak Flow)



This figure compares the both annual maximum flow level in the Tuolumne River at La Grange and the average annual maximum flow level for the pre and post-New Don Pedro Dam time periods (data from Turlock Irrigation District). With each dam construction a substantial reduction in average annual peak flow has occurred.

Figure 11. Tuolumne River Water Temperature and River Flow Volume



Source: CDFG (dm) 11-5-05 Data from CDFG (jg)

This figure shows that La Grange Dam release volume and water temperature level determines the longitudinal (downstream) water temperature level (at the mouth) during the late spring time period when salmon smolts are migrating out of the Tuolumne River. Both the reduced, and elevated, flow levels depicted in this figure occurred during similar meteorological conditions (approximately 72ºF). Elevated flows have the ability to withstand meteorologically induced thermal warming of the water as it moves downstream in the Tuolumne River.

Table 1. Tuolumne River Seine Catch at Rivermile 48 (Near La Grange)

Tuolumne Seine Catch at Rivermile 48					
Year	Date	Salmon Catch	Year	Date	Salmon Catch
1999	08APR	5	2002	09APR	58
1999	22APR	0	2002	23APR	33
1999	**05MAY**	**18**	2002	07MAY	50
1999	19MAY	1	**2002**	**21MAY**	**49**
2000	04APR	0	2003	01APR	132
2000	02MAY	1	2003	16APR	25
2000	**17MAY**	**17**	2003	30APR	0
2001	04APR	6	**2003**	**14MAY**	**27**
2001	17APR	47	2003	28MAY	0
2001	01MAY	17	2004	30MAR	109
2001	15MAY	118	2004	14APR	6
2001	**30MAY**	**211**	2004	27APR	0
			2004	11MAY	0
			2004	**25MAY**	**27**

This table shows that salmon are still present in the Tuolumne River late in the year (e.g. late May and early June) in the upper reaches of the Tuolumne River when temperatures are excessively warm for smolt development and during outmigration in the lower Tuolumne River. Data from Turlock Irrigation District's Federal Energy Regulatory Commission Annual Reports.

In addition to excessively warm spring time period water temperatures, the Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present the lower San Joaquin and lower Tuolumne Rivers during the fall adult upstream migration seasons for the years 1998 thru 2005 (Tables 8 and 10 in CDFG's Letter to the RWQCB dated February 2007). Also, the Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present in the lower Tuolumne River spawning habitat reaches, during the first half of the spawning season for years 1998 thru 2005 (Table 12 in CDFG's Letter to the RWQCB dated February 2007).

Steelhead, the anadromous form of rainbow trout.(Onchorhynchus mykiss), is a sought game fish in the Tuolumne River. Little is known regarding overall population abundance and trends over time other than adult catch is considered infrequent. Juvenile rainbow trout (smolts) out-migrating the Tuolumne River are caught annually in seining surveys conducted by the Turlock Irrigation District. Steelhead in the Tuolumne River are considered winter run. Anecdotal reports by anglers suggest that steelhead abundance is greatest following years where summer rearing conditions are good (e.g. number of river miles possessing cold water temperatures). State and Federal fish agency biologists believe that steelhead abundance trends over time have followed that of salmon, only more so precipitating the need to list Steelhead in the Central Valley as threatened. The Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present in the lower Tuolumne River juvenile steelhead rearing reach, during the summer for years 2001 thru 2006 (Table 19 in CDFG's Letter to the RWQCB dated February 2007).

Merced River

Both spring-run and fall-run salmon, and steelhead, historically occurred in the Merced River. Of the salmon runs, only the fall run has survived and the Merced River fall-run is the southernmost native Chinook salmon run in existence. Native Americans were observed harvesting salmon in the Merced River in 1852 at Merced Falls. In November 1877, John Muir noted that salmon were abundant in deep pools. It appears that adult salmon were definitely able to access the Merced River up to the confluence of the South Fork; however, some unconfirmed reports suggest that both salmon and steelhead migrated as far up the South Fork as Wawona and in the mainstem as far as into Yosemite Valley. As early as 1852, a temporary barrier was constructed, by fishermen, about 10 miles downstream of Merced Falls which blocked upstream migration of spring-run. In later years, a succession of dams was built at Merced Fall and locations upstream. These dams had impeded upstream passage of salmon by the 1920's. However, the construction of Exchequer Dam barred salmon from migrating into their former spawning grounds. As of 1928 there were three upstream migration blockages: i) Crocker-Huffman irrigation diversion dam near Snelling; ii) the Merced Falls, with non-working fishway, about three miles upriver from Crocker-Huffman dam; and iii) Exchequer Dam about 20 miles upstream of Merced Falls[21]

In 1929 G. H. Clark stated: "The salmon of the Merced River run in the spring and fall. The spawning beds extend from the mouth of the river to the Exchequer Dam on occasional gravel bars that occur along the river. Perhaps the length in linear miles of stream be available is about 12 miles. There are three obstructions that affect the salmon. The Crocker Huffman irrigation diversion dam near Snelling is the lowermost. This dam, which was built about 1918, is about 15 feet high and has a good working fishway in high water. There are a few screens but not over all the ditches. At Merced Falls there is a natural fall and a 20-foot dam has been constructed to form a millpond and to generate power for a sawmill. The dam was built prior to 1913. There is a fishway, but it has been closed and out of order for a number of years. There are screens over the intakes to the power house. The Exchequer Dam is about 20 miles above the Merced Falls and is impassable to fish. It is a 120-foot power dam.

The abundance of salmon in the Merced River now (1925) as compared to the past years tells the same story of depletion as do the other rivers. The reports of the early residents along the Merced River speak of great quantities of fish coming up the river to spawn in the summer and fall. In 1920, a letter received by the Fish and Game Commission from a resident of the country states that there were fifty salmon in the past for each one now (1920). In the above-mentioned letter the blame for this decrease was attributed to the construction of dams. Residents along the river in 1928 say that the salmon are so scarce that they rarely see any. They remember the fish being so numerous that it looked as if one could walk across the stream on their backs. One report from Merced stated there were no salmon which ran up the river any more, but later the statement was to the effect that a few went up in the fall. Another statement from a deputy of the Division of Fish

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[21] Material primarily from Yoshiyama, Ronald M., Eric R. Gerstung, Frank W. Fisher, and Peter. B. Moyle. 2001. Historical and Present Distribution of Chinook Salmon in the Central Valley Drainage of California. Fish Bulletin 179. California Department of Fish & Game Publication.

and Game, dated November 12, 1928, says that there are several hundred salmon in the Merced this fall. The deputy counted 391 in one small stream below a dam. The river was dry or a distance above the creek so the salmon could not continue up the river until the rain came and increased the water supply.

A great deal of the water in the Merced River is used for irrigation during the spring, summer and early fall. The river during this irrigation season is very low, and the salmon find it hard to get up the river until after the rains. This condition has just about killed off the spring and summer runs and now the only fish that come in active during the late fall."[22]

The statement that the salmon run was low in 1928 is not surprising as the brood production years comprising the 1928 escapement occurred during the water years 1924 through 1926, a time period that consisted of some of the lowest historical spring flow years. As stated above, the recurrent boom and near bust San Joaquin River east-side tributary salmon escapement population trend is of great concern to the Department given the associated declining population resiliency trend that continues to occur (e.g. production boom population abundance numbers are far fewer now than what historically occurred).

By 1961, the Merced River was considered to be only a marginal salmon stream due to the diversion of water by irrigation diversions. The Merced River fall-run salmon population was described as "poor." Run size estimates for fall-run in the 1960's average about 250 salmon per year. In 1970, a fall-run salmon hatchery was built was on the Merced to augment natural production. The operation of a hatchery on the Merced, in combination with increased stream flows by the Merced Irrigation District (e.g. Davis-Grunsky Program), resulted in the average annual escapement to increase from an average of 900 a year to about 5,500 per year. However the Merced, like the Stanislaus and Tuolumne River salmon escapement populations, drastically declined by the end of the six year drought (e.g. 1986-1992 average of 2,500). The cause of the decline is believed to be primarily due to low flow and elevated water temperature conditions during adult immigration into and juvenile (smolt) spring out-migration from the Merced River. When flow and water temperature improved post-drought, between 1993 and 1998, Merced River salmon escapement improved (Figure 12).

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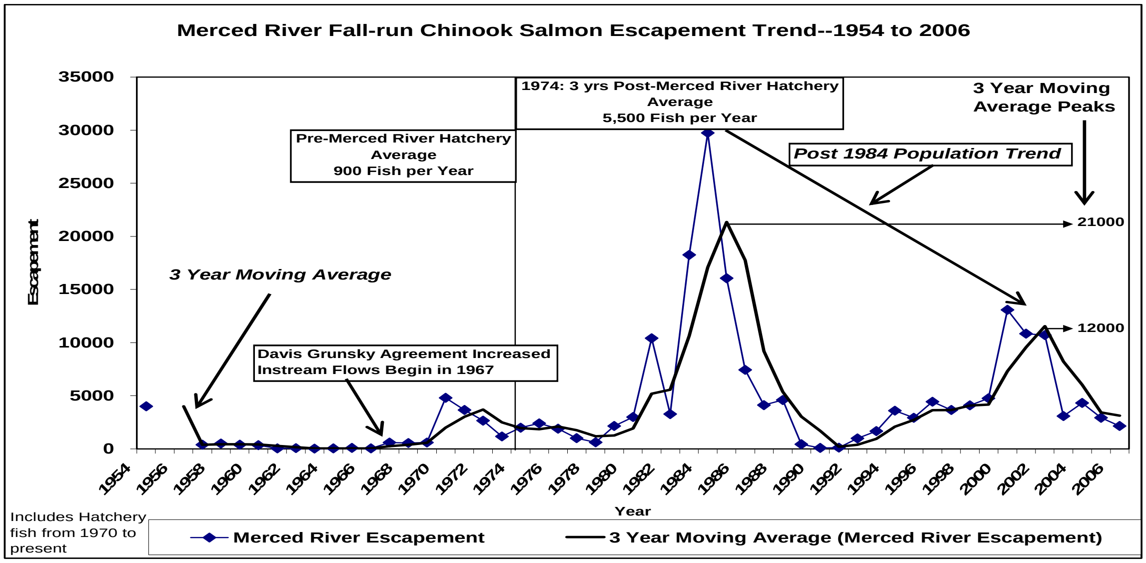
[22] From G.H. Clark. 1929. Sacramento-San Joaquin Salmon (Onchorhynchus tschawytscha) Fishery of California. Fish Bulletin No. 17. Division of Fish and Game of California.

Figure 12. Merced River Historical Salmon Escapement (1954 to 2006)



The blue dotted line represents the historical annual Merced River salmon escapement for the years 1954 to 2006 (note: escapement data not available for years 1955, 1956). The escapement trend includes salmon escapement into the Merced River Hatchery for years 1970 to 2006. Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since 1954 there have been several peak escapement periods. The 3 year moving average[23] of escapement trend is intended to account for the various ages of salmon that comprise an annual escapement. Juvenile salmon produced in one year (e.g. brood year) typically return as adults to spawn as age 2, 3, or four year old salmon. The three year moving average is intended to cover the three year period that salmon to spawn post brood production year. The three year moving average indicates that the overall Merced annual escapement is declining over time. This declining trend is consistent with the overall declining trend observed in Figure 1 for the SJR salmon escapement trend. It is also noted that the minimum instream flow levels changed (upward) during the fall spawning season (October 31 to March 31) in the approximate 20 mile spawning reach downstream of Crocker-Huffman Dam beginning 1967 per the State of California Davis-Grunsky Agreement with the Merced Irrigation District.[24]

Since the higher spring flows, and cooler spring water temperatures of 1998 and 1999, the population has declined steadily since 2000 and the fall-run salmon population has steadily declined and by 2006 (2,150 salmon) had dropped to about 84% percent below the year 2000 peak abundance of 13,076 salmon (Figure 13).

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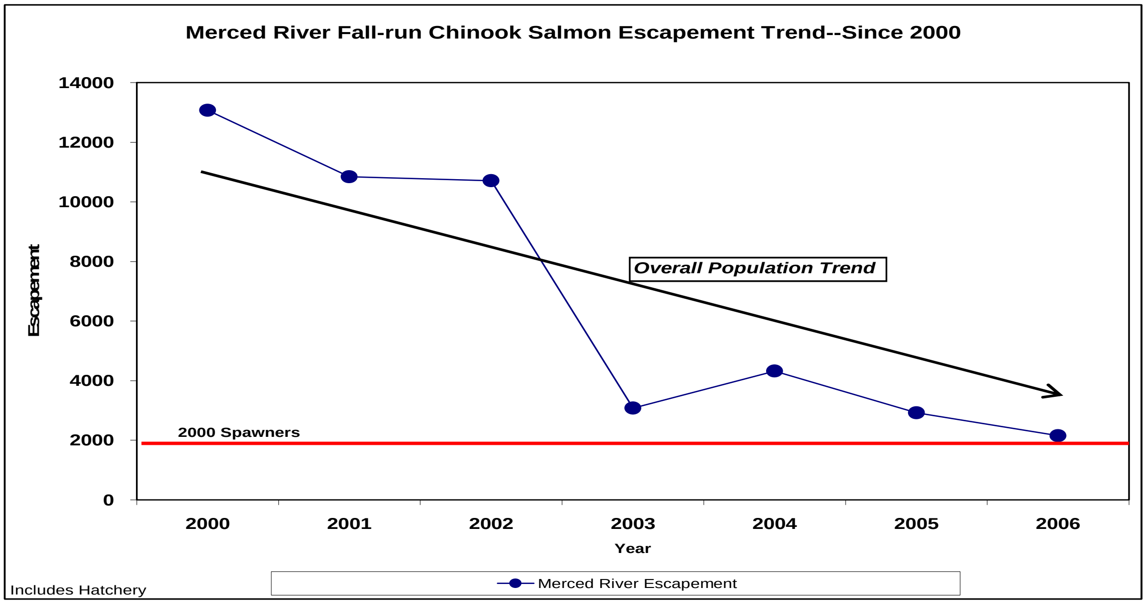
[23] The 3 year moving average is a continuous moving average for a 3 year period. The first average is the 1952 to 1954 annual escapement average. The second average is the 1953 to 1955 annual escapement average. The 3 year annual escapement averages continue up to the 2004 to 2006 time period.

[24] Vogel, D. 2003. Merced River Water Temperature Feasibility Investigation Reconnaissance Report.

Figure 13. Merced River Salmon Escapement 2000 to 2006.



This graph shows the Merced annual escapement trend for the years 2000 through 2006. Salmon escapement refers to the number of adult salmon escaping ocean harvest and returning to fresh water to spawn. Since the peak escapement in the year 2000 (over 13,000 spawners), stemming from environmental conditions two to three years earlier (e.g. reference to water years 1997-98 and 1998-99) that would have contributed the year 2000 annual escapement (e.g. reference to two and three year old salmon which typically comprise the bulk of any one escapement year's abundance) escapement has dropped sharply to 2,000 spawners in the year 2006. The Merced escapement also includes escapement of salmon into the Merced River Hatchery.

Figure 14 shows how annual flow releases into the lower Merced River has lessened over time as water development has occurred. As water development occurred, the magnitude, duration, and frequency of elevated spring flows has diminished. There is a strong correlation between annual spring flow magnitude and future year adult production (Mesick and Marston 2007). As spring flow increases, smolt survival increases[25]. As a consequence of reduced spring flows, when smolts are out-migrating, water temperatures increased. There is a strong relationship between flow volume, as represented by Crocker-Huffman Dam flows into the lower Merced River, and the longitudinal river reach water temperature trend (Figure 15). In the spring when Crocker-Huffman Dam release flows are reduced (less than 569 cfs) much warmer water temperature results (22ºC/71ºF), in comparison to when Crocker-Huffman Dam release flows are increased (about 4500 cfs) water temperature during the spring is reduced substantially (15ºC /59ºF). This longitudinal temperature trend reduction, for both low and higher flows, occurred at similar meteorological conditions and approximate release temperature strongly suggesting that Crocker-Huffman Dam release flow level is important in conveying adequate water temperatures downstream. Excessively warm water temperatures in the lower reach during the spring have occurred at a time when juvenile salmon are still present in the upper reach of the Merced River (Table 2).

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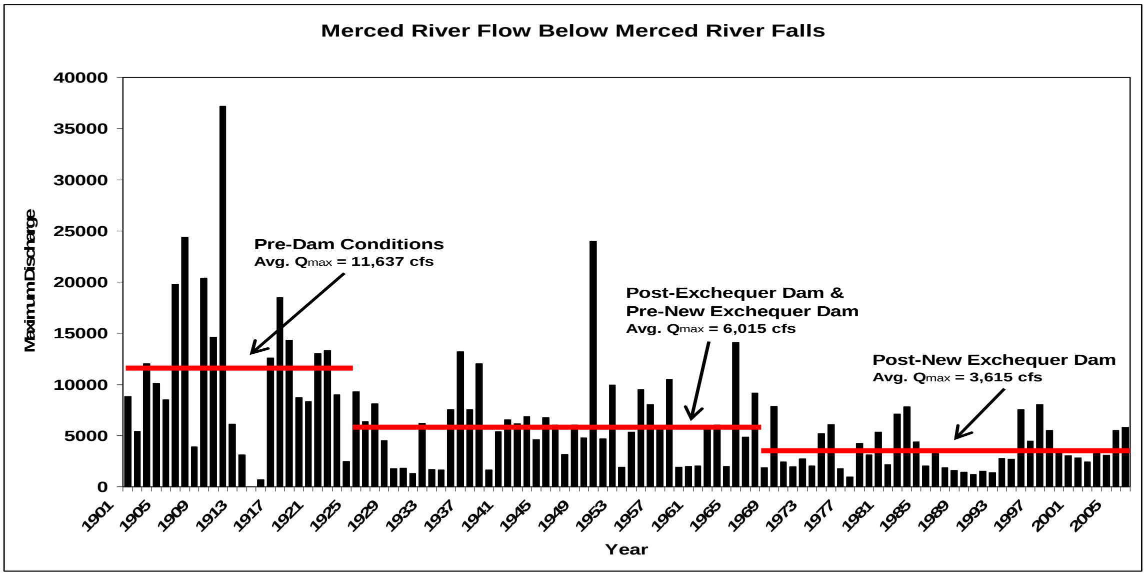
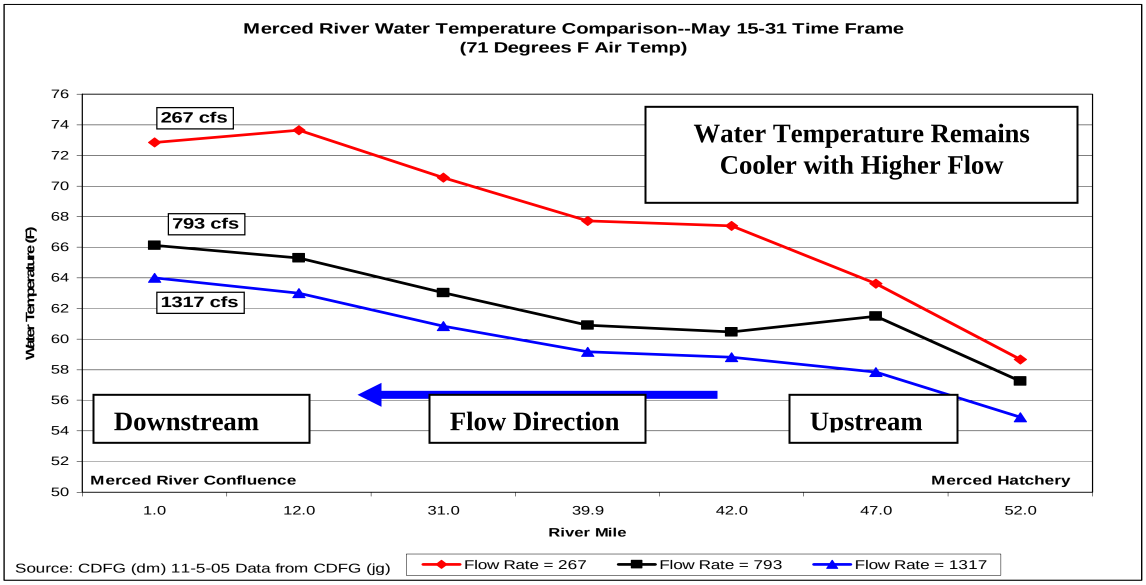
[25] California Department of Fish & Game Annual Reports.

Figure 14. Historical Merced River Flow at Merced River Falls (Annual Peak Flow)



This figure compares the both annual maximum flow level in the Merced River at Merced River Falls and the average annual maximum flow level for the pre and post-New Exchequer Dam time periods. With each dam construction a substantial reduction in average annual peak flow has occurred. Data from USGS Gage No. 11270000 Merced River Falls.

Figure 15. SJR East-side Tributary Flow and Water Temperature Comparison.



This figure shows that Crocker-Huffman Dam release, and water temperature, level determines the longitudinal (downstream) water temperature level (at the mouth) during the late spring time period when salmon smolts are migrating out of the Merced River. Both the reduced, and elevated, flow levels depicted in this figure occurred during similar meteorological conditions (approximately 71ºF). Elevated flows have the ability to withstand meteorologically induced thermal warming of the water as it moves downstream in the Merced River.

Table 2. Juvenile Salmon Catch in the Merced River Near Hopeton

Merced Upper Rotary Screw Trap Juvenile Salmon Catch					
1999	May 1-15	4593	2003	May 1-15	*
	May 16-31	**843**		May 16-31	*
	June 1-15	*		June 1-15	*
2000	May 1-15	2870	2004	May 1-15	*
	May 16-31	**15343**		May 16-31	*
	June 1-15	831		June 1-15	*
2001	May 1-15	20544	**2005**	May 1-15	5590
	May 16-31	**19595**		**May 16-31**	**6071**
	June 1-15	16		June 1-15	2204
2002	May 1-15	36374	* Trap Not Operated		
	May 16-31	**2060**			
	June 1-15	*			

This table shows juvenile salmon catch in the Merced River at Hopeton for the May 1 to June 15th time period during years 1999 to 2005. Late in the spring, when water temperatures in the lower Merced River are excessively warm for outmigrating salmon smolts, juvenile salmon are still trying to migrate from the upper reach of the Merced River to the lower reaches of the Merced River. Data from the Merced Irrigation District.

In addition to excessively warm spring time period water temperatures, the Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present the lower San Joaquin and lower Merced Rivers during the fall adult upstream migration seasons for the years 1999 thru 2005 (Tables 9 and 10 in CDFG's Letter to the RWQCB dated February 2007). Also, the Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present in the lower Merced River spawning habitat reaches, during the first half of the spawning season for years 1998 thru 2005 (Table 13 in CDFG's Letter to the RWQCB dated February 2007).

Steelhead, the anadromous form of rainbow trout.(Onchorhynchus mykiss), is a sought game fish in the Merced River. Little is known regarding overall population abundance and trends over time other than adult catch is considered infrequent. Juvenile rainbow trout (smolts) out-migrating the Merced River have been caught in rotary screw traps operated by the Department. Steelhead in the Merced River are considered winter run. Anecdotal reports by anglers suggest that steelhead abundance is greatest following years where summer rearing conditions are good (e.g. number of river miles possessing cold water temperatures). State and Federal fish agency biologists believe that steelhead abundance trends over time have followed that of salmon, only more so precipitating the need to list Steelhead in the Central Valley as threatened. The Department submitted evidence to the RWQCB regarding excessively warm water temperatures being present in the lower Merced River juvenile steelhead rearing reach, during the summer for years 1999 thru 2005 (Table 20 in CDFG's Letter to the RWQCB dated February 2007).

San Joaquin River[26]

The earliest historical reports reveal that salmon were present in the San Joaquin River above the mouth of the Merced River in great numbers. Indigenous Yokuts and Mono peoples historically utilized these runs of fish very heavily as a source of protein. Dried salmon from the San Joaquin were stored and traded with more distant Yokuts tribes from the southern San Joaquin Valley, and the remains of these fish are a feature of middens from those areas (Gobalet, 1995). Historical abundance estimates are lacking, but historian, Frank Latta (1949) reported:

> "The southern Yokuts called the San Joaquin River Tihshachu, meaning salmon spearing place. Indians traveled great distances to spear salmon on the shallow sand bars there…. South of Table Mountain was the village of Muhnowlo. North of Table Mountain, on a large flat [today, this is called Temperance Flat] by the river where the Indians speared salmon, was the Kechayi village of Kiahno. During the time when the salmon were running, every bush and most of the ground in the vicinity was red with drying salmon." (Latta 1949. P.4.)

Historical sources (Hatton and Clark, 1942) indicate that the San Joaquin watershed had a very large spring-run of Chinook salmon, along with a much smaller fall-run. The differential magnitude of these salmon runs most likely reflected the natural hydrology: i.e., heavy snow run-off flows in spring and early summer, and lower discharges in fall, as flows seasonally receded.

While salmon dominated most of the historical reports concerning anadromous fish, steelhead rainbow trout were also mentioned. Steelhead were described by Latta (1929, 1949) and by other authors as being present in good numbers and at least casually being taken and utilized by the indigenous Yokuts peoples.

By about 1920, the Chinook salmon populations had seriously declined due to important changes within the upper San Joaquin River watershed. These included: (i) the development of the "sack dam" at Dos Palos and its seasonal unscreened diversion of irrigation water, (ii) development of the Kerckhoff Dam, in 1916 by San Joaquin Power and Light Company (later PG&E), (iii) screened and unscreened water diversions at Mendota, (iv) the initial development of the Big Creek series of dams and reservoirs by Southern California Edison Company, (v) development of a dam and water storage reservoir at Crane Valley, by the San Joaquin Power and Light Company, and (vi) extensive fishing, seining, and spearing of adult migrant salmon as they attempted to migrate across greatly flow-reduced river reaches on the San Joaquin Valley floor. Some of these features are discussed in more detail below.

Beginning in the late 1800's, a sack dam was annually installed at a point near Dos Palos, on the Lower San Joaquin River. The dam itself imposed a major barrier to upstream migrating adult salmon; particularly in the fall, after San Joaquin River flows became seasonally reduced. The routine springtime and summer diversion of irrigation water through the unscreened canal intake, also created a major source of mortality to downstream migrating salmon and steelhead juveniles. During dry years, when total

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[26] The majority of information provided in this section came from Dale Mitchell, Aquatic Program Manager for the California Department of Fish & Game. 2007.

discharges were below 1,000 cfs, this unscreened diversion consumed a very large fraction of downstream migrating salmon. A.D. Ferguson wrote in 1914:

> The fishing conditions in the valley section of Fresno Division are at once important and peculiar. Important, for the reason that many thousands of people in all walks of life, … find throughout the fishing season pleasure and recreation along the banks of the two great rivers of the valley. Peculiar in that , due to the diversion of the waters for irrigation purposes, both the San Joaquin and Kings Rivers are dry throughout a portion, at least, of their lower courses, almost every fall….” (Ferguson 1914, p. 23)

Upstream water development also contributed to the reduction of San Joaquin River salmon. The construction of Kerckhoff Dam and reservoir by San Joaquin Light and Power Company, in 1916, completely blocked the upstream access to over-summer habitats and spawning grounds by adult salmon and steelhead. The following early reports probably overstate the extent of this impact, but intuitively, the dam must have had truly dramatic impacts on both salmon and steelhead, given its presentation of a major migration barrier, located in the lower portion of the watershed.

> The last of the salmon breeding grounds in the San Joaquin will be destroyed this season by the completion of the Kerckhoff dam and powerhouse by the San Joaquin Light and Power Company. The water will be diverted through a tunnel 17,000 feet in length that will dry up about 12 miles of the river bed as well as prevent any salmon from ascending above the dam. A survey of the conditions on the San Joaquin River has been made, and an estimate of the number of breeding salmon that pass Mendota Weir, about 50 miles below the Kerckhoff Dam, is in preparation. A survey has been made for a fishway over the new Mendota Weir that is now under construction. This will allow the spring run of fish to pass on up the San Joaquin River to a point where the large irrigation canals take water out of the river. These salmon ascend the river during May, June and the first part of July. In the foothills near Friants [sic] they congregate in large pools and remain until such time in the fall as the temperature is right for them to spawn, then they ascend the river into the gorge of the San Joaquin River, where they spawn during the fall. This is the result of our observations gathered from the residents and deputies who have lived in that vicinity for years. If such proves to be the facts, the only way to save the remainder of this run of fish is to establish an egg collecting station near the Kerckhoff Powerhouse, collect the eggs, and transfer them by truck to Powerhouse No. 1., a distance of about seven miles, and there hatch and rear the fry in ponds. The fry should then be held until the following spring, after they are hatched and then release them in the river during flood periods before large canals are opened for the season’s operations.
>
> If the water is turned into the large canals before the fry are ready to be released, or the water is not turned off from the large canals during the winter and early spring, the fry would have to be transported by truck down the river to where they could be distributed below the canal systems. All of this work should be forced on the power companies. They construct impassable obstructions in our rivers and streams in the shape of dams and diverting tunnels and canals without regard to the enormous destruction of the runs of commercial fishes….” (W.H. Shelby, 1920, p. 21)

> The propagation of Chinook salmon becomes a matter of greater importance each season, as the natural spawning grounds are being cut off in the rivers and streams of the state by the erection of high dams for the development of hydro-electric power and irrigation…. We desire to call particular attention to the salmon run in the Sacramento and San Joaquin rivers. Already greatly depleted, it is threatened with extermination if measures are not taken at once to increase the output of salmon fry from the hatcheries. The construction of impassable dams and the diversion of water for irrigation is fast cutting off the remaining spawning beds in the tributary streams of these rivers and this excellent fish is doomed to extermination if prompt action is not taken. This

> department has called attention to this condition for the last four years, but the Legislature and the commercial fishermen as well as the general public pay no heed to the recommendations offered and no action to save this fine fish is taken…." (W.H. Shelby 1922, p. 36)

Prior to Kerckhoff Dam's development, salmon reportedly were routinely harvested by indigenous Mono People as far upstream as Vermillion Valley (Present-day Edison Reservoir) and Graveyard Meadows, both far upstream of Present Day Mammoth Pool Dam and Reservoir (see Lee, 1998, below). To the extent these reports are correct, then about 90 percent of the overall spawning and over-summer habitat was lost with the dam's development.

> The old-timers fished year-round years ago, but their big fishing expeditions were for salmon, after they journeyed hundreds of miles from the Pacific Ocean up the San Joaquin River, surging against the swift flowing water and cresting rapids and waterfalls to finally reach their old spawning grounds upriver from Cha:tiniu. There Grandpa John reminisced, our ancestors speared salmon only a few hundred yards from the meadow where they lived…. Grandpa John also described a long-ago fishing trip. "Hotshot [Grandpa}. Willie P. [Grandpa Willie]. And John [their cousin, John Rogozinski] way down rock mountains, and then walked by river below Graveyard meadow. Lots big salmon lay on sand waiting for trout to eat…." (G. Lee, 1998, p.87) (Photo on page 15 depicts Cha:tiniu at roughly the area of Jackass Meadows, well above the location of present-day Mammoth Pool Dam.)

Water developments upstream of Kerckhoff Dam also began affecting salmon production and survival. Hydro-electric dams and reservoirs were being progressively developed, and through upstream impoundment of the otherwise free-flowing river, they altered the magnitude and timing of downstream discharges and water temperatures, which in turn affected the viability of salmon and steelhead within the now critically reduced remaining habitats downstream of Kerckhoff Dam. These upstream storage reservoirs also progressively subtracted from the amounts of water seasonally reaching and bypassing the irrigation diversion points at Dos Palos, and later at Mendota, which exacerbated those fish entrainment problems. As flows became reduced and the diverted volumes represented a larger and larger part of the total flow, an increasingly larger fraction of the downstream migrating salmon and steelhead juveniles were entrained and lost. These impacts continued to increase in magnitude over time, until, by the early 1920's, the salmon runs in the San Joaquin River (and also Sacramento River) were at alarmingly low numbers. Supplemental fish stocking of the San Joaquin River was undertaken using eggs collected at the Klamath River and reared at the Battle Creek and Mill Creek Hatcheries on the Sacramento River; both operated at the time by the State Department of Natural Resources, Division of Fish and Game, as below.

> In 1927 an investigation of the past and present status of the Sacramento-San Joaquin salmon was started by G.H. Clark, a member of the staff of this bureau, under the guidance of Dr. J.O. Snyder of Stanford University. The results of this investigation were published last year as "Fish Bulletin No. 17." The Bulletin is in three parts. … Part II of the Bulletin is a survey of the spawning grounds, in which is given in detail the conditions on the main streams and tributaries of the Sacramento-San Joaquin river systems, with their obstructions, fish ladders and screens, the time of salmon runs and the abundance of salmon in each. He estimates that there are now 510 linear miles of spawning beds suitable and available for spawning and that previous to any obstructions in the streams there were at least 6,000 linear miles of stream bed suitable for spawning. At least 80 percent of the spawning grounds have been cut off by obstructions…." (N.B. Scofield, 1930p. 119.)

> ".. The development of hydro-electric energy by the erection of high dams in the tributary streams of the Sacramento and San Joaquin Rivers has materially reduced the number of salmon in the Sacramento and San Joaquin Rivers and Monterey Bay regions. Practically all the salmon now found in the Sacramento and San Joaquin River basins and Monterey Bay region are the product of hatcheries at Battle Creek, Mill Creek, and Klamath River stations. The number of salmon fry produced in the Klamath River stations has assisted greatly in keeping up the supply in the Sacramento River. ... The larger portion of the salmon in the Klamath River are the Sacramento race of king salmon that were introduced into the Klamath River by the Fish and Game Commission in its salmon cultural operations during the past years. The native Klamath River salmon do not appear in any great numbers in the river in the last few years. Our fishcultural experts at the Klamathon station support the view that the large majority of the fish taken from the Klamath River at the Klamathon egg-collection station are of the Sacramento race." (Shelby, 1924, p.27.)

In 1929 G. H. Clark stated: “The salmon of this river run in the spring (the water is too low for the fall run). The spawning beds extend from the mouth of Fine Gold Creek to Kerchoff Dam and in the small streams of that area. Actual length of beds is about 36 miles. There are a few scattered beds below Friant. Four dams affect the salmon of this river. The lowermost is the Delta weir in a slough on the west side of the river, 14 miles southeast of Los Banos (e.g. present day Sack Dam, explanation added). The weir is about 10 feet high, 30 feet wide: a fishway on one side is in working order but there are no screens on the ditches. Stevenson’s weir is on the main river directly east of the Delta weir. The weir is 110 feet long and six feet high and has a good fishway. Both of these dams are irrigation projects. Mendota weir is on the main river a mile and a half from the town of Mendota. It is a large irrigation diversion dam owned my Miller and Lux; it is 30 feet high, 200 feet long and built of concrete. The fishway is in working order during high water. There are several large canals taking water out of this reservoir and on those that have lifts on them are screened. The Kerchoff Dam is in the foothills 35 miles above Friant. It is 180 feet high and impassable to salmon. It was built around 1920 to divert water for power generation. At the town of Friant there is a proposed project to be constructed in 1928-29. This structure is to be 125 feet high and will cut off most of the spawning grounds of the river.

Eighty to Ninety years ago, the salmon in the San Joaquin were very numerous and came in great hordes whenever prolonged spring flooding provided passage for the juveniles and adults below Sack Dam. As the various agencies of depletion such as dams, irrigation ditches and overfishing came into play, the runs fell off. In 1916-17 there was reported a very good run in the river at Mendota. In 1920 it was fairly good. The run has fallen off each year until in 1928 very few salmon were seen in the stream. In 1925 there was a fair run, better than it had been for several years.

Absent access to the upstream watershed for spawning and faced with the increases in upstream water storage and downstream diversions over time, the salmon gradually declined, until the complete seasonal discontinuation of flows occurred in 1945, when Friant Dam was completed and first operated. By the early 1940’s, despite efforts to screen the canal intakes at Mendota (Van Cleve, 1946), the fall run had disappeared completely, above the mouth of the Merced River, except in extremely wet (i.e., flood) years, when occasional individuals were encountered above the Mendota Pool area. The development of Friant Dam by the U.S. Department of the Interior, doubled the quantity of upstream storage, and significantly increased the quantities of water diverted for out-of-stream purposes. This proverbial "last straw" resulted in the elimination of even the hatchery supplemented runs of spring-run salmon from the reaches of San Joaquin River above the mouth of the Merced River.

> "Studies of Young Salmon: Fyke netting studies of downstream migrants have included studies of the time of migration in the Feather, American, Consumnes, Mokelumne and San Joaquin Rivers, and studies if the damage done by various large unscreened and inadequately screened irrigation diversions. The diversions are all taking salmon, but the ones in the Mendota area are the worst…" (Van Cleve 1946, p.32.)
>
> "… The migration of young salmon down the San Joaquin was heavy from January 27th [1944] through March, and reached its peak on February 24th. The canals diverting water at Mendota did no appreciable damage until February 11th, but from that time on the loss of young salmon was heavy. On February 18th one fyke [DFG sampling] net took 3,000 young salmon from one canal." (Van Cleve. 1944, p39.).
>
> "San Joaquin River: Only the spring run was counted in the San Joaquin River. A small fall run manages to get through in years when there is water in the river in the area between Dos Palos and Gustine… The poor run in 1944 was due to a heavy kill of fish which took place in Merced County. At this time, the river was reduced to a string of nearly isolated pools for many miles below Dos Palos, resulting from a combination of factors: a light snow pack and impoundment of water to fill Friant Dam plus normal irrigation demand. Water was finally gotten down the stream, but the flow was low enough that in many places the fish had to swim through water less than two feet deep, making them easy prey for spears. Spearing was legal, and as many as 200 spearers were counted at a single sand bar…." (Van Cleve 1946, P. 29)
>
> "… During the biennium, the salmon runs were satisfactory in all the major spawning streams of the Central Valley, except the Mokelumne and San Joaquin Rivers…. The situation on the San Joaquin River could not be worse than it is. Inadequate water releases from Friant Dam have resulted in near extinction of the salmon run. The winter of 1946-47 was relatively dry, and the U.S. Bureau of Reclamation felt that it could allot no more than 15,000 acre-feet of water for the spring run. This water was released in such manner as to be of maximum benefit, but was still so inadequate as to be disastrous. Flows of 100 to 130 second-feet are inadequate during the hot weather. Only 6,000 salmon were counted past Mendota Dam in 1947, compared to 56,000 in 1945 and 30,000 in 1946.
>
> The winter of 1947-48 started as one of the driest on record. The U.S. Bureau of Reclamation announced that no water whatsoever could be spared for salmon; and in spite of all our efforts, as well as those of sportsmen's groups, the fishing industry, and congressmen to obtain water, the river below Dos Palos remained dry during the time of the 1948 run. As the only recourse available, the Bureau of Marine fisheries operated a salvage plan which called for construction of a fish trap, hauling the salmon overland and releasing them in an canal whence they could make their way to the spawning areas. Tank trucks were furnished by the Bureau of Reclamation. The trap was located at the mouth of the Merced River. The only fish to reach the spawning beds in the San Joaquin were the 1,955 that were transported by truck. Heavy rains in April and May caused the Merced River to flood, and on May 28 the trap was lifted to allow all the fish to ascend the stream. Previously, 163 salmon had been trucked up the Merced, as these floods were not anticipated. No water was released in the San Joaquin, and those fish that did not ascend the Merced were lost in the warm backwaters of the San Joaquin. At the same time, most of the young downstream migrants also perished for want of water. "(Croker, 1948, p. 123)

Today, salmon in the San Joaquin River occur only in the wettest of years and are strays from other rivers, most likely the Merced River.

Conclusion

Salmon in the San Joaquin River basin have declined substantially over the past several decades. Concurrent with this population decline has been the reduction of stream flows in the mainstem San Joaquin, Stanislaus, Tuolumne, and Merced Rivers. Concurrent with reduction in streams flows, especially during the spring time period, has been the increase of water temperatures to levels that have been identified in the literature as being too warm for successful smolt outmigration. Both reservoir storage volume and reservoir release volume level into the river, have the ability to delay the meteorological induced warming that occurs as water flows downstream.

For steelhead, due to their diverse life history and the lack of a specific population monitoring program in the San Joaquin River basin, little is known (e.g. empirically speaking) regarding abundance trends over time. Migrating adult steelhead have been documented at the Stanislaus fish counting weir, and out going juveniles have been observed at the Caswell rotary screw traps. Out-migrating rainbow trout have been observed in each of the Stanislaus, Tuolumne, and Merced Rivers as well as the San Joaquin River at Mossdale. Anecdotal reports from anglers and guides that have fished the Stanislaus, Tuolumne, and Merced Rivers suggest that steelhead abundance trends are the same as that for salmon in that abundance levels, as defined by catch rates, improve after higher instream flow conditions occur.

As the water development pendulum swung in the direction of increased dams and water diversions in the San Joaquin River basin, a failure to provide adequate supplies of water for protection of the salmon and steelhead beneficial uses in the San Joaquin River basin occurred as noted by i) the elimination of salmon and steelhead from the mainstem San Joaquin River and ii) the substantial declines of these species in the Stanislaus, Tuolumne, and Merced Rivers concurrent with water development. By default (e.g. reference to declining population trends and linkage to instream flow conditions), the present level of instream flows are inadequate to protect the salmon and steelhead beneficial uses of the Stanislaus, Tuolumne, and Merced Rivers.

On-going studies suggest that there is sufficient non-flow habitat (e.g. spawning habitat) remaining the Stanislaus, Tuolumne, and Merced Rivers to provide for a substantially greater population of salmon and steelhead than exists today if sufficient instream flows are provided during key life history stage development time periods. When instream flow levels are increased during the spring there is an improvement in habitat quality, as measured by decreased water temperatures, that can extend to the confluence in each of the Stanislaus, Tuolumne, and Merced Rivers. The extent of flow related water temperature cooling is dependent upon reservoir storage volume and reservoir release level. This reduction in spring water temperature in the Stanislaus, Tuolumne, and Merced Rivers can influence reduced water temperatures in the San Joaquin River at Vernalis pending ratio of tributary to mainstem San Joaquin River flow.

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An evaluation of four Sacramento-San Joaquin River Delta juvenile salmon survival studies

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Executive Summary:

An evaluation of four Sacramento-San Joaquin River Delta juvenile salmon survival studies

Background.
The US Fish and Wildlife Service, Stockton Fish and Wildlife Office, has since the mid-1980s conducted several multi-year release-recovery experiments with coded-wire-tagged juvenile Chinook salmon. The objectives of the studies were (1) to estimate survival through the lower portions of the Sacramento and San Joaquin river systems, the California Delta, and (2) to quantify the factors affecting survival. Four of these studies, listed more or less by their historical start dates, are the *Delta Cross Channel*, *Interior*, *Delta Action 8*, and *VAMP* experiments.

Delta Cross Channel: These studies focused on how the position of the Delta cross-channel (DCC) gate affected survival of out-migrating juvenile salmon. When the gate(s) is open, water flow from the Sacramento river into the central Delta increases. The *a priori* hypothesis for these studies was that survival would be lowered with the gate open since the probability of entering the interior Delta would increase and the fish would thereby be more vulnerable to the water export pumps at the state water project (SWP) and at the federal Central Valley project (CVP). Temporally paired releases were made above the DCC (near Courtland) and below the DCC (at Ryde) and recoveries were made at Chipps Island and in the ocean fisheries.

Interior: These studies were somewhat of a follow-up to the *Delta Cross Channel* studies that aimed to more directly compare the survival of fish already in the interior Delta to the survival of fish remaining in the Sacramento River. Temporally paired releases were made, one in the interior Delta (in Georgiana Slough) and one in the Sacramento River (at Ryde), and recoveries were made at Chipps Island and in the ocean fisheries.

Delta Action 8: These studies were essentially an alternative analysis of the *Interior* studies in that the relative survival of interior Delta releases (compared to Sacramento River releases) was to be modeled as a function of water exports. However, with *Delta Action 8* objectives in mind, export levels were deliberately manipulated to increase the scope of inference.

VAMP: In contrast to the other three studies which examined survival for fish out-migrating from the Sacramento River, VAMP focused on the survival of salmon out-migrating from the San Joaquin River. The primary factors of interest were

> water export and flow levels. Of additional interest was the effect on survival of placing a barrier at the head of Old River (HORB). When the HORB is in place the chance that a fish will enter Old River from the San Joaquin River is decreased, and presumably the influence of the CVP and SWP, which are located adjacent to Old River, is lessened. Temporally paired releases were made at two or three locations, though a total of five release locations were at one time or another used, and recoveries were made at Chipps Island and in the ocean fisheries, and in more recent years at Antioch.

A positive design feature of all four release-recovery studies was the temporal pairing of releases made at different locations in the river system, i.e., for each upstream release (or releases), a concurrent release was made downstream. The temporal pairing aimed to control for the effect of potentially confounding factors and thereby increase precision.

USFWS staff have previously analyzed these studies at various stages of completion. These analyses utilized the temporal pairing but an underlying probability framework for the release-recovery data was not explicitly specified. The analyses did not account for unequal sampling variation (due to, for example, differing release numbers) nor between release pair variation (e.g., unaccounted-for environmental variation in underlying survival or capture probabilities). Analyses of recoveries at different locations were typically carried out separately on a location-specific basis; e.g., results for recoveries at Chipps Island were analyzed and then the analysis was repeated for recoveries from the ocean fishery.

Bayesian hierarchical models.
In this report, Bayesian hierarchical models (BHMs) were used to reanalyze the data from these studies. The BHM framework explicitly defined probability models for the release-recovery data and accounted for unequal sampling variation and between release pair variation. Recoveries from multiple locations were analyzed in combination. Such a framework is more statistically efficient and coherent than previous analyses in that several levels of uncertainty are explicitly accounted for, using recoveries from multiple locations simultaneously increases precision, and the effect of sample size on precision can be readily examined. However, the costs of the BHM approach include increased model complexity and more technically difficult model fitting procedures, in this case, Markov chain Monte Carlo.

Some assumptions of the BHMs as applied to these studies are worth highlighting. One is that for temporally paired releases the capture probabilities at recovery locations were identical; e.g., for a temporally paired Courtland and Ryde release, the probability that a fish alive at Chipps Island is then caught at Chipps Island is the same for fish from either release location. A related assumption is that the ocean recovery probabilities, which includes survival, spatial distribution, and maturation probabilities, are the same for temporally paired releases. Finally for the *VAMP* studies, where releases at two or three locations were made more or less upstream of one another, and *absolute* survival, as contrasted to *relative* survival is estimated, the survival of fish through in-common downstream sections was assumed the same. For example, given a paired release at Dos Reis and at Jersey Point, fish from Dos Reis that have survived to Jersey Point have the same survival probability from there on as do the Jersey Point releases. Thus, it is assumed that there is no temperature shock, due to differences in truck water temperature and river water temperature, which increases mortality for Jersey Point releases over and above the mortality that will be experienced by Dos Reis fish that have reached Jersey Point. To estimate relative survival, however, between release groups, such shock is acceptable so long as it is the same for both release groups.

Results.

For the most part, the substantive conclusions from the BHM analyses, summarized below, were consistent with previous USFWS analyses.

Delta Cross Channel: There was modest evidence, 64 to 70% probability, that survival of Courtland releases, relative to the survival of Ryde releases, increased when the gate was closed.

Interior: Survival for the interior Delta releases was estimated to be about 44% of the survival for the Sacramento River releases.

Delta Action 8: There was a negative association between export volume and relative survival, i.e., a 98% chance that as exports increased, relative survival decreased. Environmental variation in the relative survival was very large, however; e.g., for one paired release the actual relative survival at a low export export level could with high probability be lower than relative survival at a high export level for another paired release.

VAMP: (a) The expected probability of surviving to Jersey Point was consistently larger for fish staying in the San Joaquin River (say passing Dos Reis) than fish entering Old River, but the magnitude of the difference varied between models somewhat; (b) thus if the HORB effectively keeps fish from entering Old River, survival of out-migrants should increase; (c) there was a positive association between flow at Dos Reis and subsequent survival from Dos Reis and Jersey Point, and if data from 2003 and later were eliminated from analysis the strength of the association increased and a positive association between flow in Old River and survival in Old River appeared; (d) associations between water export levels and survival probabilities were weak to negligible. Given complexity and number of potential models for the VAMP data, however, a more thorough model selection procedure using Reversible Jump MCMC is recommended.

Discussion.

The resulting BHM analyses are not the ultimate, definitive explanations for what affects juvenile salmon survival through the Delta, particularly for out-migrants from the San Joaquin River. In general data limitations inherent to release-recovery data, i.e., that only one capture is possible, relatively low capture probabilities, relatively high environmental variation, and in the case of *VAMP* the lack of balance in the release strategy, affect the accuracy of estimates of effects on survival.

The BHM framework, however, which allowed for between release variation in survival and capture probabilities, is arguably an improvement over previous analyses. For example, models without such random effects in the survival and capture probabilities, for example, did not fit the data nearly as well as models with random effects. The variation in recoveries was greater than what would be explained by standard, non-random effects logistic regression.

Given the apparently high environmental variation, it may take many replications of temporally paired releases to more accurately quantify the effects of DCC gate position, exports, flow, and HORB on survival. Regarding future work, if CWT release-recovery data continue to be the primary source of information, then (a) making releases below the in-river recovery locations, such as Chipps Island, is recommended to allow separate estimation of capture and survival probabilities and (b) more detailed analysis of ocean recovery patterns for temporally paired releases may be useful. A promising alternative to CWT data is the use of acoustic tags and in-river receivers. Fish must be sacrificed to read CWTs while acoustic tags can be detected, and read, remotely, thus allowing repeated recaptures and increased precision in estimates of survival. Additionally, by judicious placement of receivers, acoustic tags can provide information about migration paths much more readily than CWT data.

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1. Introduction

Throughout the Sacramento and San Joaquin river systems abundances of native Chinook salmon runs are far below historical levels. The declines in abundances of some runs have been drastic enough to result in endangered species listings; e.g., Sacramento winter run Chinook salmon were put on the federal endangered species list in 1994. Reasons for the declines include man induced losses of and changes in adult spawning and juvenile rearing habitat such as the building of dams and various water diversions. To attempt to estimate the survival probabilities for juvenile salmon during the out-migration period, and to understand how survival may be associated with various water conditions and man-made structures, the US Fish and Wildlife Service (USFWS), Stockton Fish and Wildlife Office, has been carrying out various survival studies, more or less annually, for over twenty years.

Many of these studies have focused on survival through and near the California Delta (hereafter the Delta), which is located in the lower reaches of the Sacramento and San Joaquin rivers, including their confluence. The general design of the studies is to release hatchery-reared juvenile Chinook salmon at two or more locations in the river, catch fish downstream using a trawl, typically over a two to three week period, and then, over a two to four year period, recover others in samples taken from ocean fishery catches. At the hatchery the fish are tagged internally with coded-wire-tags and externally marked by excising the adipose fin.

The release and recovery locations and duration of four of the studies are summarized in Table 1. The locations of the various release locations for the studies and the downstream recovery locations (Antioch and Chipps Island) are shown in Figure 1. Schematics of the release-recovery design for each of the studies are shown in Figure 2.

The primary objectives of each study are listed below.

(1) *Delta Cross Channel studies (DCC)*: To determine whether survival of out-migrating juvenile salmon from Courtland, located on the Sacramento River just above the Delta Cross Channel, to Chipps Island is higher when the Delta Cross Channel Gates are closed than when they are open.

(2) *Interior Delta vs mainstem Sacramento studies (Interior)*: To determine whether survival of out-migrating juvenile salmon from Georgiana Slough, located in the north (interior) Delta, to Chipps Island is lower than the survival from Ryde, located in the Sacramento River, to Chipps Island.

(3) *Delta Action 8 studies (DA 8)*: To determine whether survival of Georgiana Slough releases relative to Ryde releases is associated with water project exports (see the Central Valley Project (CVP) and State Water Project (SWP) in Figure 1). (Note: this is an extension of the Interior study.)

(4) *Vernalis Adaptive Management Plan studies (VAMP)*: To determine if survival of outmigrating juvenile salmon from various locations on the San Joaquin River (Durham Ferry, Mossdale, Dos Reis, and Jersey Point) to Antioch and Chipps Island is related to water project exports and San Joaquin River flows.

There are three main purposes of this paper: (1) to evaluate the four studies, some of which are still ongoing, in terms of how well the studies did (or can) achieve their stated objectives, (2) to demonstrate alternative analysis procedures, and (3) to make recommendations for alternative study designs.

Section 2 reviews the data generation and analysis procedures of the USFWS for each study. A general probability framework, hierarchical models, for viewing all four studies is described in Section 3, particular models for each of the studies are given in Section 4, and the framework is applied, with a reanalysis, to each of the studies in Section 5. Sample size determination for some of the studies is discussed in Section 6 and the last section includes recommendations and conclusions. Appendices include technical details of some of the analysis procedures along with computer code.

2. BACKGROUND: DATA SUMMARY AND PREVIOUS ANALYSES

2.1. **Data.** In all four studies releases were made in temporally matched pairs or sets, where one release served as a control group in some regard. The term paired release-recovery experiment will be used to describe these studies, even when more than two temporally-matched releases were made. Table 2 summarizes the release-recovery notation used in this report,with more explanation below, along with some of the notation used for models. The release numbers and recoveries for the paired releases in each of the four studies are shown in Tables 3-5.

Notation. Number of fish released is denoted by R and y is the number recovered. Release locations Courtland, Georgiana Slough, Ryde, Durham Ferry, Mossdale, Dos Reis, and Jersey Point are abbreviated Ct, GS, Ry, DF, MD, DR, and JP, respectively. Similarly, recovery locations Chipps Island, Antioch, and the ocean fishery samples are abbreviated by CI, Ant, and Oc. The release and recovery abbreviations are used as subscripts for R and y; for example, recoveries at Chipps Island of releases made from Courtland are represented by $y_{Ct \to CI}$. The ocean recoveries used for analysis are estimated, not observed, values and are shown with a hat, e.g., $\hat{y}_{Ry \to Oc}$. Recovery fractions, numbers recovered divided by number released, are denoted $\hat{r}$; e.g., $\hat{r}_{Ry \to Oc} = \hat{y}_{Ry \to Oc}/R$. The fraction of total recoveries relative to number release are called combined recovery fractions and denoted, for example, $\hat{r}_{Ry \to CI+Oc}$.

In-river smolt recoveries. For all four studies a midwater trawl operating at Chipps Island has been used to capture the released salmon. The trawl is part of a longterm USFWS monitoring program to collect information on the abundance of salmon and other species. A single tow is usually of 20 minute duration and is made either along the north shore, in the middle of the river, or along the south shore. During the period when fish from the studies are out-migrating past Chipps Island, the trawl sampling effort is often increased. For example, sampling during May and June (which is when DCC fish and VAMP fish pass by) and during December and January (when Interior/Delta Action 8 fish pass by) has usually been on a daily basis. For a given sample day at least 10 tows are made, and for some days in May and June the number of tows is doubled.

For the VAMP study (since year 2000) additional trawling has been done using a Kodiak trawl at Antioch in a fashion similar to that at Chipps Island. However, the number of tows made in a sampled day has been more variable than that at Chipps Island; e.g., in year 2005, the number of tows made at Antioch on a given sample day ranged from 5 to 30.

Ocean adult recoveries. The estimated number of ocean recoveries are expansions of observed recoveries taken from samples of landed ocean catches. Spatially and temporally stratified random samples are taken of the catches landed by the commercial troll and sport fisheries at various ports along the Pacific coast throughout the fishing season. Recoveries from a given release can occur at ages 2, 3, 4 or 5; i.e., if out-migrating in year t (age 1), it could be caught in years t+1, t+2, t+3, or t+4. The expanded recoveries from a given release can be written approximately as follows, ignoring the distinction between samples taken of commercial and of sport fisheries. Within stratum h (a particular year-week-area combination), letting N_h be the total number of sample units, n_h be the number selected (within stratum h), and $obs_{x\to h}$ be the number of sample recoveries from release x, the estimated number of recoveries is

$$\hat{y}_{x\to Oc} \quad \approx \quad \sum_{year}\sum_{week}\sum_{area}\frac{N_{year,week,area}}{n_{year,week,area}} obs_{x\to year,week,area}.$$

These estimates will be referred to as *expanded* ocean recoveries. The overall sampling rate is around 20 to 25%, i.e., $n/N \approx 0.20$ to 0.25, and the precision of the estimates is likely relatively high.

Salvaged fish. Out-migrating smolts are also recovered or collected at salvage facilities at the water export locations (one near the state water project, SWP, and one near the federal water project, CVP). The collection facilities are sampled on a regular, fairly systematic basis, and salmon in the sample with a missing adipose fin are sacrificed to read the coded-wire tag. Based on these samples, the total number of tagged fish in the collection facility are estimated. This total, including sacrificed fish, is the estimated salvage. All the collected fish (excluding those sacrificed during sampling) are then trucked from the facilities to locations about 8 to 11 miles upstream of Chipps Island. Fish from the state facility are released either in the Sacramento River, at Horseshoe Bend and, or in the San Joaquin River, at Curtis Landing near Antioch Bridge; from federal facilities releases are either in the San Joaquin River at Antioch, near Antioch Bridge, or in the Sacramento River at Emmanton, near Sherman Island. Salvaged fish are potentially being recovered at Chipps Island and in the ocean fisheries, thus using estimated salvaged fish as a response variable along with recoveries at Chipps Island and elsewhere would potentially lead to double-counting. However, Newman (2003) estimated that the probability of recovery at Chipps Island is in the range of 0.001 to 0.002. Thus the number of fish salvaged and caught at Chipps Island may be relatively small.

Inland recoveries. Returning adult fish are also recovered in freshwater areas, in samples taken to estimate escapement and at hatcheries, sometimes referred to as inland recoveries.

Similar to ocean recoveries, observed and expanded numbers are calculated. Escapement sampling procedures vary considerably throughout the Central Valley, and coverage is uneven. Hatchery fish released away from the hatchery they were reared in are quite likely to stray, with straying probabilities generally increasing with increasing distance from the hatchery. If the straying pattern differs between releases within the same release set, and if the sampling effort differs between return locations, then estimates of adult freshwater returns need to be adjusted accordingly, otherwise bias will result. Such adjustments, however, would be a considerable undertaking, and has not been attempted for the work described herein.

Trawl efficiency measure. For some of the USFWS analyses, a survival "index" was calculated using a measure of the trawl gear efficiency. The idea behind the trawl efficiency measure was to adjust for possible differences in the capture probabilities between releases in a paired release. The measure is based on duration of sampling and the channel width sampled relative to the the length of out-migration time and total channel width at Chipps Island (or Antioch) during that time. The relative width of channel sampled is calculated by dividing the net width by the estimated channel width; e.g., at Chipps Island the channel width is 3900 feet, the midwater trawl net is 30 feet wide, thus the fraction sampled is $30/3900 = 0.00769$. The fraction of out-migration time sampled is calculated by dividing the total minutes the net was towed by the number of minutes elapsed between the first and last days of recovery; e.g., if the first recovery was on May 5 and the last on May 11, and the net was towed for 2608 minutes, the fraction is $2608/(7*24*60) = 0.259$. Trawl efficiency is then the product of these two fractions, e.g., $0.259*0.00769 = 0.00199$. More generically, letting f denote the trawl efficiency measure:

$$f = \left[\frac{\text{Sampling duration}}{\text{Out-migration duration}}\right] \times \left[\frac{\text{Trawl net width}}{\text{Channel width}}\right]$$

Since the calculated out-migration duration is tied to the recovery dates, efficiency estimates can differ between paired releases if the dates of first and last capture do not coincide. Problems with this measure are discussed later.

2.2. **DCC studies.** The Delta Cross Channel (DCC) was built in 1951 by the US Bureau of Reclamation to increase the amount of water transferred from the Sacramento River across the Delta to the federal pumping plant at Tracy (the CVP), which in turns pumps water into the Delta Mendota Canal. There are two movable gates, the DCC gate, which can be opened to let water from the Sacramento River enter the Delta or closed to stop such transfer. Just below the entrance to the DCC on the Sacramento River is the entrance to the Georgiana Slough, which is another way for water, and fish, to enter the Delta. Once fish enter the Delta, because of the stream geometry and the relative proximity of the SWP and CVP, they are presumably more vulnerable to mortality induced by the pumps.

To understand how the position of the Delta Cross Channel gate, as well as release location relative to the entrance to Georgiana Slough, affected the survival of fish out-migrating down the mainstem of the Sacramento River, a total of thirteen paired releases were made during the spring months (usually May) between 1983 and 1989 at Courtland and at Ryde (Figure 1). All of the releases were juvenile *fall run* Chinook salmon that had been raised at the California Department of Fish and Game's Feather River fish hatchery. The Courtland site is on the mainstem of the Sacramento River just above the entrances to the Delta Cross Channel and Georgiana Slough, while Ryde is on the mainstem below both entrances; thus fish released from Ryde are much less likely to enter the interior Delta. Four pairs were released with the DCC gate closed and nine pairs were released with the DCC gate open. Table 3 shows the numbers released at Courtland and Ryde and the number of recoveries at Chipps Island and the expanded ocean recoveries.

Simple summaries. The combined Chipps Island and ocean fishery recovery fractions for the Courtland ($\hat{r}_{Ct \rightarrow CI+Oc}$) and Ryde ($\hat{r}_{Ry \rightarrow CI+Oc}$) releases for different gate positions in Figure 3. Given that Courtland is upstream of Ryde, one might expect the Ryde recovery rate to be higher than the Courtland rate no matter what the gate position. However, in 2 of the 4 open gate and 2 of the 9 closed gate situations the point estimate of the Ryde recovery rate is less than the Courtland rate, presumably a reflection of sampling variation. Figure 4, which compares the ratio of recovery fractions, $\hat{r}_{Ct \rightarrow CI+Oc}/\hat{r}_{Ry \rightarrow CI+Oc}$, for different gate positions, suggests that Courtland releases tend to survive better when the DCC gates are closed. There was one outlier ($\hat{r}_{Ct \rightarrow CI+Oc}/\hat{r}_{Ry \rightarrow CI+Oc} > 3$) for the open gate release pairs; this is from a 1989 release (Table 3, Group 13), where there were relatively few ocean recoveries from the Ryde release.

Regarding other recoveries, the estimated number of juvenile fish salvaged by the fish export facilities varied widely between releases (Table 3). For only one of the Ryde releases were there ever any salvaged fish at the export facilities. For the Courtland releases there were four releases with a considerable number of salvaged fish, ranging from 182 to 1075; there was no association with gate position, however, in that the gate was closed for two of these four cases. When the gate was closed, some of the salvaged fish likely entered the Delta via Georgiana Slough (since no Ryde fish were recovered for those four cases). Inland recoveries were minimal (fourteen fish total from all 13 pairs), none of which were to their hatchery of origin at Feather River.

Previous USFWS analyses. A USFWS analysis of DCC studies (Brandes and McLain, 2001) was based on survival indices to Chipps Island and expanded ocean recovery rates for both Courtland and Ryde releases. Per release pair, the Chipps Island indices were calculated by dividing the observed number of recoveries at Chipps Island by the estimates of trawl efficiency, f_{Ct} and f_{Ry}, and by the number released, R_{Ct} and R_{Ry}:

$$\hat{I}_{Ct\rightarrow CI} = \frac{y_{Ct\rightarrow CI}}{f_{Ct}R_{Ct}} = \frac{\hat{r}_{Ct\rightarrow CI}}{f_{Ct}} \qquad \hat{I}_{Ry\rightarrow CI} = \frac{y_{Ry\rightarrow CI}}{f_{Ry}R_{Ry}} = \frac{\hat{r}_{Ry\rightarrow CI}}{f_{Ry}}.$$

expanded ocean fishery recovery rates were also calculated, $\hat{r}_{Ct\rightarrow Oc}$ and $\hat{r}_{Ry\rightarrow Oc}$. Brandes and McLain then carried out four paired t-tests for equality of the indices and ocean recovery rates:

$$\begin{array}{ll} H_o : I_{Ct\rightarrow CI} = I_{Ry\rightarrow CI}|\text{ DCC gate open} & H_o : I_{Ct\rightarrow CI} = I_{Ry\rightarrow CI}|\text{ DCC gate closed} \\ H_o : r_{Ct\rightarrow Oc} = r_{Ry\rightarrow Oc}|\text{ DCC gate open} & H_o : r_{Ct\rightarrow Oc} = r_{Ry\rightarrow Oc}|\text{ DCC gate closed} \end{array}$$

The null hypotheses for the Chipps Island indices were rejected, but were not rejected for the ocean recovery rates.

Manly analyses. The hypotheses tested by Brandes and McLain were hypotheses of no locational differences in survival probabilities between Courtland and Ryde releases *conditional* on a particular DCC gate position.

In contrast, Manly (2002) used the pairing of Courtland and Ryde to advantage by comparing the ratios of Chipps Island indices between the open and closed gate situations using two sample t-tests for the following hypotheses.

$$\begin{aligned} H_o &: \frac{I_{Ct\rightarrow CI,t}}{I_{Ry\rightarrow CI,t}}|Open = \frac{I_{Ct\rightarrow CI,t}}{I_{Ry\rightarrow CI,t}}|Closed \\ H_a &: \frac{I_{Ct\rightarrow CI,t}}{I_{Ry\rightarrow CI,t}}|Open < \frac{I_{Ct\rightarrow CI,t}}{I_{Ry\rightarrow CI,t}}|Closed \end{aligned}$$

Manly also tested for the equality of differences in indices. In both cases he did *not* find statistically significant differences (using a pooled estimate of variance in each case, the P-values were 0.393 for ratios and 0.250 for differences). These tests are more directly focused on the effect of gate position and are more appropriate than the tests carried out by Brandes and McLain.

2.3. **Interior studies.** In contrast to the DCC studies where the relative survival in the interior Delta was measured indirectly from the Courtland releases which *might* enter the interior Delta (via the DCC or entering Georgiana Slough), the Interior studies focused directly on the relative survival of fish *known to be* in the interior Delta A total of 15 paired releases of *late fall run* fish (reared at Coleman National Fish Hatchery) were made during the months of December and January in Georgiana Slough and at Ryde between 1993/1994 and 2005/2006 to study how the interior Delta releases' survival compared to mainstem releases (and for the related DA 8 study, to study how the relative survival related to exports). The late fall run was chosen with the intent to imitate, to the degree possible, the natural winter run, hoping to to perhaps gain understanding of how export operations impacted the winter run. Releases in Georgiana Slough were made far enough into the slough as to make it unlikely that fish would go upstream to Sacramento River and then travel down the river. Table 4 shows release and recovery data for the Interior studies.

Simple summaries. The overall recovery fractions, recoveries at Chipps Island and in the ocean fisheries divided by release number, are compared for the Georgiana Slough and Ryde release pairs in Figure 5. While there is considerable between-pair variation, the overall recovery fractions for Ryde releases remained higher than those for Georgiana Slough in all cases.

Figure 6 compares the four sets of recovery fractions, at Chipps Island, in the ocean, at the fish facilities, and at inland locations. The straight line drawn on each plot has a slope equal to the mean of the ratio of recovery fractions of Georgiana Slough to Ryde releases, e.g., $(y_{GS\rightarrow CI}/R_{GS})/(y_{Ry\rightarrow CI}/R_{Ry})$. The means of the ratios were 0.26, 0.43, and 0.39 for at Chipps Island, in the ocean, and inland, respectively, consistent evidence that Georgiana Slough fish were surviving with a lower probability. Conversely, the relative fraction of fish salvaged was proportionately much higher for Georgiana Slough releases compared to Ryde releases, over 16 times greater.

The inland recoveries are perhaps comparable in this study given that the stray rates, calculated as the relative fraction of inland recoveries returning to Coleman National Fish Hatchery (CNFH), e.g., $y_{GS\rightarrow CNFH}/y_{GS\rightarrow Inland}$, were much the same for Georgiana Slough and Ryde. Excluding one extreme observation, the relationship was quite linear and the correlation coefficient was 0.93.

Previous USFWS analyses. The published analyses (Brandes and McLain, 2001) were made using the data available at the time and it is these results that are discussed below. Since then the analyses have been updated to include the most recent data (Pat Brandes, personal communication), but the analyses have been similar to what is described here. Brandes and McLain (2001, pp 72-77) calculated survival indices to Chipps Island for the Georgiana Slough and Ryde releases,

$$\hat{I}_{GS\to CI} = \frac{\hat{r}_{GS\to CI}}{f_{GS}} \qquad \hat{I}_{Ry\to CI} = \frac{\hat{r}_{Ry\to CI}}{f_{Ry}},$$

and ocean recovery rates, $\hat{r}_{GS\to Oc}$ and $\hat{r}_{Ry\to Oc}$. Paired t-tests were used to test hypotheses of equality of survival indices or ocean recovery rates for Georgiana Slough and Ryde releases.

$$H_o : I_{GS\to CI} = I_{Ry\to CI} \qquad\qquad H_o : r_{GS\to Oc} = r_{Ry\to Oc}$$

The test results were highly significant in both cases, with Chipps Island survival indices and ocean recovery fractions for Georgiana Slough releases significantly lower than for Ryde releases.

2.4. **Delta Action 8 Experiments.** These experiments overlap with the Interior studies in that the same release-recovery data are used. How the two studies differ is that the Interior studies focus on identifying whether or not differences in survival exist, and, if so, what the magnitude of the differences are, while DA 8 is aimed at *modeling* differences as a function of exports. Thus, on one hand, the DA 8 studies are not so much studies but different analyses of the data provided by the Interior studies. On the other hand, however, export levels have been deliberately manipulated to increase the scope of inference about the possible relationship with survival. Furthermore, in recent years the spatial scope of the DA 8 studies has expanded by additional releases being made at Sacramento, Sherman Island, Vorden, and Port Chicago. These additional releases are, however, not discussed in this report.

Simple summaries. The estimated fractions of juvenile fish salvaged are plotted against exports for both release groups (Figure 7). The loess smooth drawn across the plot suggests a positive association between exports and the fraction of the Georgiana Slough releases that is salvaged. With the exception of the 1995 release, the fraction salvaged for Ryde releases appears to be unrelated to exports.

Previous USFWS analyses. Brandes and McLain (2001, p 75) used an indirect approach to model the ratio of Chipps Island survival indices for Georgiana Slough releases to Ryde releases as a function of exports. Data from some fall run releases (raised at Feather River hatchery) made in the spring months of 1992-1994 were also included in the analysis. The

Chipps Island survival indices were first calculated for the Georgiana Slough and Ryde releases separately and then the ratio of indices was regressed against exports:

$$\frac{I_{GS \rightarrow CI}}{I_{Ry \rightarrow CI}} = \beta_0 + \beta_1 \text{Exports} + \epsilon.$$

The resulting slope estimate, $\hat{\beta}_1$=-0.03, was significantly less than zero, which suggested a negative relationship between exports and the ratio of survival indices.

2.5. **VAMP and earlier studies.** Prior to VAMP which began in 2000, between 1985 and 1999, several release and recovery experiments were carried out in the lower San Joaquin river system and Delta. The objectives of these studies included comparing survival between fish that traveled down Old River, which branches off the San Joaquin River, with the survival of those that continued down the San Joaquin River. Old River passes by the CVP and SWP pumping plants (Figure 1), and water, and fish, from Old River are drawn directly towards the water export pumps. During the first years of experimentation, 1985-1990, paired releases were made directly into Old River and directly into the San Joaquin River near Dos Reis, which is a short distance downstream of the head of Old River. In terms of recovery fractions at Chipps Island, the Old River releases had considerably lower fractions than did Dos Reis releases (the median ratio of fraction for Old River releases to fraction of Dos Reis releases was 0.46 (Table 5)).

Given what was learned about apparent survival in Old River, no further releases were made directly into Old River after 1990, and a removable barrier was installed at the head of Old River (HORB) starting in 1992 to lower the probability that an out-migrating salmon would go down Old River. Partially to study the effectiveness of the HORB, paired releases were made at Mossdale, just upstream of the head of Old River, at Dos Reis, and Jersey Point starting in 1994. The HORB, however, cannot be *placed* in the river when flows are above 5000 cfs and it cannot be *present* in the river at flows above 7000 cfs (San Joaquin River Group Authority 2006), so it has not always been in place every year.

The VAMP studies (year 2000 to the present) have the primary aim of studying the effects of flow and exports on salmon survival given that the HORB is in place. During the VAMP studies exports are not to exceed 3000 cfs. The intended experiment design is to make near-simultaneous releases from three locations: (1) at Durham Ferry on the San Joaquin River, about 12 miles upstream of Old River, (2) Mossdale, and (3) Jersey Point (relatively near the confluence with the Sacramento River); and then to make recoveries downstream at Antioch by a kodiak trawl, further downstream at Chipps Island by a mid-water trawl, and in the ocean fishery (Figure 1). In 2005 and 2006 flows were too high for HORB installation, however, and releases were made at Dos Reis instead of Mossdale in 2005, and at Mossdale instead of Durham Ferry in 2006.

Table 5 includes the release and recovery data from the pre-VAMP and VAMP studies. Some of the associated covariates used in modeling recoveries are also shown and definitions are provided in Table 6.

The fish used in the pre-VAMP and VAMP studies were all fall run, but the hatchery from which the fish came has varied over time (see the stock column in Table 5). In the earliest years, 1989-1995 most fish came from Feather River Hatchery. For 1996-1999 fish came from both the Feather River Hatchery and the Merced River Fish Facility, but within any given release set all fish came from the same hatchery. Since the VAMP studies began, all fish have come from the Merced River Fish Facility.

A schematic of the release and recovery locations by year is shown in Table 7. A relatively large number of observations (206 in total) have been generated, but imbalance in the release-recovery locations is evident. Lack of balance in the design is also apparent in terms of the covariates of interest, HORB position, flow, and exports (see Figure 8), the export and flow levels are always relatively low when the HORB is in (due to the cfs bound mentioned previously). The imbalance can cloud interpretation of the parameter estimates due to potential confounding. For example, recovery fractions may be higher for Mossdale releases when the barrier is in than when the barrier is out, but exports are (by design), on average, lower when the barrier is in. Fortunately, there are observations with low exports and the barrier being out. Similarly, there are observations with low flows and the barrier out, thus potential confounding may be somewhat alleviated.

A comparison of the combined recovery fractions ($\hat{r}_{x \rightarrow Ant+CI+Oc}$) for different release sites is shown in Figure 9. Such a comparison is quite simplistic in that the pairing of releases is not accounted for and sampling variation is ignored. With these limitations in mind, Durham Ferry and Mossdale releases have relatively similar recovery rates, Old River recovery rates are generally lower than Dos Reis recovery rates, and Jersey Point release recovery rates are highest.

Salvage and adult inland recoveries. The estimated numbers of juvenile fish salvaged at the fish facilities have been, on occasion, relatively large (Table 5). For example, a 1986 release from Old River of 100,181 fish had an estimated 62,564 fish salvaged, or about 62% of the number released. The relationship between the HORB (in or out) and the estimated fraction salvaged is plotted in Figure 10 (excluding Old River releases). For Durham Ferry and Mossdale, both located upstream of the head of Old River, there was a sizeable difference in the fraction salvaged depending on HORB placement with the fraction decreasing with the HORB in; note, however, sampling variation is not being accounted for in this comparison and that for Durham Ferry, in particular, there were only two releases with the barrier out. For Dos Reis and Jersey Point, the HORB had little to no relationship on the fraction salvaged (ignoring the four extreme fractions).

The fraction of observed adult inland recoveries are shown in Figure 11. During the early years (1985-1996) just a few recoveries were made anywhere (it could be due to lower survival or sampling effort); for releases from recent years (2004-2006), adults have yet to return to freshwater (in any numbers). During the intervening years (1997-2003), the observed fraction returning was consistently highest for the Jersey Point releases, while the fraction for Durham Ferry tended to be lower than for Mossdale. When release were made from both Dos Reis and Mossdale, the fraction was slightly higher for Dos Reis releases. Thus the general pattern was higher adult return fractions for releases made further down river. As for the Interior/DA 8 studies, the amount of straying from the natal hatchery was considerable, but an effect of release location on straying was evident in the VAMP releases. For example, for a 2001 release set from Merced River Fish Facility (group 25 in Table 5), fish released from Durham Ferry returned to Feather River Hatchery, Nimbus Hatchery, Stanislaus River, Tuolumne River, as well as the Merced River Fish Facility. Fish released from Jersey Point strayed even more, including above Red Bluff Diversion Dam, Butte Creek, Feather River Hatchery, and Coleman National Fish Hatchery.

Previous USFWS analyses. Previous analyses by the USFWS of the juvenile recoveries (in the trawl samples) and adult recoveries (in the ocean fishery catch samples) from the VAMP and pre-VAMP experiments are described in Chapter 5 of the 2005 Annual Technical Report for the San Joaquin River Agreement (San Joaquin River Group Authority 2006). Discussion herein focuses on some of the analyses on pages 61 through 70 of that report. The VAMP analyses primarily used recovery fractions with no trawl efficiency adjustments. In some cases the observed recovery fraction was calculated with recoveries at a single recovery location, Chipps Island alone or ocean fisheries alone (denoted RR in the Technical Report), i.e., for release x, $\hat{r}_{x\rightarrow CI}$ and $\hat{r}_{x\rightarrow Oc}$. In other cases the observed recovery rate was based on recoveries at two locations, Antioch and Chipps Island, (denoted CRR for Combined Recovery Rate in the Technical Report), namely, $\hat{r}_{x\rightarrow (Ant+CI)}$. In all cases ocean fisheries recoveries were analyzed separately from Antioch and Chipps Island recoveries. The ratio of recovery fractions for upstream releases (Durham Ferry, Mossdale, or Dos Reis) to recovery fractions for downstream releases (Jersey Point) was the response variable used to study the relationships with flow, export, or HORB effects[2]. Thus releases from Jersey Point were viewed as controls for upstream releases. For example, the response variable used in regression models for Durham Ferry releases relative to Jersey Point releases was $\frac{\hat{r}_{DF\to CI}}{\hat{r}_{JP\to CI}}$. As will be shown later, these ratios can be interpreted as estimates of the ratio of survival probabilities for upstream releases to survival probabilities for downstream releases.

Analysis of the ratios of recovery fractions was carried out in a somewhat piecemeal fashion with freshwater recovery fractions and ocean fishery recovery fractions analyzed separately and analyses primarily examining one covariate at a time, e.g., ratio of ocean fishery recovery fractions regressed on flow, with HORB value fixed (either HORB was in or it was not). Some of the results are summarized in Table 8. In all cases, there were positive associations (although sometimes quite weak) between ratios of recovery rates and flows, but the regression coefficient was statistically significant (at α=0.10 level) with HORB in and non-significant when HORB was not in. Somewhat paradoxically, exports were positively associated with ratios of recovery fractions; an explanation offered for this paradox is that exports and flows were highly positively correlated (the correlation coefficient is 0.88).

2.6. **Comments about previous analyses.**

- *Pairing is advantageous.* A strength of all four designs is the use of paired releases. For the DCC studies, the Ryde releases served as controls to the Courtland releases in that river conditions (temperature, salinity, turbidity, etc) were relatively similar for the two groups. For the Interior and DA 8 studies, the Ryde releases served as controls to the Georgiana Slough releases. For the VAMP studies, the Jersey Point releases were controls for the upstream releases at Dos Reis, Mossdale, and Durham Ferry, although the similarity in river conditions were perhaps weakest in these studies given the greater distances between release locations. This pairing is advantageous in the sense that if these extraneous variables which could (and likely do) affect survival are controlled for, then the statistical efficiency (as measured by standard errors, say) is greater than what unpaired releases could achieve.
- *Trawl efficiency measures and survival indices have questionable accuracy.* Ideally, the trawl efficiency measure would be an estimate of the probability of capturing a fish given that it survived to the trawl location. Then the expected number caught would be the product of number released, survival probability (S) between point of

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[2] When the recovery rates in the ratio were based on recoveries at a single location, the ratio was denoted DRR, Differential Recovery Rate. When recovery rates in the ratio were based on recoveries at Antioch and Chipps Island, the ratio was denoted CDRR, Combined Differential Recovery Rate.

release and trawl location, and trawl capture probability p, say , $E[Y] = RSp$. Then an estimate of survival is $y/R\hat{p}$. The survival index calculation implicitly aims to make such an estimate using f as an estimate of p.

However, there are several problems with the calculation of f. Mathematically there is the problem that the observed recovery rate, y/R, can exceed the trawl efficiency measure, f, which then results in survival "indices" exceeding 1. For example, with one of the DCC releases at Courtland (1983), the survival index was 1.22. There is also the potential that prior to the day of first recovery, or after the day of last capture, there were fish passing but none were caught. Assuming, momentarily, that the use of duration of sampling and relative width of river sampled were adequate measures of capture probability, the omission of days prior to first capture and after last capture where fish were still passing would lead to an underestimate of p. Thus the estimate of S, $y/R\hat{p}$, is an overestimate. There is also the practical problem that when there are no captures, the measure of trawl efficiency is zero.

The efficiency calculation should involve a comparison of the volume of water swept by the net with the total volume of water passing Chipps Island during the out-migration period. For example, assuming that the gear has 100% efficiency for fish in the water the mouth of the net passes through, i.e., there is no net avoidance or selectivity for these smolt sized salmon, the probability of capture could be defined to be the fraction of the total water volume passing Chipps Island, say, during the out-migration, that the net passes through.

Due to the likely biases in trawl efficiency estimates, working with the unadjusted recoveries, or raw recovery proportions (numbers caught/number released) seems preferable. Some releases were made downstream of a recovery site, e.g., Chipps Island, and capture probabilities can be estimated directly (Newman 2003 and see Section 6.1).

- *Combined analysis of in-river and ocean recoveries would be more efficient.* Both the Chipps Island and the ocean recoveries provide information about the survival between release points and Chipps Island. Separate analyses of recoveries are not as statistically efficient as analyses that incorporate both sets of recoveries simultaneously, or in the case of VAMP, not as efficient as analyses incorporating Antioch, Chipps Island, and ocean recoveries.
- *Accounting for unequal sampling variability.* None of the analyses for any of the four studies accounts for the fact that the level of sampling variation is not constant. As release numbers change, for one thing, the precision of estimation recovery probabilities will change.

For example, in the 1987 DCC pair, over 100,000 were released from Courtland, in contrast to releases of around 50,000 in 1989; the variances for estimated recovery probabilities will differ even if the underlying true probabilities of recovery were identical.

- *Accounting for between-release pair variability.* The environmental conditions of each paired release vary over time, i.e., between release pairs. The survival and capture probabilities can be viewed as random variables. Ignoring this between-release pair variation may result in overestimates in the precision of the inferences.
- *Indirect analyses may be less accurate than integrated analyses.* Statistical analyses of the data from all four studies proceeded in somewhat of a two-step manner, which will be labeled an indirect analysis. For the DCC studies, the survival indices were calculated first, and then paired t-tests were carried out treating these calculated indices as if they were observations. Similarly, for the Interior studies, the survival indices were calculated for the Georgiana Slough and Ryde releases separately, and then paired t-tests were conducted with these indices. For the DA 8 studies, the ratio of survival indices were first calculated, and then the ratio was regressed against exports. Similarly for the VAMP studies, ratios of recovery fractions were calculated first and then regressed against covariates like flow and exports.

  The criticism leveled at this indirect approach is related to the previously mentioned issues of unequal sampling variability and between-release variability. Ignoring such variability may bias the inferences, or at least provide inaccurate measures of the degree of uncertainty. A more integrated approach for data analysis is to *work directly with the observed recoveries* and to *explicitly allow for unequal sampling variability and environmental variability*, and that is the basis for the hierarchical models described in Section 3.
- *Study-specific comments.* For the DA 8 analyses by Brandes and McLain (2001), the use of fall and late-fall races in the same regression implies a rather strong assumption that the ratio of survival indices, for a fixed export level, is the same for both races. It should be noted that at the time of the previous analysis considerably less data were available (only up through 1998 for Chipps Island recoveries) and fall run results were included to increase sample size. More recent analyses (Pat Brandes, personal communication) have been based on larger sample sizes and only late fall releases.

  For the VAMP analyses, fitting multiple regressions that included flow, exports, and HORB simultaneously would be more statistically efficient and perhaps easier to interpret than doing several simple linear regressions.

3. HIERARCHICAL PROBABILITY MODELS

The objectives of each of the four studies can be restated as aims to estimate unknown parameters of probability models, namely, survival probabilities and parameters for covariates, e.g., water exports, thought to affect survival. Probability models provide a rigorous, statistically defensible basis for both estimating such parameters as well as providing measures of uncertainty about the estimates. Additionally, such models are useful for evaluating study designs and assessing the impact of changes in sample sizes.

Hierarchical, or multi-level, probability models can be used as a common framework for analyzing each of the four studies. Hierarchical models can explicitly account for two levels of variation, temporal and sampling, which exist with the studies. Temporal or environmental variation is the variation over time in survival and capture probabilities. Because each of the studies took place over several years with multiple pairs or sets of releases made, such temporal or between group variation undoubtedly exists. Sampling variation is the between-fish variation within a single release in terms of their fates, e.g., whether or not they are caught at Chipps Island. A third level of variation, reflecting a Bayesian approach, can be included to quantify uncertainty about parameters that characterize the between group variation in survival and capture probabilities.

The hierarchical framework has an additional benefit, which will manifest itself in the VAMP analysis, in that information available in one time period for one spatial location can be used to make inferences for other time periods where such data were not available. For example, releases were only made in Old River during some years of the pre-VAMP period but that data can be used to make inferences about survival in Old River during the other years.

A simplified representation of Bayesian hierarchical models as they relate to the analysis of the release-recovery tag data is shown below.

Level 1, Observations: y's $\sim$ Probability Distribution(R, S_t and p_t)

Level 2, Random effects: S_t, p_t $\sim$ Probability Distribution(η, Covariates)

Level 3, Hyperparameters: η $\sim$ Prior Probability Distribution

The first level describes how the number of recoveries varies at random as a function of number released (R) and the survival and capture probabilities, describing sampling variation. The second level describes how survival and capture probabilities vary with time (or release set) and how they depend upon hyperparameters (η) and covariates, e.g., flow. The third level describes prior opinion about the hyperparameters, for example, $\eta = \mathrm{E}[S_t]$, an average or expected survival probability. Scientific interest is largely focused on these hyperparameters. A non-Bayesian hierarchical model would simply remove Level 3 and view the hyperparameters as constants to be estimated along with standard errors and confidence intervals, while Bayesian inference will yield a posterior probability distribution for the hyperparameters.

3.1. **General description of Bayesian hierarchical models (BHMs) for recoveries.**

Let $S_{i \to j,t}$ denote the probability of surviving from location i to location j for release pair or set t and let $p_{k,t}$ be the probability of capture at location k for set t. Also let $R_{i,t}$ equal the number of fish released at location i for release set t and let $y_{i \to j,t}$ be the number of fish out of the $R_{i,t}$ that were recovered at location j. Unless deemed necessary, the subscript for set t will often be omitted. The notation r will be used for recovery probabilities which are the product of survival and capture probabilities, e.g., $r = Sp$.

Level 1, within release sampling variation: The first level in the hierarchy is a probability model for the recoveries *given* the release group specific survival and capture probabilities. For example, suppose R_{Ryde} fish are released at Ryde and captures are then made at Chipps Island. The recoveries, $y_{Ryde \to CI}$, follow some distribution that depends on R_{Ryde} and the product $S_{Ryde \to CI} p_{CI}$:

$$y_{Ryde \to CI} \sim \text{Distribution}(R_{Ryde}, S_{Ryde \to CI} p_{CI})$$

Particular distributions will be described later[3].

Level 2, between release temporal variation: The second level in the hierarchy is a probability model for the survival and capture probabilities, S and p. Referring to the previous Ryde to Chipps Island example:

$$\begin{aligned} S_{Ryde \to CI} &\sim \text{Distribution}\left(\mu_{S_{Ryde \to CI}}, \sigma^2_{S_{Ryde \to CI}}\right) \\ p_{CI} &\sim \text{Distribution}\left(\mu_{p_{CI}}, \sigma^2_{p_{CI}}\right) \end{aligned}$$

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[3] It should also be noted that the expanded ocean recoveries, $\hat{y}_{i \to Oc}$, will be modeled at this level rather than the observed ocean recoveries. Thus in fairness to previous USFWS analyses, this approach is to some degree an indirect approach and is not fully integrated.

where μ and σ^2 are the mean and variance, respectively. For all four studies the questions to be answered can be re-expressed as questions about how S, or, more basically, how μ_S varies between release locations or under different experimental conditions.

Level 3, parameter value uncertainty. The third level of the hierarchy consists of probability distributions for the unknown parameters of the distributions in the second level. These distributions are called prior probability distributions, or simply priors. In particular, priors are specified for the parameters of the distributions for survival and capture probabilities. For example, again referring to the Ryde to Chipps Island example:

$$\begin{aligned} \mu_{S_{Ryde \rightarrow CI}} &\sim \text{Distribution}(\alpha_1, \beta_1) & \sigma^2_{S_{Ryde \rightarrow CI}} &\sim \text{Distribution}(\alpha_2, \beta_2) \\ \mu_{p_{CI}} &\sim \text{Distribution}(\alpha_3, \beta_3) & \sigma^2_{p_{CI}} &\sim \text{Distribution}(\alpha_4, \beta_4), \end{aligned}$$

where α_i, β_i, i=1,2,3,4, are fixed *hyperparameters*.

3.2. **Remarks.** Before describing the specific hierarchical model formulations for the four studies, some general comments about BHMs for release-recovery data are made.

(1) *Bayesian vs Frequentist inference.* With Bayesian methods (Carlin and Louis 1996, Gelman, Carlin, Stern, and Rubin 2004), uncertainty about unknown parameters before analyzing (and sometime before collecting) the data is expressed by means of specifying prior probability distributions for these parameters; e.g., Level 3 above. Bayesian inference proceeds by calculating the *posterior* distribution for the parameters conditional on the data. This procedure is known as updating the prior with the data and proceeds by using Bayes theorem, which can be written generically as follows. Letting θ denote the unknown parameters,

$$\Pr(\theta|Data) \;=\; \frac{\Pr(\theta, Data)}{\Pr(Data)} = \frac{\Pr(Data|\theta)\Pr(\theta)}{\Pr(Data)},$$

where $\Pr(\theta)$ is the prior distribution and $\Pr(\theta|Data)$ is the posterior distribution. Note that $\Pr(Data|\theta)$ is the likelihood, i.e., the probability of the observed data viewed as a function of the parameter θ.

An alternative is classical frequentist inference whereby parameters are viewed simply as unknown constants and no probability distributions are used to characterize uncertainty about them. In the case of a hierarchical model, there are just two levels, the first and second levels. Inference calculations are based solely on the likelihood, $\Pr(Data|\theta)$ and maximum likelihood estimates of the unknown parameters, e.g., $\mu_{S_{i \rightarrow j}}$, are calculated. Such estimates are, somewhat confusingly, called empirical Bayes estimates; however, the inference procedure is frequentist, not Bayesian.

A Bayesian approach has been chosen here for pragmatic reasons. With modern computing resources, integration algorithms such as Markov chain Monte Carlo (MCMC, Gilks, Spiegelhalter, and Richards, 1996), and associated software such as WinBUGS (Spiegelhalter, Thomas, and Best, 2003), it is easier to fit a hierarchical model using Bayesian methods than it is using frequentist methods.

However, the most common complaint about Bayesian methods is the influence of prior distributions on the results. If there are sufficient data and if the prior distributions are sufficiently "non-informative", then the resulting posterior distribution is largely a function of the data. In the analyses described later, sensitivity to the choice of prior is assessed.

For the sake of comparison, however, for the DCC and Interior studies it turns out that classical analyses of hierarchical models are relatively easy to carry out and will be presented along with the Bayesian analyses.

(2) *Level 1 models.* Multinomial distributions for recoveries are one possibility for the first level. Such distributions result by assuming that within and between release groups the fates of each fish are independent and that within a particular release group, all fish have the same probabilities of survival and capture. For example, suppose releases are made at Ryde and recoveries are made at Chipps Island and in the ocean fisheries. The conditional distribution for recoveries at Chipps Island and in the ocean fisheries is multinomial (Mn):

$$y_{Ry\to CI}, y_{Ry\to Oc}|\Theta \quad \sim \quad \mathrm{Mn}\left(R_{Ry}, S_{Ry\to CI}p_{CI}, S_{Ry\to CI}(1-p_{CI})r_{CI\to Oc}\right),$$

where $\Theta = (S_{Ry\to CI}, p_{CI}, r_{CI\to Oc})^4$.

On the other hand, if fish within a single release do not behave independently, e.g., they school, then the variability in observed recoveries can be larger than that expected according to multinomial (or binomial) distributions. When the observed variance exceeds that expected for a particular distribution, then it is said that there is overdispersion. For example, suppose R=50,000 fish are released on ten occasions, the expected recovery probability is Sp=0.02, and the number of recoveries is hypothesized to be Binomial(R=50,000, Sp=0.02). The expected number of recoveries is RSp=1000 and the theoretical variance is $RSp(1-Sp)$= 50,000*0.02*0.98 = 980. Suppose the observed number of recoveries from ten groups of 50,000 releases was (951, 1026, 955, 942, 945, 1021, 1059, 955, 1059, 998). The average is 991, close to the expected number, but the variance is 2236, much larger than 980, and evidence for overdispersion. An alternative to the binomial distribution is the negative binomial and details as to its formulation are given later.

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[4] The ocean recovery probability $r_{CI\to Oc}$ is a rather coarse summarization. It is a complicated function of survival, movement, maturation, and fishery harvest probabilities.

Overdispersion can also result from the fact that expanded ocean recoveries, $\hat{y}_{1\to 3,t}$, will be used instead of actual recoveries and the negative binomial distribution is again one means to approximately account for this.

(3) *Level 2 models.* The Level 2 models that will be considered are all based on normal distributions for transformations of survival and capture probabilities or their products. The logistic-normal formulation is commonly used to model probabilities (Newman 2003), and often done for convenience. The logit transformation of a probability π is

$$logit(\pi) \;=\; \log\left(\frac{\pi}{1-\pi}\right).$$

While π is restricted to the interval [0,1], $logit(\pi)$ can take on any real number value, thus capable of being modeled by a normal distribution. Logistic-normal probability models for the survival and capture probabilities would be

$$\begin{aligned} logit(S_{i\to j,t}) &\sim \text{Normal}\left(\mu_{S_{i\to j}}, \sigma^2_{S_{i\to j}}\right) \\ logit(p_{k,t}) &\sim \text{Normal}\left(\mu_{p_k}, \sigma^2_{p_k}\right). \end{aligned}$$

The expected values, e.g., $\mu_{S_{i\to j}}$, will in some cases be modeled as functions of covariates.

Even if independence does hold at the observation level (Level 1), the variation in the survival and capture parameters between releases will induce overdispersion in the observations. In other words, the variation in the observed recoveries will be larger than that due to a multinomial distribution with parameters equaling the expected survival and capture probabilities. As a simple example,

$$\begin{aligned} y|S,p &\sim \text{Binomial}(R, Sp) \\ S &\sim \text{Distribution}(\mu_S, \sigma^2_s) \\ p &\sim \text{Distribution}(\mu_p, \sigma^2_p) \end{aligned}$$

While the *conditional* variance of y is RSp, the *unconditional* variance is *not* $R\mu_S\mu_p$, it is larger than that[5].

(4) *Accounting for the pairing of releases.* The grouping or pairing of releases will be reflected in levels 1 and 2 of the hierarchical model. Within a release pair a shared capture probability will be assumed. Thus a single value of p realized at Level 2 will be used for the paired releases in the Level 1 distributions. Furthermore, within a release pair, when one release is made directly upstream of another release, then

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[5] Suppose $y|\theta$ is Binomial(R,θ) and E[θ]=μ_θ and Var[θ]=σ^2_θ. The conditional variance of y is $R\theta(1-\theta)$ while the unconditional variance is $R\theta(1-\theta) + \sigma^2_\theta R(R-1)$. Thus $\sigma^2_\theta R(R-1)$ is the amount of overdispersion.

the survival probabilities are assumed the same for the stream sections that both groups travel down. Note that this assumption means that fish released downstream of an upstream release do not experience any additional mortality at time of release, say a release shock effect, as might be due to a temperature difference between water temperature in the truck transporting the fish and the water temperature in the river. Additionally, there is an assumption that the upstream and downstream releases essentially overlap one another spatially and temporally from the downstream location onwards—i.e., the two releases temporally and spatially coincide; the issue of timing is discussed in the next enumerated point.

For example, consider a paired release made at Durham Ferry and Mossdale with kodiak trawl sampling at Antioch. The recovery probability for Durham Ferry releases is the product $S_{DF\rightarrow MD}S_{MD\rightarrow Ant}p_{Ant}$, while the recovery probability for Mossdale releases is $S_{MD\rightarrow Ant}p_{Ant}$.

The efficiency of the paired release design manifests itself by these shared parameter values, e.g., $S_{MD\rightarrow Ant}$ and p_{Ant}. Not only are there fewer parameters to estimate, but also variation in capture probabilities and other shared survival probabilities have been *controlled for* within the release pair. There are many environmental conditions, e.g., water temperature, turbidity, or salinity, that can influence survival and capture probabilities in addition to the factors of interest, e.g., DCC gate position, geographic location, exports. With paired releases, however, the environmental conditions are often quite similar meaning that parameters that do differ within a release pair can be estimated more precisely than for unpaired releases.

(5) *Assumption of equal capture probabilities.* Within a release set, parameters for which shared values are assumed include the freshwater capture probabilities (i.e., Chipps Island midwater trawl for all four studies, and Antioch kodiak trawl for VAMP studies). This assumption can be assessed if releases are made downstream of the freshwater trawl sites and if the ocean recovery probabilities are assumed the same, because then estimates of the freshwater capture probabilities can be made (Newman 2003, and see later in this report). In the absence of such data, a less formal comparison can be made by examining the recovery pattern over time along with the trawl fishing schedule and effort. If the trawl effort is more or less consistent throughout the out-migration periods of releases in a release pair, then whether or not the out-migration timing is the same does not matter.

As an informal check, the distributions of recoveries at Chipps Island over time were compared within release pairs for a few cases. Figure 12 shows the percentage of total recoveries by date for three sample sets, one from DCC, one from Interior/DA 8, and one from VAMP. For the DCC example (from 1983),the time intervals of recovery were very similar (both had first recoveries on 19 May, Courtland's last recovery was 20 June and Ryde's last was 7 June), and the general distribution is relatively similar. For the Interior/DA 8 example (from 1999), the Ryde recoveries tended to arrive earlier than the Georgiana Slough recoveries, but the duration of the recovery period was longer for the Ryde releases. For the VAMP example (from 2000), the recovery distributions by date are consistent with what one would expect, with Jersey Point recoveries tending to precede those from Mossdale which in turn preceding those from Durham Ferry.

(6) *Estimability of survival and capture probabilities.* The release-recovery design affects the estimability of parameters. Unless a release is made downstream of a recovery location (say j), the capture probability at the recovery location cannot be estimated separately from the survival probability for the next-nearest upstream release (located at i say). What can be estimated is the product of the survival probability and the capture probability, $S_{i \to j} p_j$. In the case of two releases made above a single recovery point, assuming equal recapture probabilities at a downstream location, the ratio of survival probabilities can be estimated. In the case where the furthest upstream releases must travel past the downstream release location, this ratio will be the survival probability between the two upstream locations.

For example, the case where releases are made in the same linear stretch of waterway (locations 1 and 2) with a single downstream recovery site (location 3) is shown schematically as:

$$1 \xrightarrow{S_1} 2 \xrightarrow{S_2} \underset{p_3}{3}$$

In this case the parameter combinations $S_1S_2p_3$ and S_2p_3 are estimable; e.g., $\widehat{S_1S_2p_3} = y_{1\to3}/R_1$ and $\widehat{S_2p_3} = y_{2\to3}/R_2$. The upstream survival, S_1, is then estimable, e.g., $\hat{S}_1 = \widehat{S_1S_2p_3}/\widehat{S_2p_3}$, but downstream survival, S_2 is not.

When releases are made at locations upstream of a recovery point where one release group's travel path does not completely coincide with the other group's path is shown schematically as:

$$\begin{tikzcd}
\mathrm{A} \arrow[dr, "S_A"] & & \\
& 2 \arrow[r, "S_2"] & \underset{p_3}{3} \\
\mathrm{B} \arrow[ur, "S_B"] & &
\end{tikzcd}$$

where releases are made at locations A and B, but not 2. In this case $S_AS_2p_3$ and $S_BS_2p_3$ are estimable, as is the ratio S_A/S_B. In the case of non-estimable parameters, notation for estimable *combinations* of parameters will be written; e.g., r for Sp.

4. Methods

4.1. **DCC Studies.** The primary objective is to determine how DCC gate position affected the relative survival of Courtland to Ryde releases. This relative survival will be quantified in the hierarchical model(s) by a parameter θ_t that is the ratio of the survival probability between Courtland and Chipps Island to the survival probability between Ryde and Chipps Island, where θ_t is a function of DCC gate position. It was assumed that gate position did not affect Ryde releases.

Several different Bayesian hierarchical models were fit (and one non-Bayesian model) but for all the models the parameterization of the ocean recovery probabilities were the same. The probability that a fish from a Ryde release is recovered in the ocean fishery is denoted $r_{Ry\rightarrow Oc}$ and can be viewed as being the following product of survival and capture probabilities:

$$r_{Ry\rightarrow Oc} \quad = \quad S_{Ry\rightarrow CI}(1-p_{CI})r_{CI\rightarrow Oc}.$$

Furthermore, this probability was assumed the same for Ryde and Courtland releases within the same release pair. Within a release pair, it was also assumed that the capture probability at Chipps Island was the same.

Bayesian hierarchical model. The details of one of the BHMs are shown here. Variations on this BHM included changes in all of the three levels of the model (possibilities are discussed in Section 4.6). This BHM was based on the following assumptions (repeating some stated previously):

- individual fish fates are independent;
- within a single release, S and p are identical for all travel paths and recovery locations;
- the survival probability from Courtland to Chipps Island is no greater than the survival probability from Ryde; i.e., $0 \leq \theta_t \leq 1$;
- within a paired release, the capture probability at Chipps Island is the same;
- within a paired release, the probability that a fish alive just below Chipps Island (thus not captured at Chipps Island) is then caught in the ocean fisheries is the same.

Level 1:

$$y_{Ct\rightarrow CI,t}, \hat{y}_{Ct\rightarrow Oc,t}|\theta_t, r_{Ry\rightarrow CI,t}, r_{Ry\rightarrow Oc,t} \quad \sim \quad \text{Mn}\left(R_{Ct,t}, \theta_t r_{Ry\rightarrow CI,t}, \theta_t r_{Ry\rightarrow Oc,t}\right) \tag{1}$$

$$y_{Ry\rightarrow CI,t}, \hat{y}_{Ry\rightarrow Oc,t}|\theta_t, r_{Ry\rightarrow CI,t}, r_{Ry\rightarrow Oc,t} \quad \sim \quad \text{Mn}\left(R_{Ry,t}, r_{Ry\rightarrow CI,t}, r_{Ry\rightarrow Oc,t}\right). \tag{2}$$

Level 2:

$$logit(\theta_t) \sim \text{Normal}\left(\beta_0 + \beta_1 I_{DCC_t=closed}, \sigma^2_\theta\right) \tag{3}$$

$$logit(r_{Ry\to CI,t}) \sim \text{Normal}\left(\mu_{r_{Ry\to CI}}, \sigma^2_{r_{Ry\to CI}}\right) \tag{4}$$

$$logit(r_{Ry\to Oc,t}) \sim \text{Normal}\left(\mu_{r_{Ry\to Oc}}, \sigma^2_{r_{Ry\to Oc}}\right) \tag{5}$$

where $I_{DCC_t=closed}$ equals 1 when the cross-channel gates are closed, and 0 otherwise.

Level 3:

$$\beta_0, \beta_1, \mu_{Ry\to CI,t}, \mu_{Ry\to Oc,t} \sim \text{Normal}(0, 1.0E+6) \tag{6}$$

$$\sigma^{-2}_\theta, \sigma^{-2}_{r_{Ry\to CI}}, \sigma^{-2}_{r_{Ry\to Oc}} \sim \text{Gamma}(0.001, 0.001) \tag{7}$$

Priors for the variances were specified in terms of the inverse of variance, the precision, i.e., inverse gamma prior distributions were used.

The key parameter in this formulation is β_1 in Level 2. Positive values would be consistent with the DCC closure increasing survival.

The Level 2 modeling of the Ryde recovery probabilities, $r_{Ry\to CI,t}$ and $r_{Ry\to Oc,t}$, is simplistic in that variation in the survival and capture probabilities is to some degree a function of nonrandom measurable factors. For example, the capture probabilities at Chipps Island are indeed a function of the amount of trawling that occurs; similarly, capture probabilities in the ocean fishery are a function of fishing seasons and gear regulation. The overall results are thought to be relatively robust to ignoring such structural, i.e., nonrandom, effects, unless there is some systematic trend in such factors, and one consequence of such coarse modeling will likely be relatively large variances in the logit normal model.

Non-Bayesian hierarchical model. In this formulation the Level 1 formulation is identical to the BHM. For Level 2, however, the exact distributions for the survival and capture probabilities were not specified, just the means and variances are denoted.

Level 1:

$$\begin{aligned} y_{Ct\to CI,t}, \hat{y}_{Ct\to Oc,t}|\Theta &\sim \text{Mn}\left(R_{Ct,t}, \theta_t r_{Ry\to CI,t}, \theta_t r_{Ry\to Oc,t}\right) \\ y_{Ry\to CI,t}, \hat{y}_{Ry\to Oc,t}|\Theta &\sim \text{Mn}\left(R_{Ry,t}, r_{Ry\to CI,t}, r_{Ry\to Oc,t}\right). \end{aligned}$$

Level 2:

$$\theta_t \sim \text{Distribution}\left(\mu_{\theta(DCC_t)}, \sigma^2_{\theta(DCC_t)}\right) \tag{8}$$

$$r_{Ry\to CI,t} \sim \text{Distribution}\left(\mu_{r_{Ry\to CI}}, \sigma^2_{r_{Ry\to CI}}\right) \tag{9}$$

$$r_{Ry\to Oc,t} \sim \text{Distribution}\left(\mu_{r_{Ry\to Oc}}, \sigma^2_{r_{Ry\to Oc}}\right) \tag{10}$$

where DCC_t= Open or Closed and μ and σ^2 denote the mean and variance of the (unspecified) distribution.

Under this formulation, the key parameter is $\mu_{\theta(Closed)}/\mu_{\theta(Open)}$. To estimate this ratio, the individual release specific θ's are estimated as follows.

$$\hat{\theta} = \frac{\hat{r}_{Ct\to CI+Oc}}{\hat{r}_{Ry\to CI+Oc}} \tag{11}$$

The parameters $\mu_{\theta(Open)}$ and $\mu_{\theta(Closed)}$ can be estimated by weighted averages of the $\hat{\theta}$'s:

$$\hat{\mu}_{\theta(Open)} = \sum_{t=1}^{n_{Open}} w_{t|Open}\hat{\theta}_{t|Open} \tag{12}$$

$$\hat{\mu}_{\theta(Closed)} = \sum_{t=1}^{n_{Closed}} w_{t|Closed}\hat{\theta}_{t|Closed}, \tag{13}$$

where the weights are inversely proportional to the estimated variances:

$$w_t = \frac{1/var(\hat{\theta}_t)}{\sum_{i=1}^{n} 1/var(\hat{\theta}_i)}. \tag{14}$$

The variances are estimated using the delta method. Details of the delta method are given Appendix A (in particular a sample based estimate of $V(\hat{\theta}_t)$, shown in the lines following Equation (59), is used).

The ratio of $\mu_{\theta(Open)}$ and $\mu_{\theta(Closed)}$ can be estimated using (12) and (13):

$$\widehat{\left(\frac{\mu_{\theta(Open)}}{\mu_{\theta(Closed)}}\right)} = \frac{\hat{\mu}_{\theta(Open)}}{\hat{\mu}_{\theta(Closed)}} \tag{15}$$

The standard error for (15) can be calculated by using a hierarchical bootstrapping procedure (described in Appendix B) to produce resampled estimates of $\hat{\mu}_{\theta(Closed)}$ and $\hat{\mu}_{\theta(Open)}$.

4.2. **Interior studies.** For the Interior studies, interest is solely in the ratio of survival probabilities of interior Delta releases (Georgiana Slough) and mainstem releases (Ryde), which will be denoted θ and defined equal to $S_{GS\rightarrow CI}/S_{Ry\rightarrow CI}$.

Several BHMs and one non-Bayesian hierarchical model were fit to the Interior data. Just one of the BHMs is shown in detail here, and the assumptions for this model are essentially identical to the one shown for DCC and are not repeated here.

Bayesian hierarchical model.

Level 1:

$$y_{GS\rightarrow CI,t}, \hat{y}_{GS\rightarrow Oc,t}|\theta_t, r_{Ry\rightarrow CI,t}, r_{Ry\rightarrow Oc,t} \sim \text{Mn}\left(R_{GS,t}, \theta_t r_{Ry\rightarrow CI,t}, \theta_t r_{Ry\rightarrow Oc,t}\right) \quad (16)$$

$$y_{Ry\rightarrow CI,t}, \hat{y}_{Ry\rightarrow Oc,t}|r_{Ry\rightarrow CI,t}, r_{Ry\rightarrow Oc,t} \sim \text{Mn}\left(R_{Ry,t}, r_{Ry\rightarrow CI,t}, r_{Ry\rightarrow Oc,t}\right). \quad (17)$$

Level 2:

$$log(\theta_t) \sim \text{Normal}\left(\mu_\theta, \sigma^2_\theta\right) \quad (18)$$

$$logit(r_{Ry\rightarrow CI,t}) \sim \text{Normal}\left(\mu_{r_{Ry\rightarrow CI}}, \sigma^2_{r_{Ry\rightarrow CI}}\right) \quad (19)$$

$$logit(r_{Ry\rightarrow Oc,t}) \sim \text{Normal}\left(\mu_{r_{Ry\rightarrow Oc}}, \sigma^2_{r_{Ry\rightarrow Oc}}\right) \quad (20)$$

Level 3:

$$\mu_\theta, \mu_{Ry\rightarrow CI,t}, \mu_{Ry\rightarrow Oc,t} \sim \text{Normal}(0, 1.0E+6) \quad (21)$$

$$\sigma^{-2}_\theta, \sigma^{-2}_{r_{Ry\rightarrow CI}}, \sigma^{-2}_{r_{Ry\rightarrow Oc}} \sim \text{Gamma}(0.001, 0.001) \quad (22)$$

The key parameter in this model is the parameter μ_θ, where negative values would indicate lower survival for Georgiana Slough releases relative to Ryde releases.

Non-Bayesian hierarchical model. The level 1 model is identical to the BHM.

Level 1:

$$y_{GS\rightarrow CI,t}, \hat{y}_{GS\rightarrow Oc,t}|\theta_t, r_{Ry\rightarrow CI,t}, r_{Ry\rightarrow Oc,t} \sim \text{Mn}\left(R_{GS,t}, \theta_t r_{Ry\rightarrow CI,t}, \theta_t r_{Ry\rightarrow Oc,t}\right)$$

$$y_{Ry\rightarrow CI,t}, \hat{y}_{Ry\rightarrow Oc,t}|r_{Ry\rightarrow CI,t}, r_{Ry\rightarrow Oc,t} \sim \text{Mn}\left(R_{Ry,t}, r_{Ry\rightarrow CI,t}, r_{Ry\rightarrow Oc,t}\right).$$

Level 2:

$$\theta_t \sim \text{Distribution}\left(\mu_\theta, \sigma^2_\theta\right) \tag{23}$$

$$r_{Ry\rightarrow CI,t} \sim \text{Distribution}\left(\mu_{r_{Ry\rightarrow CI}}, \sigma^2_{r_{Ry\rightarrow CI}}\right) \tag{24}$$

$$r_{Ry\rightarrow Oc,t} \sim \text{Distribution}\left(\mu_{r_{Ry\rightarrow Oc}}, \sigma^2_{r_{Ry\rightarrow Oc}}\right) \tag{25}$$

The parameter of primary interest in this formulation is μ_θ which can be estimated by

$$\hat{\mu}_\theta = \sum_{t=1}^{n} w_t \frac{\hat{r}_{GS\rightarrow CI+Oc,t}}{\hat{r}_{Ry\rightarrow Ci+Oc,t}}, \tag{26}$$

where the weight, w_t, is equation (14). For the 2005 and 2006 release pairs, only the Chipps Island recoveries are available (Table 4), and $\hat{r}_{GS\rightarrow CI}/\hat{r}_{Ry\rightarrow CI}$ was used instead. Bootstrapping was used to estimate standard errors and calculate confidence intervals.

4.3. **Delta Action 8 Experiments.** The Bayesian hierarchical models tried were nearly identical to those for the Interior study except that the ratio $\theta = S_{GS\rightarrow CI}/S_{Ry\rightarrow CI}$ was modeled as a function of exports.

The assumptions are the same as for the Interior model with an additional assumption about export effects.

- releases from Ryde are unaffected by export levels.

One of the Bayesian hierarchical models fit (similar to the Interior model shown in Equations 16 - 22) is the following.

Level 1:

$$y_{GS\rightarrow CI,t}, \hat{y}_{GS\rightarrow Oc,t}|\theta_t, r_{Ry\rightarrow CI,t}, r_{Ry\rightarrow Oc,t} \sim \text{Mn}\left(R_{GS}, \theta_t r_{Ry\rightarrow CI,t}, \theta_t r_{Ry\rightarrow Oc,t}\right) \tag{27}$$

$$y_{Ry\rightarrow CI,t}, \hat{y}_{Ry\rightarrow Oc,t}|r_{Ry\rightarrow CI,t}, r_{Ry\rightarrow Oc,t} \sim \text{Mn}\left(R_{Ry}, r_{Ry\rightarrow CI,t}, r_{Ry\rightarrow Oc,t}\right) \tag{28}$$

Level 2:

$$logit(\theta_t) \sim \text{Normal}\left(\beta_0 + \beta_1 Exp_t^*, \sigma_\theta^2\right) \tag{29}$$

$$logit(r_{Ry\to CI,t}) \sim \text{Normal}\left(\mu_{r_{Ry\to CI}}, \sigma^2_{r_{Ry\to CI}}\right) \tag{30}$$

$$logit(r_{Ry\to Oc,t}) \sim \text{Normal}\left(\mu_{r_{Ry\to Oc}}, \sigma^2_{r_{Ry\to Oc}}\right) \tag{31}$$

Exp_t^* were scaled exports, $\frac{(Exports_t - \overline{Exp})}{s_{Exp}}$.

Level 3:

$$\beta_0, \beta_1, \mu_{Ry\to CI}, \mu_{Ry\to Oc} \sim \text{Normal}\left(0, 1.0E+6\right) \tag{32}$$

$$\sigma_\theta^{-2}, \sigma^{-2}_{r_{Ry\to CI}}, \sigma^{-2}_{r_{Ry\to Oc}} \sim \text{Gamma}\left(0.001, 0.001\right) \tag{33}$$

The key parameter in terms of an export effect is β_1; if β_1 equals 0 there is no export effect, while $\beta_1 < 0$ indicates a negative export effect.

4.4. **VAMP studies.** The hierarchical models considered for the VAMP studies were much more complicated than for the other three studies due to the greater number of release and recovery locations, more complex stream geometry, and additional covariates of interest (flow, exports, HORB). The models defined below aim to estimate, and model as a function of covariates, the survival through different "reaches" of the out-migration path. For example, suppose a release is made at Durham Ferry, and assume that with the HORB in place, there is 100% probability that a fish passing the entrance to Old River will stay in the San Joaquin River. Then the probability of surviving to Antioch, say, could be viewed as the product of four reach-specific survival probabilities:

$$S_{DF\to Ant} = S_{DF\to MD} S_{MD\to DR} S_{DR\to JP} S_{JP\to Ant}$$

The hierarchical models aim to model *some* of these reach-specific survival probabilities when they are estimable. Before describing the hierarchical model details, the geometry of the out-migration routes and the issue of estimability of survival probabilities are discussed.

4.4.1. *Geometry of out-migration routes.* A simplistic network of the relative positioning of the five release locations and the three recovery locations for the VAMP and pre-VAMP studies is shown below, with approximate distances (miles) between locations in parentheses.

```
                               (40*)                (15)
                         OR----------------------\---------------
     (15)      (2) (1/4)/                         \              \
DF---------> MD--->HOR---->DR------------------->JP---->Ant----->CI----->Ocean
                       (3)     (38*)               (7)     (8)
```

HOR denotes the head of Old River.

The actual geometry is considerably more complex. The distances marked with an asterisk, Dos Reis to Jersey Point and Old River to Jersey Point, denote situations where the actual distances traveled by salmon between locations can vary considerably. Between Dos Reis and Jersey Point there are multiple routes that salmon could take, e.g., after passing Stockton on the San Joaquin River they could turn toward the CVP and SWP facilities at several other locations (Turner Cut, Middle River, and at Franks Tract where Old River reconnects with the San Joaquin River).

Similarly, distances traveled between “an” Old River release site and Jersey Point can vary for several reasons: (a) there are multiple alternate channels a fish can take to reach Jersey Point, (b) some of the Old River releases are “salvaged” at the CVP and SWP fish facilities and then transported by truck to one of four possible locations on the Sacramento or San Joaquin rivers (see Section 2), thus some of the surviving Old River releases would have less chance of passing Jersey Point than others; (c) in 1985 the Old River release site was approximately 6 miles further downstream than the location used for 1986-1990 releases.

While the term reach-specific survival probability will be used, it admittedly may be a misnomer due to this complex stream geometry. One may want to mentally substitute the phrase, “probability of reaching point B from point A”, for the notation $S_{A\rightarrow B}$.

4.4.2. *Estimability of survival probabilities using paired releases.* Survival probabilities are a component of the second level of the hierarchical models and these survival probabilities can, in principle, be modeled as functions of covariates. One might reasonably question whether or not such functional models can be fit given the complex geometry and variation in the grouping of release locations, i.e., “are the parameters of such models estimable?”. Explanations for the estimability, or not, of some of the survival probabilities in the context of paired releases are given first and followed by explanations for the use of underlying models for survival to facilitate reach-specific survival probability estimation at time t when releases were not made at both endpoints of the release.

To begin, survival probabilities immediately above recovery locations *cannot* be estimated separately from capture probabilities. The lack of releases below the recovery locations (Table 7), e.g., between Antioch and Chipps Island, means that the survival and capture probabilities are confounded. However, the recovery probabilities, combinations of survival and capture probabilities, between Jersey Point and the three recovery locations are estimable; e.g., the recovery probability from Jersey Point to Antioch, $r_{JP\rightarrow Ant}$, is estimable, but the components of $r_{JP\rightarrow Ant}$, namely the survival probability for that reach, $S_{JP\rightarrow Ant}$, and the capture probability at Antioch, p_{Ant}, are not individually estimable. The following notation is used for these recovery probabilities.

$$\begin{aligned}
r_{JP\rightarrow Ant} &\equiv S_{JP\rightarrow Ant} p_{Ant} \\
r_{JP\rightarrow CI} &\equiv S_{JP\rightarrow Ant}(1-p_{Ant}) S_{Ant\rightarrow CI} p_{CI} \\
r_{JP\rightarrow Oc} &\equiv S_{JP\rightarrow Ant}(1-p_{Ant}) S_{Ant\rightarrow CI}(1-p_{CI}) S_{CI\rightarrow Oc} p_{Oc}
\end{aligned}$$

The survival probability between Durham Ferry and Mossdale can be estimated quite simply, given paired releases at both locations and assuming that survival and capture probabilities are identical from Mossdale onwards, namely the assumption that pairing of releases is intended to ensure. For example, given recoveries at Antioch, Chipps Island, and in the ocean,

$$\hat{S}_{DF\rightarrow MD} = \frac{(y_{DF\rightarrow Ant} + y_{DF\rightarrow CI} + y_{DF\rightarrow Oc})/R_{DF}}{(y_{MD\rightarrow Ant} + y_{MD\rightarrow CI} + y_{MD\rightarrow Oc})/R_{MD}}. \tag{34}$$

Such an estimate is a method of moments estimate. This can be made clear by substituting the expected number of recoveries for the observed recoveries.

$$\hat{S}_{DF\rightarrow MD} \approx \frac{(R_{DF}\ S_{DF\rightarrow MD}\ (r_{MD\rightarrow Ant} + r_{MD\rightarrow CI} + r_{MD\rightarrow Oc}))/R_{DF}}{(R_{MD}\ (r_{MD\rightarrow Ant} + r_{MD\rightarrow CI} + r_{MD\rightarrow Oc}))/R_{MD}} = S_{DF\rightarrow MD}$$

Similarly, the survival between Dos Reis and Jersey Point can be estimated for paired releases, assuming identical survival and capture probabilities from Jersey Point onwards:

$$\hat{S}_{DR\rightarrow JP} = \frac{(y_{DR\rightarrow Ant} + y_{DR\rightarrow CI} + y_{DR\rightarrow Oc})/R_{DR}}{(y_{JP\rightarrow Ant} + y_{JP\rightarrow CI} + y_{JP\rightarrow Oc})/R_{JP}} \tag{35}$$

To estimate survival for a reach including the head of Old River, however, is not so straightforward. For example, for a release at Mossdale, located just above the head of Old River, the expected number of recoveries at Antioch (or Chipps Island or in the ocean) is a weighted sum of survival probabilities. Assuming that all surviving fish will go by Jersey

Point, the expected number of recoveries at Antioch is:

$$E[y_{MD\rightarrow Ant}] \quad = \quad R_{MD}(p_{OR}S_{OR\rightarrow JP}r_{JP\rightarrow Ant} + (1-p_{OR})S_{MD\rightarrow DR}S_{DR\rightarrow JP}r_{JP\rightarrow Ant}),$$

where p_{OR} is the probability of going down Old River, $S_{OR\rightarrow JP}$ is the survival probability between the head of Old River and Jersey Point, and survival between Mossdale and Old River is assumed to be 100%. The ratio of recovery fractions at Antioch between a Mossdale release and a Dos Reis release is approximately

$$\text{(36)} \qquad \frac{y_{MD\rightarrow Ant}/R_{MD}}{y_{DR\rightarrow Ant}/R_{DR}} \approx \frac{p_{OR}S_{OR\rightarrow JP} + (1-p_{OR})S_{MD\rightarrow DR}S_{DR\rightarrow JP}}{S_{DR\rightarrow JP}}.$$

If one assumes that the probability of going down Old River is zero when the HORB is in place, then the right hand side of the above equation reduces to $S_{MD\rightarrow DR}$. However, if that assumption is not made, or if the HORB is not in place, then to estimate $S_{MD\rightarrow DR}$, one needs estimates of p_{OR}, $S_{OR\rightarrow JP}$, and $r_{JP\rightarrow Ant}$. If releases are made in Old River and at Jersey Point, then $S_{OR\rightarrow JP}$ and $r_{JP\rightarrow Ant}$ can be estimated. Estimation of p_{OR} is problematic, however, due to a lack of data.

4.4.3. *Modeling of survival probabilities.* The previous examples of estimating reach-specific survival were based on the use of paired releases that were made at both endpoints of the reach. Implicit to the calculations was the notion that the survival estimates were release-time specific. Unfortunately, as was discussed previously and as Table 7 makes clear, the release location "pairings" have varied considerably. For example, direct estimation of $S_{DR\rightarrow JP}$ between 2000 and 2004 using equation (35) is not possible due to the absence of Dos Reis releases[6].

However, if an underlying structure is assumed for reach-specific survival, one which is not over-parameterized given the number of observations, survival for reaches which lack releases at both endpoints can be estimated (or predicted) so long as such paired releases at those endpoints have occurred at *some time* during the study. The following heuristic example is given to provide some intuition as to why this is possible, but the actual estimation details are omitted.

Suppose that at time t releases were made at Mossdale and Jersey Point but not Dos Reis and the objective is to separately estimate $S_{MD\rightarrow DR,t}$ and $S_{DR\rightarrow JP,t}$. To keep the example simple, assume the HORB was in place and prevented all fish from entering Old River, thus

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[6] As an aside, the HORB was in place during this period, 2000-2004, and if one assumes 100% survival between Mossdale and Dos Reis when the barrier is in place, then $S_{DR\rightarrow JP}$ can be directly estimated since $S_{MD\rightarrow JP}$ can be estimated and $S_{MD\rightarrow JP} = S_{MD\rightarrow DR}S_{DR\rightarrow JP} = 1{*}S_{DR\rightarrow JP}$.

all the Mossdale fish reaching Old River stayed in the San Joaquin River, and $S_{MD\rightarrow JP,t}$ can be defined as the product $S_{MD\rightarrow DR,t}S_{DR\rightarrow JP,t}$. Also assume that $S_{MD\rightarrow DR}$ is a function of flow at Mossdale and $S_{DR\rightarrow JP}$ is a function of flow at Dos Reis. Note first that $S_{MD\rightarrow JP,t}$ can be directly estimated using the method of moments procedure (e.g., equation 35). $S_{MD\rightarrow DR,t}$ and $S_{DR\rightarrow JP,t}$ can be individually estimated given (a) recovery data from *other* sets of paired releases made at Mossdale and Dos Reis and at Dos Reis and Jersey Point; (b) underlying models for $S_{MD\rightarrow DR}$ and $S_{DR\rightarrow JP}$; (c) relevant covariates at time t. Given a sufficient number of these *other* paired releases and corresponding flow data, the following models can be fit:

$$\begin{aligned} logit(S_{MD\rightarrow DR}) &= \beta_0 + \beta_1 Flow_{MD} \\ logit(S_{DR\rightarrow JP}) &= \gamma_0 + \gamma_1 Flow_{DR}. \end{aligned}$$

Given estimates of β_0, β_1, γ_1, and γ_2 and the flow measurements at time t, $S_{MD\rightarrow DR,t}$ and $S_{DR\rightarrow JP,t}$ can be predicted. Thus, if $S_{MD\rightarrow JP,t}$ can be directly estimated and $S_{MD\rightarrow DR,t}$ and $S_{DR\rightarrow JP,t}$ can be predicted, then one can imagine (in a hand-waving way) that an integrated procedure could be carried out to use all the release-recovery data simultaneously to both estimate the parameters β_0, β_1, γ_0, and γ_1 and the time t-specific probabilities $S_{MD\rightarrow DR,t}$ and $S_{DR\rightarrow JP,t}$.

4.4.4. *Hierarchical models.* Several different formulations for the modeling of reach-specific survival were considered, but a common underlying out-migration framework was assumed. Durham Ferry releases go downstream to Mossdale. Fish at Mossdale go to the head of Old River and proceed on to Dos Reis if they stay in the San Joaquin or they enter Old River. Fish entering Old River then pass the Old River release site(s) and proceed to Jersey Point (even fish that are salvaged at the fish facilities are assumed to have a positive probability of going by Jersey Point). Fish passing Dos Reis proceed to Jersey Point, too. From Jersey Point, fish pass Antioch, then Chipps Island, and then enter the ocean.

The following additional assumptions were made:

- When the HORB is in place, Durham Ferry and Mossdale releases do not enter Old River.
- When the HORB is not in place, Durham Ferry and Mossdale releases enter Old River with probability p_{OR}, which is either a constant or a function of relative flow.
- Survival between the head of Old River and Dos Reis (about 3 miles) is 100%, and survival between the head of Old River and the Old River release point(s) (about 0.25 miles) is 100%.

The last assumption is made for reasons of parameter estimability for releases at Durham Ferry or Mossdale. The survival probability from Mossdale to Jersey Point can be written as follows.

$$S_{MD\to JP} = S_{MD\to HOR}[p_{OR}S_{HOR\to OR}S_{OR\to JP} + (1-p_{OR})S_{HOR\to DR}S_{DR\to JP}]$$

Given paired releases from Old River and Jersey Point, and Dos Reis and Jersey Point and recoveries at Chipps Island, say, it is clear that $S_{OR\to JP}$ and $S_{DR\to JP}$ can be estimated; e.g., $\hat{S}_{OR\to JP} = [y_{OR\to CI}/R_{OR}]/[y_{JP\to CI}/R_{JP}] \approx [S_{OR\to JP}r_{JP\to CI}]/r_{JP\to CI} = S_{OR\to JP}$. That leaves four unknown parameters, $S_{MD\to HOR}$, p_{OR}, $S_{HOR\to OR}$, and $S_{HOR\to DR}$, and only one can be estimated using Mossdale or Durham Ferry recoveries at Chipps Island, say. Assuming that $S_{HOR\to OR}$=1 and $S_{HOR\to DR}$=1, leaves $S_{MD\to HOR}$ and p_{OR} unknown. The probability of traveling down Old River, p_{OR}, was, for some models, set equal to the relative flow-based values shown in Table 5, and then $S_{MD\to HOR}$ was estimable. The basis for the calculated values of p_{OR} are described in Table 6. In other models, p_{OR} was a fixed but unknown parameter to be estimated and $S_{MD\to HOR}$ was set equal to 1.0.

The three levels of the hierarchical models are as follows; release set subscripts (t) have been omitted.

Level 1: the distributions for the recoveries of fish released at Durham Ferry, Mossdale, Dos Reis, Old River, and Jersey Point (Θ denotes survival and recovery probabilities)

$$\begin{aligned}
(37)\quad y_{DF\to Ant}, y_{DF\to CI}, \hat{y}_{DF\to Oc}|\Theta &\sim \text{Mn}(R_{DF}, S_{DF\to MD}S_{MD\to JP}r_{JP\to Ant},\\
&\quad S_{DF\to MD}S_{MD\to JP}r_{JP\to CI},\\
&\quad S_{DF\to MD}S_{MD\to JP}r_{JP\to Oc})\\
(38)\quad y_{MD\to Ant}, y_{MD\to CI}, \hat{y}_{MD\to Oc}|\Theta &\sim \text{Mn}(R_{MD}, S_{MD\to JP}r_{JP\to Ant},\\
&\quad S_{MD\to JP}r_{JP\to CI}, S_{MD\to JP}r_{JP\to Oc})\\
(39)\quad y_{DR\to Ant}, y_{DR\to CI}, \hat{y}_{DR\to Oc}|\Theta &\sim \text{Mn}(R_{DR}, S_{DR\to JP}r_{JP\to Ant},\\
&\quad S_{DR\to JP}r_{JP\to CI}, S_{DR\to JP}r_{JP\to Oc})\\
(40)\quad y_{OR\to CI}, \hat{y}_{OR\to Oc}|\Theta &\sim \text{Mn}(R_{OR}, S_{OR\to JP}r_{JP\to CI}, S_{OR\to JP}r_{JP\to Oc})\\
(41)\quad y_{JP\to Ant}, y_{JP\to CI}, \hat{y}_{JP\to Oc}|\Theta &\sim \text{Mn}(R_{JP}, r_{JP\to Ant}, r_{JP\to CI}, r_{JP\to Oc})
\end{aligned}$$

where by assumption

$$(42)\quad S_{MD\to JP} = S_{MD\to HOR}[p_{OR}S_{OR\to JP} + (1-p_{OR})S_{DR\to JP}]$$

and when HORB is in place, $S_{MD\to JP} = S_{MD\to HOR}S_{DR\to JP}$.

Level 2: Random effects models for survival and recovery probabilities; (X = covariates)

$$logit(S_{DF\to MD}) \sim \text{Normal}\left(X_1'\beta, \sigma^2_{DF\to MD}\right) \tag{43}$$

$$logit(S_{MD\to HOR}) \sim \text{Normal}\left(X_2'\gamma, \sigma^2_{MD\to DR}\right) \tag{44}$$

$$logit(S_{DR\to JP}) \sim \text{Normal}\left(X_3'\xi, \sigma^2_{DR\to JP}\right) \tag{45}$$

$$logit(S_{OR\to JP}) \sim \text{Normal}\left(X_4'\zeta, \sigma^2_{OR\to JP}\right) \tag{46}$$

$$logit(r_{JP\to Ant}) \sim \text{Normal}\left(\mu_{JP\to Ant}, \sigma^2_{JP\to Ant}\right) \tag{47}$$

$$logit(r_{JP\to CI}) \sim \text{Normal}\left(\mu_{JP\to CI}, \sigma^2_{JP\to CI}\right) \tag{48}$$

$$logit(r_{JP\to Oc}) \sim \text{Normal}\left(\mu_{JP\to Oc}, \sigma^2_{JP\to Oc}\right) \tag{49}$$

Level 3:

$$\beta, \gamma, \xi, \kappa, \zeta, \mu_{JP\to Ant}, \mu_{JP\to CI}, \mu_{JP\to Oc} \sim \text{Normal}\left(0, 1.0E+6\right) \tag{50}$$

$$\sigma^{-2}_{i\to j}, \sim \text{Gamma}\left(0.001, 0.001\right). \tag{51}$$

The Level 1 models for the years 1985-1999 excluded Antioch recoveries (since the trawl was not in place) and for the years 2005-2006 excluded ocean recoveries (because none were available at the time of analysis). Also the first release set used spray-dying to mark individuals and ocean recoveries were not available (Table 5). When flow and export levels were used as covariates in the Level 2 models they were standardized (mean was subtracted and the difference divided by standard deviation); how flow and exports were calculated is described in Table 6.

Given the multiple reaches and branching, the number of potential models is very large, far more than for the other three data sets. A relatively small set was fit, however, due to time constraints. As a demonstration of the general utility, or not, of random effects, some models were fit without any random effects (thus resulting in Bayesian logistic regressions) and some were fit with random effects only in the recovery probabilities, the $r_{JP\to Ant}$, $r_{JP\to CI}$, and $r_{JP\to Oc}$ terms, with the intent of allowance for temporal variation in capture probabilities but not survival probabilities.

4.5. **BHM fitting and assessment.** For the Bayesian analysis of the hierarchical models, the program `WinBUGS` (Spiegelhalter, Thomas, and Best 2003) was used to generate samples from the posterior distributions for the parameters, random effects, and expected numbers of recoveries. `WinBUGS` is based on a technique known as Markov chain Monte Carlo, MCMC (Gilks, Richardson, and Spiegelhalter 1996). MCMC is a computer simulation method where samples are generated from a Markov chain which has a limiting distribution equal to the distribution of interest, in this case the posterior distribution.

By a limiting distribution it is meant that the samples do not initially come from the desired distribution, but once "enough" samples are generated, the so-called burn-in period, all additional samples do come from the desired distribution. WinBUGS includes measures (e.g., the Brooks-Gelman-Rubin statistic) for determining an adequate burn-in period which are based upon the results of simulating from multiple Markov chains. Informally stated, the point at which the chains begin to overlap is the necessary burn-in period. For all four studies, three different chains were run in parallel and the summary statistics are based on the pooled output.

Quality of fit was assessed in two general ways, by making between model comparisons of DIC, deviance information criterion (Gelman, et al. 2004), and, within a given model, by examining the quality of fit to individual observations. The deviance for a particular observation y and a particular parameter value θ is defined as follows:

$$D(y,\theta) \quad = \quad -2\log(p(y|\theta)),$$

where $p(y|\theta)$ is the probability (or density) of y given θ. The total deviance for a set of observations is the sum of individual deviances. When comparing two models, say two different values of θ, the model with the smaller deviance is preferred. In the case of normal linear models, the total deviance is proportional to the sum of squared deviations of the observed values from the fitted values; e.g., with a simple linear model, $D(y,\beta_0,\beta_1)=\frac{1}{2\sigma^2}(y-\beta_0-\beta_1 x)^2$. MCMC yields a sample from the posterior distribution of θ and the mean deviance, based on an MCMC sample of size L, is calculated by

$$\hat{D}_{avg}(\mathbf{y}) \quad = \quad \frac{1}{L}\sum_{l=1}^{L} -2\log(p(\mathbf{y}|\theta^l)),$$

where $\mathbf{y}$ is the entire vector of observed values.

Increasing the number of parameters typically decreases deviance and to compare models with differing numbers of parameters, a measure that includes deviance but exacts an increasing penalty for an increasing number of parameters is DIC, the deviance information criterion, defined as follows.

$$DIC \quad = \quad 2\hat{D}_{avg}(y) - D(\mathbf{y},\hat{\theta}),$$

where $\hat{\theta}$ is the posterior mean for θ.

Assessment of quality in terms of fit to individual observations was examined by calculating Bayesian P-values and scaled residuals. Bayesian P-values are defined as the proportion of time a predicted value exceeds the observed value:

$$\text{Bayesian P-value} \quad = \quad \frac{1}{L}\sum_{l=1}^{L} I(y_l^{pred} \geq y),$$

where $I()$ is an indicator function equaling 1 when the condition inside () is met. The predicted value, y_l^{pred} is found by simulating y from its probability distribution evaluated at the parameter value θ^l (taken from the MCMC sample). Bayesian P-values near 0 or 1 are indicative of a poor fit. Scaled residuals are defined by

$$\text{Scaled residual} \quad = \quad \frac{y - \overline{y}^{pred}}{s_{y^{pred}}},$$

where $\overline{y}^{pred}$ and $s_{y^{pred}}$ are the mean and standard deviation of the predicted values.

4.6. **Sensitivity analysis.** The sensitivity of the results to the particular Bayesian hierarchical formulations was evaluated by making changes in each of the three levels of the hierarchy. In Bayesian methods sensitivity analysis is often focused on the choice of prior distributions (Level 3), however, it can also include comparisons with alternative likelihood models (Level 1) and random effects models (Level 2). The latter comparisons sometimes are viewed as problems of model selection, but they can also be viewed as a form of sensitivity analysis. Several of the alternatives discussed below were either directly suggested or indirectly stimulated by comments from reviewers.

Negative Binomial likelihood (Level 1): A distribution sometimes used for overdispersed count data is the negative binomial. Overdispersed in this case is with reference to a Poisson distribution where the variance equals the mean. The Poisson distribution itself is often used as an approximation to the binomial distribution when the probability of success is relatively small, the number of trials is large, and the expected number of successes is relatively small; and in that case, if $X \sim \text{Binomial}(n, p)$, then $X \approx \text{Poisson}(np)$. Thus the negative binomial can be used to approximate "overdispersed" binomial data in such a setting (large n, small p, etc).

An example formulation for one of the outcomes, recoveries at Chipps Island of releases from Ryde, is the following.

$$y_{Ry\to CI} \sim \text{NegBinom}\left(k_{CI}, \frac{k_{CI}}{R_{Ry}r_{Ry\to CI} + k_{CI}}\right),$$

where k is a non-negative constant that affects the degree of overdispersion (relative to a Poisson, or indirectly a Binomial, random variable). The larger k is, the less the overdispersion. Let $p = \frac{k_{CI}}{R_{Ry}r_{Ry\to CI}+k_{CI}}$

$$E[y_{Ry\to CI}] = \frac{k_{CI}(1-p)}{p} \equiv R_{Ry}r_{Ry\to CI}$$

and

$$V[y_{Ry\to CI}] = \frac{k_{CI}(1-p)}{p^2} \equiv R_{Ry}r_{Ry\to CI}\frac{R_{Ry}r_{Ry\to CI} + k_{CI}}{k_{CI}}$$

Negative binomial formulations were applied independently to recoveries at two (Chipps Island and the ocean) or three (Antioch, Chipps Island, and the ocean) locations from the same release. This univariate treatment ignores the Level 1 probabilistic dependence between y_{CI} and y_{Oc}, say, that the multinomial likelihood models recognize. While multivariate negative binomial distributions do exist (Winkelmann 2000), the use of independent marginal negative binomial distributions for each of the outcomes is probably adequate given how extremely small the covariances are between the outcomes (due to the very small capture probabilities).

Alternative random effects models (Level 2): Reviewers of an earlier draft had several useful suggestions regarding Level 2 models. They are described below for completeness, but all suggestions were not tried for all four studies.

(1) *Log link function for θ.* A ratio between survival probabilities, denoted by θ, was of interest in all four studies. The logit link function bounds the ratio between 0 and 1, thus the survival in the numerator of the ratio was implicitly assumed to be less than the value in the denominator. An alternative link function is the natural log which would allow the survival in the numerator to exceed that in the denominator; e.g., in the case of the Interior and DA 8 studies, the Georgiana Slough releases could potentially have higher survival rates than the Ryde releases. In contrast to the logit link function, there is the potential that fitted probabilities could mathematically exceed 1 (which will cause the fitting algorithm in the multinomial case to fail).

(2) *Correlated random effects.* Survival rates in different parts of the river, particularly for the VAMP studies, might be positively correlated in the sense that when conditions are good in one part of the river, it could well be that conditions are good in other parts of the river (Bryan Manly, personal communication). One way to allow for this possibility to specify a multivariate distribution for the Level 2 random effects. For example, with the Interior study, a multivariate normal distribution could be specified for the (logit transformed) vector of (θ, $r_{Ry\to CI}$, $r_{Ry\to Oc}$):

$$\begin{bmatrix} logit(\theta) \\ logit(r_{Ry\to CI}) \\ logit(r_{Ry\to Oc}) \end{bmatrix} \sim \text{Multivariate Normal}\left(\begin{bmatrix} \mu_\theta \\ \mu_{r_{Ry\to CI}} \\ \mu_{r_{Ry\to Oc}} \end{bmatrix}, \begin{bmatrix} \sigma^2_\theta & \sigma_{\theta,r_{Ry\to CI}} & \sigma_{\theta,r_{Ry\to Oc}} \\ \sigma_{\theta,r_{Ry\to CI}} & \sigma^2_{r_{Ry\to CI}} & \sigma_{r_{Ry\to CI},r_{Ry\to Oc}} \\ \sigma_{\theta,r_{Ry\to Oc}} & \sigma_{r_{Ry\to CI},r_{Ry\to Oc}} & \sigma^2_{r_{Ry\to Oc}} \end{bmatrix} \right)$$

(3) *Extended logit-type link functions for $r_{i\to j}$ and $r_{i\to k}$.* For both the non-Bayesian and Bayesian formulations the sum $r_{Ry\to CI,t} + r_{Ry\to Oc,t}$ must be less than 1 by definition, but such constraints are not built in. However, recovery probabilities are so small in practice that the chance of estimating $r_{Ry\to CI,t} + r_{Ry\to Oc,t}$ to be > 1 is negligible. An alternative logit-like formulation (Russell Millar, personal communication) that does satisfy this constraint is the following:

$$\log\left(\frac{r_{Ry\to CI,t}}{1 - r_{Ry\to CI,t} - r_{Ry\to Oc,t}}\right) \tag{52}$$

$$\log\left(\frac{r_{Ry\to Oc,t}}{1 - r_{Ry\to CI,t} - r_{Ry\to Oc,t}}\right). \tag{53}$$

Then in the case of the Bayesian model,

$$E[r_{Ry\to CI,t}] \approx \frac{\exp(\mu_{r_{Ry\to CI}})}{1 + \exp(\mu_{r_{Ry\to CI}}) + \exp(\mu_{r_{Ry\to Oc}})}.$$

(4) *Secondary release-specific covariates.* The random effects components at Level 2 will to some degree account for factors influencing survival over and above the *primary* covariates that are being structurally modeled, namely DCC gate position (DCC), location (Interior), location and exports (DA 8), and flow, exports, and HORB (VAMP). For example with the Interior study, $\theta_t \sim \text{Normal}(\mu_\theta, \sigma^2_\theta)$. Deviations from μ_θ are in a sense a function of *secondary* covariates that are not modeled, such as temperature (Baker, Speed, and Ligon, 1995). If the values of such covariates vary widely and have a large effect on survival, then the variation in the random effects parameter will be large, e.g., σ^2_θ is large, and predictions of release-specific parameters, such as θ_t, will have considerable uncertainty. Including such covariates into the Level 2 model can however increase precision. After-the-fact assessment of secondary covariate influence can be done by comparing fitted values, e.g., $\hat{\theta}_t$, or random effect “residuals”,

with covariate values, and/or by including such covariates in the Level 2 model and comparing the quality of fit.

Alternative priors (Level 3): Gelman (2006) has discussed potential problems with inverse gamma priors for the variance components of a hierarchical model. While he describes sophisticated alternatives, a relatively simple choice is the use of a uniform distribution for the standard deviation. For example,

$$\sigma_{\theta}, \sigma_{r_{Ry \to CI}}, \sigma_{r_{Ry \to Oc}} \quad \sim \quad \text{Uniform}(0, 20)$$

was tried for some of the models.

Sensitivity to the above changes were assessed in terms of changes in the posterior means for observations and parameters and by examining DIC, Bayesian p-values, and scaled residuals.

5. RESULTS

The `R` package `R2WinBUGS` was used as an interface to `WinBUGS` to fit the BHMs and the code for both are given in the appendices. For all models fit, three Markov chains were run using different starting values. The Brooks-Gelman-Rubin statistic (see documentation in `WinBUGS` and Brooks and Gelman (1998)) was calculated to assess convergence; values near 1 are consistent with convergence, i.e., the variance within a chain is more or less the same as the variance between chains.

5.1. **DCC studies.**

5.1.1. *Non-Bayesian results.* Recall $\hat{\theta} = \hat{r}_{Ct \to CI+Oc} / \hat{r}_{Ry \to CI+Oc}$, $\theta = S_{Ct \to CI} / S_{Ry \to CI}$, and μ_θ=E[θ]. The weighted estimates of μ_θ were 0.40 when the DCC gate was open and 0.64 when the gate was closed. The estimate of $\mu_{\theta(Open)} / \mu_{\theta(Closed)}$ was 0.40/0.64 = 0.63 with a standard error of 0.20. The bootstrapped 95% confidence interval (using the percentile method, Efron and Tibshirani (1993, p 170)) was (0.28, 1.10). Thus there is evidence suggesting that when the gate is open, the survival of Courtland releases decreases, but there is considerable uncertainty about this conclusion (see the bootstrap histogram of ratio estimates in Figure 13).

The weighting of the $\hat{\theta}$'s had considerable effect on the results. Assigning equal weights to each release pair yielded $\hat{\mu}_{\theta(Open)} = 0.92$ and $\hat{\mu}_{\theta(Closed)} = 1.02$ and the estimate of $\mu_{\theta(Open)} / \mu_{\theta(Closed)}$ was 0.89. If the 1989 observation was removed (an apparent outlier), however, the equally weighted estimate of $\mu_{\theta(Open)} / \mu_{\theta(Closed)}$ was 0.60, quite similar to the weighted results.

5.1.2. *Bayesian results.* A combination of model formulations were fit, with multinomial or negative binomial likelihoods at Level 1, logit or log transformations of θ at Level 2, and inverse gamma or uniform priors for the variances or standard deviations of the random effects at Level 3. One combination that did not work was the multinomial with a log transformation of θ which sometimes led to the recovery "probabilities", θr_c and θr_o, exceeding one. Table 9 shows the DIC values for some of the models tried. The model selected for inference was the negative binomial with log transformed θ and uniform priors for the standard deviations. The `R` and `WinBUGS` program code are shown in Appendix E.1. For the negative binomial binomials, a burn-in of 10,000 samples was used for each chain and an additional 40,000 samples were generated. Based on the Brooks-Gelman-Rubin statistic for convergence, all values lying between 1.00 and 1.04, the chains had converged to the posterior distribution.

Parameters of interest. Summaries of the posterior distributions of the selected model are shown in Table 9. Of most relevance to the objectives of the DCC studies is the slope coefficient β_1, which when positive, suggests that closing the DCC gate increases survival for Courtland releases. The mean value of β_1 was 0.33, but the posterior distribution is quite wide. A more direct measure of the DCC gate effect is the ratio of the closed gate ratio (Courtland/Ryde) to the open gate ratio, $\theta_{Open}/\theta_{Closed}$, which when less than 1.0 indicates that survival for Courtland releases relative to Ryde releases is less with the DCC gates open than with the gates closed. The posterior median for $\theta_{Open}/\theta_{Closed}$[7] is 0.72, but the probability that $\theta_{Open}/\theta_{Closed}$ is less than 1.0 is only 64%.

While not of direct relevance to the DCC studies, some of the other parameters are of interest. The median recovery probability for Ryde releases at Chipps Island was 0.0008, and for ocean recoveries it was 0.0080, an order of magnitude larger. The negative binomial parameter k_{CI} for Chipps Island recoveries is very large (mean value = 493), which indicates little evidence for overdispersion, in contrast to k_{Oc} for ocean recoveries which was considerably smaller (mean value = 17). The group 13 pair is perhaps to some degree responsible for k_{Oc}'s value since the estimated ocean recoveries for Ryde were so much less than those for Courtland.

Quality of fit. Forty-seven of the 52 observations (90%) had Bayesian P-values within the middle 90% of the posterior predictive distributions. The five "outlying" observations were the group 13 Ryde recoveries at Chipps Island (P-value=0.98) and in the ocean fisheries (P-value=0.99) (see Figures 14 and 15), and Courtland recoveries at Chipps Island for groups 3, 9, and 10 (Figure 16). The scaled residuals are plotted against mean posterior predictions in Figure 17 The largest scaled residuals are for the Chipps Island recoveries from Courtland releases in groups 3 and 9, but, in contrast to the P-values, the group 13 Ryde residuals are not outliers.

The influence of group 13 was assessed by removing those observations and re-fitting the negative binomial model. The median value for $\theta_{Open}/\theta_{Closed}$ changed only slightly (from 0.72 to 0.65) and the probability that $\theta_{Open}/\theta_{Closed}$ was less than 1.0 only went from 64% to 70%. Thus the effect of this group on the most relevant parameters was minor.

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[7] The mean is 1.32, reflecting strong right skewing in the posterior distribution. Note that an approximate estimate of $\mu_{\theta(Open)}/\mu_{\theta(Closed)}$ is $\text{logit}(\beta_0)^(-1)/\text{logit}(\beta_0+\beta_1)^(-1)$, or $(1+\exp(\beta_0+\beta_1))/(\exp(\beta_1)+\exp(\beta_0+\beta_1))$. Substituting the posterior means for β_0 and β_1 yields 0.82.

Random effects. Sensitivity to the Level 2 formulation was also examined by fitting a multivariate normal random effects model for θ, $r_{Ry \to CI}$, and $r_{Ry \to Oc}$. The extended logit transformation was used for $r_{Ry \to CI}$ and $r_{Ry \to Oc}$. An inverted Wishart distribution was used for the joint prior distribution of random effects. `WinBUGS` model code is shown in Appendix E.2. The DIC value (Table 9) was slightly higher than for uncorrelated multinomial models, and considerably higher than for the negative binomial models. The posterior median for the ratio of ratios was 0.96. Negative correlations (on the logit and extended logit scales) were found between θ and $r_{Ry \to CI}$ (correlation coefficient = -0.58), between θ and $r_{Ry \to Oc}$ (correlation coefficient = -0.53), while the correlation between $r_{Ry \to CI}$ and $r_{Ry \to Oc}$ was positive (correlation coefficient = 0.62).

The value of random effects in the model was examined by fitting a negative binomial model without any random effects for θ_t, $r_{Ry \to CI}$, and $r_{Ry \to Oc}$, i.e., purely deterministic Level 2 models. The apparent benefit to survival of having the DCC gates closed increased sizeably, the probability that $\theta_{Open}/\theta_{Closed}$ was less than 1.0 went from 64% to 95%. However, the model fit and predictive power worsened notably: the DIC increasing from 567.3 to 656.7, the Bayesian P-values tended to become more extreme (particularly for ocean recoveries), and the magnitude of scaled residuals in some cases nearly doubled (Figure 18).

5.2. **Interior studies.**

5.2.1. *Non-Bayesian results.* The estimate of the expected ratio of Georgiana Slough survival to Ryde survival, μ_θ, based on a weighted average of $\hat{\theta}$ ($\hat{r}_{GS \to CI+Oc}/\hat{r}_{Ry \to CI+Oc}$) was 0.33 with a bootstrap standard error of 0.038 and a 95% confidence interval of (0.26,0.41). The unweighted average of the $\hat{\theta}$'s was 0.40 (median=0.33) with a standard error 0.055 and a 95% confidence interval of (0.30,0.51). In either case the evidence that the survival for Georgiana Slough releases was low relative to Ryde releases was strong.

5.2.2. *Bayesian results.* Several combinations of models were fit to the Interior data. Based on the DIC values, the multinomial models were all quite similar in terms of fit and preferable to the negative binomial models (Table 10). However, the parameter estimates under the negative binomial were very similar to those for the multinomial distribution. There was little evidence for overdispersion based on the negative binomial model; e.g., for the log transformed θ and uniform priors on the σ's of the random effects, the median values for k_{CI} and k_{Oc} equaled 15 and 208. The results presented below are based on the multinomial model with log transformed θ and uniform priors for the σ's. The WinBUGS program code for the multinomial model is shown is shown in Appendix E.3. For each of the three chains a burn-in of 50,000 samples was used and an additional 150,000 samples were generated. The Brooks-Gelman-Rubin statistics were between 1.00 and 1.04 for all parameters.

Parameters of interest. Summary statistics for the posterior distributions are shown in Table 10. The key parameter is θ, the ratio of Georgiana Slough to Ryde recoveries, and the posterior mean predicted value was around 0.44, strong evidence, consistent with the non-Bayesian analysis, that the Georgiana Slough recovery rates are considerably less than the recovery rates for Ryde releases. However, the upper 4.9% of the distribution for θ was above 1.0, meaning that there was a 4.9% chance that Georgiana Slough recovery probabilities could be higher than the Ryde recovery probabilities. The posterior mean predicted value of θ was quite similar for all models, ranging from 0.41 to 0.44. The median recovery probability at Chipps Island, $r_{Ry \to CI}$, was 0.0004 and, as for DCC studies, the ocean fisheries recovery probability was an order of magnitude higher, 0.0036.

Quality of fit. Of the 60 observations, 55 (or 92%) fell within the middle 90% of the posterior predictive distributions. The five observations with extreme Bayesian P-values were groups 1 and 6 Ryde recoveries at Chipps Island, the group 5 Georgiana Slough recoveries at both Chipps Island and in the ocean, and the group 12 Georgiana Slough recoveries at Chipps Island. In each case, the observed value was either exceptionally small or large relative to the predicted values; e.g., for the group 1 Ryde releases, the observed 37 recoveries at Chipps Island were larger than 98% of the predicted values (Figure 19). The scaled residuals are plotted against mean posterior predictions in Figure 20, and the largest residuals are for those Chipps Island recoveries of Ryde releases with extreme P-values.

Random effects. A multivariate normal random effects model was also fit (using the same approach as for the DCC implementation). Based on the DIC value, this model was of nearly equivalent quality to the uncorrelated multinomial models (Table 10). The correlations between the random effects were relatively low; correlation between θ and $r_{Ry \to CI}$ (on the logit scales) was 0.11, between θ and $r_{Ry \to Oc}$ it was 0.23, and between $r_{Ry \to CI}$ and $r_{Ry \to Oc}$ it was 0.31.

To determine the impact on results of including random effects, the multinomial model with log transformed θ was fit without any random effects, i.e., deterministic Level 2 models. The posterior mean for the expected value of θ, μ_θ, was -0.86, in contrast to -1.02 for the value for the model that included random effects. However, $\exp(\mu_\theta) = 0.42$, which is quite similar to the posterior mean for the simulated value θ in the model including random effects (E[θ] $\approx$ 0.44). The key difference was in the considerably greater variability in the distribution for θ, with the coefficient of variation for the random effects model equal to 82% compared to 3% for the model without random effects. The expected recovery probability for Ryde releases at Chipps Island was 0.00045 and in the ocean was 0.0044, about 20% less than for the random effects model. The prediction ability and quality of fit was considerably worse when random effects were removed: the DIC value increased from 428 to 2184, the frequency of relatively extreme Bayesian P-values increased considerably, and the magnitude of scaled residuals increased four- to five-fold (Figure 21). The variation in the observed recovery fractions was simply far larger than could be explained by a model without random effects.

Secondary covariates. The effect of secondary covariates was examined by plotting the median fitted θ's per release set against release temperature at Georgiana Slough and average length of fish at release (Figure 22). No pattern was apparent. The release temperatures at Ryde were very similar to those at Georgiana Slough with one exception, the tenth set, in year 2000 with tags 05-51-31 and 05-51-33, where Ryde temperature was 50 degrees Fahrenheit in contrast to 63 degrees at Georgiana Slough. However, this release pair was not unusual in terms of Bayesian P-values or scaled residuals, and it may be that the 63 degrees was a data recording error (Pat Brandes, personal communication).

It is worth noting that the use of temperature at time of release is only a very limited measure of the temperatures possibly experienced by a fish as it out-migrates. Potentially, during the period of out-migration the variation in water temperatures could be extreme and temperature at time of release would not necessarily be very reflective of the temperatures encountered enroute.

Analyses with inland recoveries. Given the relatively similar stray rates for inland recoveries between Georgiana Slough and Ryde releases, additional model runs were made using the inland recoveries in combination with the expanded ocean recoveries. The results for the selected multinomial model (log transformed θ and uniform priors for the σ's) were very similar, e.g., the posterior mean for μ_θ was -1.03 compared to -1.02 for the results without inland recoveries, but the posterior standard deviations for some of the fitted θ's were slightly smaller with inland recoveries included.

5.3. **Delta Action 8 Experiments.**

5.3.1. *Exploratory data analysis.* Non-BHM estimates of the ratio $\theta = S_{GS\rightarrow CI}/S_{Ry\rightarrow CI}$, namely $\hat{\theta} = \hat{r}_{GS\rightarrow CI+Oc}/\hat{r}_{Ry\rightarrow CI+Oc}$, are plotted against exports in Figure 23. The vertical lines in the plot mark ± 1 standard error, which was calculated using delta method (i.e., the sample based estimates of $\sqrt{V(\hat{\theta}_t)}$ shown in Appendix A). Thus these standard errors reflect within release pair variability only. The two especially large standard errors (middle and right side of the plot) are for 2005 and 2006 and their magnitude is due to the lack of ocean recovery information to date.

Also plotted in Figure 23 is a weighted,nonparametric regression curve. The curve was fit using a supersmoother function in `R` and weights based on the delta method standard errors. While this graph is a non-Bayesian, non-hierarchical, and indirect analysis, the gist of the results is, as will be shown next, consistent with the Bayesian, hierarchical, and integrated analysis, i.e., suggesting a slight negative association between exports and θ.

5.3.2. *Bayesian analysis.* As for the Interior analysis multinomial and negative binomial distributions, logit and log transformations of θ (with θ now defined as a function of exports), and uniform and gamma distributions for σ's were all tried. The WinBUGS code for the multinomial distribution is shown in Appendix E.4. Burn-in time was set at 50,000 iterations and then at least 100,000 iterations were used for the posterior samples. The Brooks-Gelman-Rubin statistics were between 1.0 and 1.03 for all parameters and trace plots of the parameters were consistent with good mixing.

The preferred model based on DIC is the multinomial with log transformed θ and uniform priors for the σ's (Table 11), but all the multinomial models yielded quite similar results. The DIC for this model, 427.0, however, was only slightly less than the DIC for the models without exports (the "Interior" models where minimum DIC was 427.7). Summary statistics from the posterior distributions are shown in Table 11. The negative binomial's overdispersion parameters were quite large (median values of 192 for k_{CI} and 311 for k_{Oc}) indicating very little overdispersion relative to a multinomial distribution.

Parameters of interest. The key parameter is β_1 (the coefficient for exports in the logistic regression of θ; see equation 29). It had a 98% probability of being negative, indicative of a negative association between the relative survival of Georgiana Slough and Ryde releases (θ) and exports. A posterior sample of predicted θ for different levels of exports was generated and the results are plotted in Figure 24. The plot shows the decline in mean θ as exports increases (when exports are at 2000 cfs, mean θ is 0.62, and when exports are at 10,000 cfs, mean θ is 0.31). The plot also shows the considerable range of variability in θ for any given level of exports. The noise in this relationship is indirectly apparent given that the DIC value for a model *without* exports (an Interior model) was not much higher than the corresponding model with exports. Note that upper bounds on θ for lower levels exceed 1.0, allowing for the possibility that Georgiana Slough releases could have better survival than Ryde releases (consistent with results for the Interior model).

Figure 25 compares the BHM *predicted* values of θ at different export levels with predictions from indirect, non-Bayesian analyses. Model M1 mimics Brandes and McLain (2001) in that a linear regression of the ratio of Chipps Island recovery fractions ($\hat{r}_{GS\rightarrow CI}/\hat{r}_{Ry\rightarrow CI}$) was regressed against (standardized) exports. Another model, M2, is a regression of the natural logarithm of $\hat{r}_{GS\rightarrow CI+Oc}/\hat{r}_{Ry\rightarrow CI+Oc}$ against (standardized) exports; the predicted values are $\exp(\hat{\beta}_0 + \hat{\beta}_1 Exp^* + \sigma^2/2)$. All three models had a negative association with exports but the BHM results (M3) had a higher relative survival for Georgiana Slough releases than the two non-Bayesian models.

Table 12 compares the BHM *fitted* values of θ compared to non-BHM estimates. The BHM fitted values are the posterior means for the particular releases in contrast to posterior predicted values for any release at a specified export level (as shown in Figure 25). The non-BHM estimates are simply the release-specific ratios, $r_{GS\rightarrow CI+Oc}/r_{Ry\rightarrow CI+Oc}$, i.e., not modeled as a function of exports. Despite the underlying differences in estimation procedures, the posterior means of fitted values and non-BHM estimates are quite similar. The posterior standard deviations and standard errors are also similar with the exception of the two most recent years without ocean data, where the posterior standard deviations are considerably smaller than the standard errors, indicative of the information from other releases that BHMs utilize. The last column of Table 12 shows the estimates of the survival ratios using the method of Brandes and McLain (2001) with the Chipps Island recoveries. While there are several release pairings with values similar to θ (a 1995 pairing, a 1999 pairing, 2000, 2004, and 2005), there are several, sometimes large differences as well (e.g., 1994 and a 1995 pairing).

The posterior distributions of recovery probabilities for Ryde releases at Chipps Island and in the ocean fisheries were nearly identical to the Interior study (Table 11).

Quality of fit. The Bayesian P-values and scaled residuals were essentially the same as for the fitted Interior model. The relationship between temperature and length and fitted θ's would be similar to that for the fitted Interior model, too.

Additional analyses. The multivariate random effects model was also fit. The DIC value was only slightly higher for the uncorrelated random effects models with log transformed θ. The correlation between random effects, as compared to the Interior study, was slightly higher: between θ and $r_{Ry \to CI}$ (on the logit scales) it was 0.33, between θ and $r_{Ry \to Oc}$ it was 0.47, and between $r_{Ry \to CI}$ and $r_{Ry \to Oc}$ it was 0.33.

As for the *Interior* model, the inland recoveries were added to the ocean recoveries and the preferred multinomial model was fit. The results were quite similar to those excluding the inland recoveries. The DIC value was 427.6 (versus 427.0). The probability that $\beta_1 < 0$ was again 98%, although the posterior mean fitted values for $\theta | Exports$ differed by as much as 10% from the model without inland recoveries (e.g., for group 10, the posterior fitted value of θ was 0.55 versus 0.65, Table 12).

Based on suggestions from anonymous reviewers, the ratio of exports to flow was substituted for absolute exports as a covariate. The DIC value was very similar (426.9 versus 427.0) and the probability that $\beta_1 < 0$ was 0.98 still. Bayesian P-values and scaled residuals were nearly identical.

5.4. **VAMP studies.** Initial analyses compared multinomial and negative binomial formulations at Level 1. For the negative binomial model, three dispersion parameters were included, for Antioch, Chipps Island, and the ocean recoveries. For further analyses and the results presented here, the multinomial formulation was selected over the negative binomial based on the facts that the dispersion parameters were all very large (at least 500 in all three cases), indicating little overdispersion, and that the Bayesian P-values and and scaled residuals were considerably better for the multinomial model.

The particular multinomial model used for inference used logit transformations of survival probabilities for Level 2 and uniform priors for the σ's for Level 3. The use of log transformations for Level 2 was not tried to lessen problems with probabilities exceeding one during the fitting process. Inverse gamma priors for σ^2 at Level 3 led to similar results. The `R` and `WinBUGS` code used to fit a multinomial model is shown in Appendix E.5.

Including random effects had a considerable impact on DIC values. Table 13 compares the DIC values for three models with only a single covariate (an indicator for HORB was used to model $S_{DR \to JP}$). When no random effects were included, the DIC was about six times larger than for a model with random effects for the recovery probabilities, and inclusion of random effects for survival and recovery probabilities further reduced DIC by about 2/3's. Thus including random effects considerably improved the DIC values.

Models where p_{OR} was assumed known and a function of the relative flow into Old River (see Table 6) were compared to models where p_{OR} was fixed but unknown were compared. To otherwise make the two situations equal, in both cases $S_{MD\rightarrow HOR}$ was fixed equal to 1.0, even though it was estimable with p_{OR} known. For a model with no covariates, the DIC values were nearly equal (DIC=1499 with p_{OR} known and DIC=1496 with p_{OR} estimated). Somewhat arbitrarily, believing that p_{OR} does in fact vary as a function of flow, and not wanting to necessarily assume $S_{MD\rightarrow HOR}$=1.0, results for varying p_{OR} are presented and discussed below. The quality of fit and the relative magnitude of coefficients were much the same for known and varying p_{OR} and unknown and fixed p_{OR}, however.

Table 14 summarizes results for some of the models (with varying p_{OR}). The model with the smallest DIC value models $S_{DR\rightarrow JP}$ and $S_{OR\rightarrow JP}$ both as functions of flow and export levels (labeled Null.FE.FE); i.e.,

$$\begin{aligned} logit(S_{DR\rightarrow JP}) &\sim \text{Normal}\left(\xi_0 + \xi_1 Flow_{DR} + \xi_2 Exports_{DR}, \sigma^2_{DR\rightarrow JP}\right) \\ logit(S_{OR\rightarrow JP}) &\sim \text{Normal}\left(\zeta_0 + \zeta_1 Flow_{UOR} + \xi_2 Exports_{MD}, \sigma^2_{OR\rightarrow JP}\right). \end{aligned}$$

Figure 26 contains histograms of a sample from the posterior distribution for the flow and export coefficients (ξ_1, ξ_2, ζ_1, ζ_2) for this model. While the DIC value was lower than for models without export coefficients and upper Old River flow, the posterior probabilities suggested only weak effects of exports and the upper Old River flow on survival. Also based on this model, Figure 27 plots, for each of the 35 release sets, the posterior mean survival probabilities for travel down Old River exclusively, travel down the San Joaquin River exclusively, and the expected values down the combination of rivers (given HORB and p_{OR}). The expected survival probability down Old River was always less than the survival down the San Joaquin River. Different models yielded somewhat different expected values, but the survival down Old River was generally, if not always, lower than those for the San Joaquin.

The PI for the VAMP study asked how different the results would be if the release sets from 2003 through 2006 were removed, since these were years with particularly low recovery numbers for Durham Ferry and Mossdale releases. Only a couple of models were tried, but the results were quite similar to those for the full data set. The most practically significant results were that the positive effect of flow on $S_{DR\rightarrow JP}$ and $S_{OR\rightarrow JP}$ was considerably stronger: the probability that the coefficients was positive was 100% for $S_{DR\rightarrow JP}$ and 97% for $S_{OR\rightarrow JP}$.

Quality of fit. The posterior mean predicted values for the Null.FE.FE model are plotted against the observed values for some of the data in Figure 27 (excluding Old River just to avoid clutter). Note that these are predicted, not fitted values which include case-specific random effects. The observed values are in many cases far from the mean predicted values; for cases of relatively large numbers of ocean recoveries in particular, the posterior mean values are underestimates. The Bayesian P-values are perhaps more informative in that they indicate just how extreme, or not, the observations are relative to the entire predictive distribution. Of the 206 outcomes, 197 (96%) of the observations fell within the middle 90% of the posterior predictive distributions. The "minimum" P-values, and posterior predictive samples, for the worst fitting subset, recoveries at Antioch from Mossdale releases, are shown in Figure 28, where there were three releases with one or zero recoveries at Antioch. The scaled residuals, grouped by release-recovery category (again excluding Old River releases), are plotted against posterior predictive means in Figure 29. For a few observations, e.g., Chipps Island recoveries from a Jersey Point release, the residuals exceeded 2 in absolute value.

Secondary covariates. At a presentation of preliminary results to the VAMP science group, the question of the effects of water temperature on survival was raised. The observed, or in some cases estimated, water temperatures at release points were compared to the Level 2 random effects residuals, i.e., deviations from the mean value (on the logit scale), using the Null.FE.FE model. For example, the survival, on the logit scale, between Durham Ferry and Mossdale for release set t can be written as follows.

$$logit(S_{DF\rightarrow MD,t}) \quad = \quad \beta_0 + \epsilon_{DF\rightarrow MD,t},$$

where

$$\epsilon_{DF\rightarrow MD,t} \quad \sim \quad \text{Normal}(0, \sigma^2_{S_{DF\rightarrow MD}}).$$

`WinBUGS` output included samples from the posterior distribution for these ϵ's and the means from these samples are what are plotted against the stream section temperatures in Figure 30. The Jersey Point plot is based on the residuals for relative survival to Chipps Island, where $\epsilon_{JP\rightarrow Ant\rightarrow CI,t}$ and $\epsilon_{JP\rightarrow CI,t}$ have been combined. The scatterplot smooths over the plots suggests at most a slightly negative association between temperature and the random effects for Durham Ferry releases, i.e., as release temperature increases the estimated survival (on a logit scale) tends to decrease, but otherwise there was no evidence for an association.

As an aside, there was a single very large negative random effect for one of the Durham Ferry releases (this was from a year 2000 release, group 24), as can be seen in Figure 30. This was undoubtedly the cause of the very large variance term, $\sigma^2_{DF\rightarrow MD}$. The reason for the large "residual" may be due to the low percentage of ocean recoveries, 0.2%, relative to Jersey Point release which had 1.5%, in comparison to other Durham Ferry releases. It is worth noting that the scaled residuals did not reveal this outlier because the large random effects variance scaled down the residual considerably. Thus scaled residuals alone are not an adequate diagnostic of model fit in some cases.

Another concern raised by the VAMP science group and one of the reviewers was the use of two different hatchery stocks, from Feather River Hatchery and Merced River Fish Facility. There is some degree of temporal confounding in that Feather River Hatchery fish were used only during the early years (1985-1998), while Merced River Fish Facility fish were (mostly) used in the later years (1996-2006). If environmental conditions during the early years were particularly poor for survival, for any stock, then it would be incorrect to attribute the cause to stock. It should also be noted that another possible confounding factor is that beginning in 1998, the sampling effort at Chipps Island essentially doubled, relative to previous years. With these caveats in mind, the random effects residuals (Null.FE.FE model) for two river sections, $DR \rightarrow JP$ and $JP \rightarrow CI$ for the two stocks were compared and side-by-side boxplots are shown in Figure 31. The Durham Ferry to Mossdale section was not included since all releases from Durham Ferry came from Merced River Fish Facility; and the Mossdale to Dos Reis section was treated as having constant survival. Evidence for a higher survival probability for the MRFF stock is apparent, particularly for the Jersey Point releases. To allow for a stock effect, an expanded model for the recovery probabilities was fit, i.e.,

$$logit(r_{JP\rightarrow x}) \sim \text{Normal}\left(\mu_{JP\rightarrow x} + \chi I_{MRFF}, \sigma^2_{JP\rightarrow x}\right)$$

where x=Ant, CI, or Oc and I_{MRFF} is an indicator variable for Merced River Fish Facility stock. Some results for a model including this stock effect and $S_{DR\rightarrow JP}$ modeled as a function of flow are shown in Table 14. The DIC was higher than for a model without the stock effect but the posterior means for parameters were much the same, suggesting that general conclusions are robust to a possible stock effect.

Lastly, another concern expressed by reviewers was how recoveries of fish at the fish facilities at CVP and SWP might affect results. Random effects residuals (Null.FE.FE model) for different reaches were plotted against the estimated salvage (Figure 32). The residuals for the logit of $S_{OR\rightarrow JP}$ did not necessarily always apply to the Durham Ferry and Mossdale releases because the HORB was sometimes in position and by assumption those fish would only travel down the San Joaquin River. For the Old River releases, the residuals for the logit of $S_{OR\rightarrow JP}$ did tend to increase as fish salvaged increased, i.e., the fitted survival probabilities were elevated somewhat as number of fish salvaged increased. For the Durham Ferry, Mossdale, Dos Reis, and Jersey Point releases there is no apparent relationship between number salvaged and the survival random effects.

6. Study design and sample size issues

The objectives for all four multi-year studies have been translated into parameter estimation problems, namely

- *DCC*: for comparing open gate to closed gate effects on survival, estimate $\mu_{\theta(Close)}/\mu_{\theta(Open)}$ (equation 8);
- *Interior*: for comparing survival from Georgiana Slough to survival from Ryde, estimate μ_θ (equation 23);
- *DA 8*: for evaluating the effect of exports on the survival of Georgiana Slough releases (relative to the survival of Ryde releases), estimate β_1 (equation 29);
- *VAMP*: for evaluating the effect of flow on survival from Dos Reis to Jersey Point, for example, estimate a parameter ξ_1, say (equation 45).

Sample size and design issues translate into statements about bias and precision of these parameter estimates.

6.1. **Bias.** Bias in parameter estimates depends primarily on model correctness, i.e., whether or not the model assumptions hold. For example, at Level 1 were multinomial models appropriate? Were the fish fates independent? Were the capture probabilities the same for all fish within a paired release, e.g., the same probability of capture at Chipps Island or in the ocean fisheries? At Level 2 were normal distributions appropriate for the random effects?

The question of independence was addressed indirectly by using the negative binomial model as an alternative to the multinomial, and in the case of the DCC studies, the negative binomial was preferable[8]. The question of equal capture probabilities within a release pair was addressed non-rigorously (Section 3.2) by comparing the distribution of recovery times at Chipps Island within a release pair for a few cases (Figure 12). To better answer these two questions, two additions to the general release-recovery design are recommended.

(1) *Use embedded replicates for some release groups.* Embedded replicate tags provide a means of detecting whether or not the assumption of independence has been violated. With embedded replicate tags, the tag numbers vary from tag to tag within the same "spool" of tagging wire that is used to tag a given release group. Schnute (1992)

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[8] Although the better fit of the negative binomial in this case could be due to the estimation error in the ocean recoveries more so than dependence between fish.

pointed out that embedded replicate tags provide no additional information regarding sampling variation *if* fish are independent and identically distributed. However, if fish are not independent and identically distributed, then embedded replicates can provide evidence for lack of independence, e.g., clustering. If variation between embedded replicates is higher than expected according to the underlying multinomial models, then dependence, such as clustering, could be the explanation. The negative binomial distribution is one possible remedy in that case, but the development of other alternative probability models would be worth exploring.

While embedded replicate data are not currently available, there were some "near" replicate tag codes used for some of the releases in the VAMP studies. Table 15 contains information from five sets of Durham Ferry releases. The fish within each set were reared in the same pond but differed by tag code. This is not exactly the same as embedded replicate groups in that the lots tagged with different tag numbers were tagged at different times. For each set a χ^2 test was carried out to test that the proportions recovered by location were the same within a set. The P-values shown in Table 15 suggest departures from homogeneous multinomial distributions for four of the five sets. The underlying probability distribution for the χ^2 test is multinomial. However, because ocean recoveries are estimated, not observed directly, this assumption is not true and some extra-multinomial variation undoubtedly exists. The ocean recoveries were then aggregated into the "non-caught" group and the χ^2 tests were repeated, and this time no departures from homogeneity were observed. Note that these results indicate that using multinomial distributions for Level 1 of the hierarchical model is likely inaccurate, but they do not necessarily indicate a lack of independence between fish.

(2) *Make releases below the recovery locations.* By making releases immediately downstream of capture locations, i.e. Chipps Island and Antioch, *assuming* that subsequent ocean recovery probabilities are the same for releases within a pair or grouping, the capture probabilities at Chipps Island or Antioch can be estimated separately of the survival probability of the immediately upstream section (Newman 2003). Furthermore, estimates of capture probabilities provide a means of evaluating the assumption of constant capture probabilities for paired releases.

For some of the releases in the DCC and the Interior/DA8 studies, downstream releases were made below Chipps Island at Port Chicago or Benicia (see Tables 3 and 4). Method of moments estimates of the capture probabilities for the Courtland or Georgiana Slough releases and the Ryde releases were calculated as follows

$$\hat{p}_{CI} = \frac{y_{Up\to CI}}{y_{Up\to CI} + \frac{\hat{y}_{Up\to Oc} * R_{PC}}{\hat{y}_{PC\to Oc}}},$$

where the subscript Up is for any release location above Chipps Island. The resulting estimates of p_{CI} for the paired upstream releases are shown in Table 16. On average the capture probabilities were higher for Ryde releases than for the Courtland or Georgiana Slough releases. For the DCC studies, a simple paired t-test of equal capture probabilities yielded a P-value of 0.21, suggesting that the differences could be due to sampling variation alone (a more refined test would account for different estimation errors). For the Interior/DA8 studies, however, the same test resulted in a P-value of 0.017 suggesting that Ryde releases were indeed captured with a higher probability than Georgiana Slough releases.

If in fact, the Ryde releases were recovered at a higher rate, then estimates of the relative survival rates of Georgiana Slough to Ryde releases are likely biased low, i.e., Georgiana Slough releases are surviving at a higher rate. Excluding the three release pairs without associated Port Chicago releases, the non-Bayesian estimate of μ_θ (equation 26) assuming equal capture probabilities is 0.46, while if different capture probabilities are allowed the estimate is 0.57.

The hierarchical model can be modified to accommodate both recoveries of Port Chicago releases, and separable upstream survival and capture probabilities, e.g., for the Interior studies,

Level 1:

$$\begin{aligned}
y_{GS\to CI}, y_{GS\to Oc} &\sim \text{Mn}\left(R_{GS}, \theta S_{Ry} p_{GS,CI}, \theta S_{Ry}(1-p_{GS,CI}) r_{PC\to Oc}\right) \\
y_{Ry\to CI}, y_{Ry\to Oc} &\sim \text{Mn}\left(R_{Ry}, S_{Ry} p_{Ry,CI}, S_{Ry}(1-p_{Ry,CI}) r_{PC\to Oc}\right) \\
y_{PC\to Oc} &\sim \text{Binomial}\left(R_{PC}, r_{PC\to Oc}\right)
\end{aligned}$$

Level 2:

$$\begin{aligned}
logit(\theta) &\sim \text{Normal}\left(\mu_\theta, \sigma^2_\theta\right) \\
logit(S_{Ry}) &\sim \text{Normal}\left(\mu_{S_{Ry}}, \sigma^2_{S_{Ry}}\right) \\
logit(p_{GS,CI}) &\sim \text{Normal}\left(\mu_{p_{GS,CI}}, \sigma^2_{GS,CI}\right) \\
logit(p_{Ry,CI}) &\sim \text{Normal}\left(\mu_{p_{Ry,CI}}, \sigma^2_{Ry,CI}\right) \\
logit(r_{PC\to Oc}) &\sim \text{Normal}\left(\mu_{r_{PC\to Oc}}, \sigma^2_{PC\to Oc}\right)
\end{aligned}$$

The assumption of equal ocean recovery probabilities has not been addressed. Earlier unpublished work by the author used cluster analyses to analyze the ocean recovery patterns for some Sacramento River and Delta releases. The estimated proportions caught by age-port-time strata were used as the variable to cluster on and the results indicated greater similarities between releases made in the same year than between years. More work is needed in this area.

6.2. **Precision.** Precision is the magnitude of the sampling error as measured by the size of the standard error of parameter estimates (classical analysis) or the size of the standard deviation of posterior distributions (Bayesian analysis). Sampling error of estimated survival probabilities and related parameters is a function of the parameter values, capture probabilities, inherent between year variation, sample size, and the degree of blocking or controlling for variation. With regard to blocking, the pairing (or tripling, etc) of releases is a positive feature of all the studies because it controls for at least some confounding factors and thereby increases precision.

As sample sizes increase and capture probabilities increase, the standard error or standard deviation of posterior distributions for the survival probabilities will generally decrease. For these multi-year studies there are two kinds of sample sizes: the number of fish released (R) and the number of years (or replications) of study (n). Increasing R or n will increase precision.

With paired releases there are at least two R's and how fish numbers are allocated to each R will affect precision. For example, in a VAMP release group with 100,000 total fish available, one could allocate 25,000 fish each to Durham Ferry, Mossdale, Dos Reis, and Jersey Point, or one could put 40,000 at Durham Ferry and 20,000 each at the other three sites. Determining “optimal” allocation is thus another problem.

Covariate values affect precision, too. For the DA 8 studies, increasing the number of observations at the “extremes” of export levels will increase the precision in the estimate of the slope parameter (β_1 in Equation 29). Similarly, for the VAMP studies, increasing the number of observations at the “extremes” of flow and exports will increase the precision of the related (partial) slope parameters (Equations 43-46).

Thus there are an infinite number of ways to achieve a desired precision by varying the number of years of study, varying the total number of fish released, varying the allocation of fish to release sites within a pairing, and by manipulating the covariate values to the degree possible. Ideally an analytic formula is derived which takes as input n, the total release numbers, e.g., R_1+R_2, and the allocation to release sites (R_1, R_2), covariate values when appropriate, guesses as to parameter values, and inherent between year variation (e.g., σ_θ^2), and then outputs the standard error or standard deviation of the posterior distribution for the parameter of interest. Or, more directly, an analytic formula takes as input the desired standard error or posterior standard deviation, and whatever non-manipulable factors there are (e.g., σ_θ^2), and outputs the combinations of n, R_1, R_2, and covariate values that will achieve the target precision.

The complexity of the hierarchical models for the DCC, DA 8, and VAMP studies is such that analytic solutions are difficult, at best, to derive. In these cases, simulation studies are an alternative: for different sample sizes and input values, simulate the data generation and estimation processes and then look at the resulting standard deviation of estimates (or posterior means). The following sections discuss sample size determination for each of the studies.

6.2.1. *DCC: Sample size for estimating* $\mu_{\theta(Open)}/\mu_{\theta(Closed)}$. Simulations of the data generation and data analysis processes were used to study the effect of changing n, the number of replications of paired releases, on the standard error of the estimate of $\mu_{\theta(Open)}/\mu_{\theta(Closed)}$. Results from the Bayesian analysis were used for the simulation of observations, but the estimation procedure was non-Bayesian and bootstrapping was used to calculate standard errors. Carrying out a full Bayesian analysis using `WinBUGS` to produce posterior standard deviations would have taken considerably longer.

The simulations used recovery probabilities estimated from a BHM fit to the DCC data. The BHM used the multinomial distribution at Level 1 and the 1989 outlier had been removed from the data set. The median posterior values for β_0 and β_1 were used to generate the relative survival probability for Courtland releases compared to Ryde releases (θ); the true value of θ was around 0.73. Similarly recovery probabilities at Chipps Island and in the ocean were generated. Recoveries at Chipps Island and in the ocean were simulated using the multinomial distributions, and $\mu_{\theta(Open)}/\mu_{\theta(Closed)}$ was estimated using equation (15). Bootstrapping was then used to estimate the standard error. The `R` code for this exercise is given in Appendix D.4.

The above procedure was carried out 100 times for n=10, 14, 20, and 24, where gates were open in exactly half the replications, i.e., 5, 7, 10 and 12 replications of open gates. The release numbers were fixed at 100,000 each for Courtland and for Ryde releases. The bootstrap standard errors for the estimates are plotted in Figure 33. The median standard errors for 10, 14, 20, and 24 replications were 0.72, 0.46, 0.42, and 0.36, which are large relative to ratio value of 0.73.

The effect of doubling the release numbers to 200,000 was examined. The reduction in standard errors was negligible, indicating that the between replication variation, as reflected in σ_θ, $\sigma_{Ry\to CI}$, and $\sigma_{Ry\to Oc}$, overshadows the sampling variation (given that R is at least 100,000).

The DCC studies consisted of only 13 replications, 4 with gates closed and 9 with gates open, and the average release numbers were 90,000 for Courtland releases and 64,000 for Ryde releases. Thus even if the true value of the ratio were 0.73, the chance of an estimated value being found to be "statistically significant" is likely relatively low for this amount of data.

6.2.2. *Interior: Sample size for estimating μ_θ.* An analytic formula for the variance of $\hat{\mu}_\theta$ was calculated in a classical, non-Bayesian framework (Appendix A). The resulting formula can be used to determine the effect of release numbers and the number of replicate pairs on the variance. Assuming that the same number are released in each group every year, i.e., $R_{1t} = R_{2t} = R$, simplifies the weights to w_t=$1/n$. The formula, in this case, for $\hat{\mu}_\theta$ (equation (26)) is:

$$\hat{\mu}_\theta = \frac{1}{n}\sum_{t=1}^{n}\hat{\theta}_t = \frac{1}{n}\sum_{t=1}^{n}\frac{y_{13,t}+y_{14,t}}{y_{23,t}+y_{24,t}}.$$

Calculation of the variance of $\hat{\mu}_\theta$ is quite lengthy and the details are provided in Appendix A. After some algebra the theoretical variance of $\hat{\mu}_\theta$ can be rewritten as follows:

$$V(\hat{\mu}_\theta) \approx \frac{1}{n}\left[\frac{X}{R}+\sigma_\theta^2\right], \tag{54}$$

where X is a long tedious calculation (see Appendix C, where X=$A + 0.5B$ and equation (62)).

For a given release number R and specified variance, the necessary number of years can be calculated:

$$n = \frac{\frac{X}{R}+\sigma_\theta^2}{V}. \tag{55}$$

Similarly for a fixed number of years n and specified variance, the necessary release numbers can be calculated:

$$R = \frac{X}{Vn-\sigma_\theta^2}. \tag{56}$$

One crucial factor in sample size determination is σ^2_θ. The output from a BHM fit (logit transformed θ with inverse gamma priors for the σ^2's) was used to estimate σ^2_θ. A median value for σ^2_ϵ of 1.05 and the median value for μ_θ of -0.40 were used to generate a sample of 1000 $logit(\theta)$'s. The inverse logit transformation was applied to calculate θ and the sample variance of θ, an estimate of σ^2_θ, was calculated to be 0.044. Also needed (in the "X" term) are values for the means and variances of the recovery probabilities at the two recovery locations. For the demonstration below values were chosen arbitrarily, but similar to estimated values from BHM fits to the real data.

Figure 34 is a plot of the number of replications, n, to achieve a range of desired standard errors for $\hat{\mu}_\theta$ based on $\sigma^2_\theta = 0.044$ and $R =$ 50,000, 75,000, or 150,000. The effect of numbers released (over this range of values) is minor in comparison to the number of years of experimentation. If σ^2_θ were smaller, then the relative importance of R would increase.

As a check on the theoretical calculations, the plotted values were compared to the bootstrap standard error for $\hat{\theta}$ in the Interior studies. There were 14 "years" of release pairings and the bootstrap standard error for $\hat{\theta}$ was 0.055. The mean number released at Georgiana Slough was 58,000 and at Ryde it was 45,000, so assume roughly 50,000 for both groups. If one plots the point (0.055, 14) on Figure 34, the point is very close to the line for R=50,000.

6.2.3. *DA 8: estimating* β_1. To study the effect of sample size (both n and R) on the precision of estimates of β_1, the slope coefficient in a linear model of the relative survival of Georgiana Slough releases regressed against exports (equation 29)), simulation of the data generation and data estimation was processes was used. To be consistent with a fully Bayesian analysis, `WinBUGS` would be used to generate samples from the posterior distribution for β_1 and calculate the standard deviations. This would be very computer intensive and take a considerable amount of time.

An approximate, but easier alternative was chosen. Recoveries were simulated according to the hierarchical model but the approximate indirect estimation procedure (which ignores unequal sampling and between pair variation) was used to estimate β_1. To simulate the recoveries the medians of the posterior distributions for the parameters (σ^2_θ, $\sigma^2_{r_{Ry\to CI}}$, $\sigma^2_{r_{Ry\to Oc}}$, β_0, and β_1) from one of the fitted BHMs were used. The export levels were randomly selected from a Uniform(1500, 11000) distribution, and then standardized using the mean (6376) and standard deviation (3284) of the observed data. The logit transform of θ was simulated using Equation 29. The fitted regression was of the logit transform of $\hat{\theta}$ on standardized exports.

The standard errors of $\hat{\beta}_1$ based on 10,000 simulations per combination of R and n are shown in Table 17. The `R` code is given in Appendix D.6. Again the standard errors are more sensitive to n than R, at least for $R \geq$ 50,000 per release. In relative terms the standard errors were large given that the true value of β_1 was 0.57; even with 25 release pairs with R=150,000, the coefficient of variation was 40% (0.228/0.57). Thus the between pair variation is the factor most affecting how easily a "significant" export effect can be detected. The coefficient of variation could be reduced to around 20% if $n = 100$ paired releases were made.

6.2.4. *VAMP: estimating regression coefficients for flow, exports, and HORB.* As for the DA 8 studies, linear regression coefficients are of primary interest. The analysis of sample size effects on estimates of coefficients discussed here is based on a version of a VAMP model that precedes those presented in this report (subsequently modified based on suggestions from reviewers). With the earlier version there were no branching probabilities at the head of Old River and survival between Mossdale and Dos Reis was modeled without explicit allowance for travel down Old River when the HORB was not in place. Due to time limitations, the sample size analysis was not repeated with the newer models. However, the analysis was based on data simulated from the earlier model and the general conclusions are expected to be consistent with what would be observed if the analysis were carried out using simulated data from the final VAMP models.

Data were simulated according to the following reach-specific survival probability models:

$$\begin{aligned}
logit(S_{DF\to MD}) &\sim \text{Normal}\left(\beta_0 + \beta_1 Flow, \sigma^2_{DF\to MD}\right)\\
logit(S_{MD\to DR}) &\sim \text{Normal}\left(\gamma_0 + \gamma_1 Flow + \gamma_2 I_{HORB} + \gamma_3 Exports \times (1 - I_{HORB}, \sigma^2_{MD\to DR}\right)\\
logit(S_{DR\to JP}) &\sim \text{Normal}\left(\xi_0 + \xi_1 Flow + \xi_2 I_{HORB} + \xi_3 Exports, \sigma^2_{DR\to JP}\right)
\end{aligned}$$

Again, for convenience, simulations from the hierarchical model were used to generate observations, then non-Bayesian estimates of the section-specific survival probabilities (or θs) were regressed, on a per river segment basis, against the relevant covariates.

The simulated model structure and parameter values are shown in Appendix D.7. A positive flow effect was assumed between Durham Ferry and Mossdale. To reduce the probability of maximum likelihood estimates being truncated at 1, the intercepts for the logit transforms were made relatively negative. For reporting the effect of sample sizes, the interquartile range was calculated instead of the standard deviation to lessen the impact of potentially skewed sampling distributions.

The results are shown in Table 18. Again number of replications of the release sets has a larger effect on the variability of point estimates than number released. The relative error, IQR/true value, tends to decrease the further downstream the releases are made. This is presumably due to the fact that more fish are providing information about survival for the lower reaches; e.g., from Dos Reis to Jersey Point there are the Dos Reis releases as well as surviving fish from the Durham Ferry and the Mossdale releases. This suggests that a more refined sample size determination could lead to fewer releases for further downstream releases relative to upstream releases.

6.3. **Acoustic tagging studies as an alternative.** Acoustic tagging experiments have been, and are currently being, conducted in the Sacramento-San Joaquin system. It would be worthwhile to make a cost and precision comparison between acoustic tagging and CWTs in terms of estimating survival probabilities and related parameters. Acoustic tags and receivers are quite expensive compared to CWTs; e.g., the cost for a single acoustic tag in early 2008 was around $300 while an individual CWT costs a fraction of a cent. On the other hand, detection probabilities using hydrophonic receivers are orders of magnitude greater than capture probabilities at Chipps Island, for example, and the precision of estimated survival probabilities, per number of fish, are considerably greater with acoustic tags compared to CWTs. Furthermore, acoustic tags combined with strategically placed receivers can more readily provide information about the out-migration route taken by the juvenile salmon. Statistical analysis procedures are not yet entirely worked out for such studies but Skalski, et al. (2002) and Muthukumarana, Schwarz and Swartz (2008) have developed methodologies for radio-tagged salmon that could be applicable to the Sacramento-San Joaquin system. The general features of BHMs would still be appropriate for multi-year studies using acoustic tags.

7. Conclusions and Recommendations

7.1. **Comparison with previous analyses.** The reanalysis of the four studies within a Bayesian hierarchical framework led to conclusions that were more often consistent with previous analyses than not and a comparison of the alternative analyses is summarized below. Major differences between previous analyses and the BHM analyses for all studies were that previous analyses did not account for unequal sampling variation and between release pair variation while the BHMs did.

(1) *DCC:* The analysis of Manly (2002) is more directly comparable to the hierarchical model than the previous USFWS analyses (Brandes and McLain, 2001). Manly used only Chipps Island recoveries and calculated survival indices (recovery rates adjusted by Chipps Island sampling effort). The ratio of the Courtland to Ryde survival indices when the gates were open was estimated to be 0.650, and 0.705 when the gates were closed. Using *t*-tests, Manly found no significant difference in these ratios.

The Bayesian hierarchical model analysis used Chipps Island and ocean recoveries simultaneously and, with the negative binomial formulation, allowed for overdispersion relative to binomial models. The *conclusions were similar to those of Manly*: survival for Courtland releases relative to Ryde releases appears to be lower with the gates open (median=0.54) than with the gates closed (median=0.75), with the median ratio of ratios equal to 0.72. The BHM median ratio of ratios was lower than Manly's implied value of 0.92 (0.650/0.705), but the BHM posterior 97.5 percentile value was over 5.

(2) *Interior:* Brandes and McLain (2001) had a shorter time series available when they did their analyses so results are not directly comparable with the BHM results. They analyzed the available recoveries from Georgiana Slough and Ryde releases of Chipps Island (using survival indices) and ocean recoveries separately. Based on paired *t*-tests of the null hypothesis of equal survival indices for Georgiana Slough and Ryde, they found statistically significant differences between the two release locations.

The Bayesian hierarchical model (while using Chipps Island and ocean recoveries simultaneously) led to *conclusions similar to Brandes and McLain*: Georgiana Slough releases have a lower survival probability than Ryde releases with the median value of the posterior distribution for the ratio of the survival probabilities equal to 0.36.

(3) *DA 8:* Again, using the shorter time series available at the time Brandes and McLain (2001) used an indirect approach (applied separately to Chipps Island and ocean recoveries, and using a combination of fall run and late fall run releases) to analyze

the effect of exports on the relative survival of Georgiana Slough releases. They found a statistically significant negative association between exports and survival.

The Bayesian hierarchical model (fitted only to the late fall run) used Chipps Island and ocean recoveries simultaneously, and modeled the relationship between exports and survival directly. The hierarchical model results again led to *conclusions similar to Brandes and McLain*: there is over a 98% probability that as exports increase the survival decreases for Georgiana Slough releases. The posterior median value for the slope coefficient was -0.31. This is just slightly less negative than a non-Bayesian indirect estimate of -0.39, where $logit(\hat{\theta})$ was regressed on exports. However, the intercept in the linear model regression survival against exports was considerably higher for the BHM than for the non-Bayesian models; thus the BHM was suggesting an overall higher relative survival for Georgiana Slough releases.

(4) *VAMP:* Previous analyses of VAMP and pre-VAMP data (2005 Annual Technical Report by San Joaquin River Group Authority) were carried out in a piecemeal fashion using several simple linear regressions of release-specific recovery rates against flow, exports, and flow/exports when HORB was either in or out (see Table 8. Also the recovery fractions for the freshwater recoveries (Antioch and Chipps Island combined) and ocean recoveries were analyzed separately, and releases at Durham Ferry and Mossdale were treated as a single release. The results were that with the HORB out, survival of releases above the head of Old River was *not* significantly related to flow, exports, or flow/exports (at α=0.05). However, with HORB in, survival of releases made above the head of Old River was significantly related to flow, but the relationship with exports and flow/exports was inconsistent and sometimes paradoxical (e.g., exports were positively associated with survival, weakly statistically significant using Antioch and Chipps Island recoveries and insignificant using ocean recoveries). The fact that the presence of the HORB affected the relationships with flow suggests an interaction between flow and HORB.

The Bayesian hierarchical model analyzed the multiple release and recovery data, including Antioch, Chipps Island, and ocean recoveries, simultaneously. Reach-specific survival probabilities were linked together, along with recovery probabilities at the three recovery sites. Logit transformations of survival and recovery probabilities were modeled with random effects and various covariates, particularly flow and exports, were tried. For the various models fitted, there were two in-common conclusions: (1) flow is positively associated with the probability of surviving from Dos Reis to Jersey Point and (2) the survival probability for that reach is generally greater than the survival probability for fish traveling down Old River. Assuming that the HORB effectively keeps out-migrating salmon from entering Old River, the second conclusion implies that the HORB can increase salmon survival. For fish that do enter Old River, there was some evidence that flow in Old River was positively associated with survival between Old River and Jersey Point, but the evidence was not as consistently strong as for the Dos Reis to Jersey Point reach. There was little evidence for any association between exports and survival, and what evidence there was pointed towards a somewhat surprising positive association with exports.

7.2. **Criticisms of and concerns about the BHMs.** The BHMs as formulated for the CWT release-recovery data do not provide the ultimate definitive explanations of what affects the survival of out-migrating juvenile Chinook salmon through the Delta, nor of the magnitude of effect of the factors of interest. Some of the limitations are inherent to CWT release-recovery data: the fish can only be captured once, the capture probabilities are relatively low, and information about out-migration paths through the Delta is difficult to acquire unless recoveries can be made at multiple locations.

Other limitations are a function of the accuracy of assumptions made, in particular, that capture probabilities are the same for temporally paired releases, relatedly that ocean survival, spatial-distribution, and maturation probabilities are the same for such paired releases, and, in the case of the VAMP model, that the survival in downstream sections is the same for all fish within a paired release that pass through the section. A potential violation of this last assumption could occur if downstream releases experienced some additional mortality at the time of release, such as might be caused by extreme differences in truck water temperatures and river water temperatures, a shock effect (Newman 2003), that is not experienced by fish released upstream that are passing by. Regarding the assumption of equal ocean capture probabilities, a relatively simple cluster analysis of catch recoveries (unpublished work) had been done prior to earlier analyses of Sacramento River releases (Newman and Rice 2002). The results suggested greater between release year variation than within release year variation, but a more rigorous examination may be fruitful.

The BHMs for the DCC, Interior, and Delta Action 8 studies are relatively simple and the number of models considered was relatively few. However, for the VAMP data, the number of models and complexity of models considered was much greater. The use of DIC to select amongst the different VAMP models is not entirely satisfying and the use of posterior model probabilities may be a better alternative (see comments by Giminez, et al. (in review)). A Reversible Jump MCMC add-on procedure for `WinBUGS`, which allows one to search through model space, is now available (`http://www.winbugs-development.org.uk/rjmcmc.html`) and might be usable for some of the BHMS considered. In short, a more thorough model selection procedure needs to be carried out, particularly for the VAMP models.

While acoustic tags and receivers are not necessarily a complete solution, due to occasional difficulty in successfully placing receivers in the Sacramento-San Joaquin system (Pat Brandes, personal communication), they potentially offer considerable advantages over CWT release-recovery data. First, multiple recaptures are possible, which thereby increases precision. Second, capture probabilities with acoustic receivers are sometimes two orders of magnitude greater than capture probabilities by a mid-water trawl. Third, judicious placement of receivers at junctions can provide information about out-migration paths that are much more difficult to determine using CWT data, which require trawling at the same junctions, and preferably the release of additional fish at those same points.

7.3. **Recommendations.** Recommendations on alternative data generation procedures were made earlier (Section 6.1). These recommendations are summarized briefly here along with additional recommendations.

(1) Use embedded replicate tags to check for violations of the assumption of independence between fish.
(2) Make releases below freshwater recovery locations, e.g., below Chipps Island, so as to allow separate estimation of capture probabilities at the recovery location.
(3) Carry out a more detailed analysis of the ocean catch recovery patterns by age-port-month of recovery to better determine how similar the recovery patterns are within paired releases.
(4) Carry out a benefit-cost comparison of CWTs and acoustic tags, including a comparison of the precision of estimates of survival probabilities per number of fish released.
(5) Specify an underlying probability model for any analyses of release-recovery data, and in the case of multi-year survival studies, in particular, formulate hierarchical probability models.
(6) Use such probability models *prior* to carrying out release-recovery experiments to evaluate design and sample size options.
(7) Estimate the sampling errors for estimated ocean recoveries and incorporate the errors into the probability model for observed and estimated recoveries; hierarchical models can be extended to another level to include such variation.
(8) Carry out a more rigorous model-selection procedure for the various VAMP models using Reversible Jump MCMC.

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TABLES

Table 1. Overview of the release and recovery locations, and duration, of the four studies.

Study	Duration	Primary Release Locations	Recovery Locations
DCC	1983-1989	Courtland and Ryde	Chipps Island, Ocean
Interior and DA 8	1994-present	Georgiana Slough and Ryde	Chipps Island, Ocean
VAMP (and pre-VAMP)	1985-present	Durham Ferry, Mossdale, Dos Reis, Jersey Point	Antioch, Chipps Island, Ocean

Table 2. Summary of notation for releases, recoveries, and model parameters.

Symbol	Definition
Ct, Ry, GS	release locations: Courtland, Ryde, Georgiana Slough
DF, MD, DR, JP	release locations (VAMP): Durham Ferry, Mossdale, Dos Reis, and Jersey Point
CI, Oc, A	recovery locations: Chipps Island, Ocean, and Antioch
R_a	number of fish released at location a
$y_{a\rightarrow b}$	number of recoveries at location b of CWT fish that were released at location a
$\hat{y}_{a\rightarrow Oc}$	estimated number of ocean recoveries of CWT fish that were released at location a
$\hat{r}_{a\rightarrow b}$	observed recovery fraction, $y_{a\rightarrow b}/R_a$
$S_{a\rightarrow b}$	probability of surviving between location a and location b
p_b	probability of capture at location b (given alive at that location)
$logit(\pi)$	logistic transform of a probability, π, $\log\left(\frac{\pi}{1-\pi}\right)$
μ_θ	expected (average) value of a random variable θ
σ^2_θ	standard deviation of a random variable θ
	Notation used in DCC BHM
$\theta(DCC)$	$S_{Ct\rightarrow CI}/S_{Ry\rightarrow CI}$, which varies as a function of DCC gate position
$I_{DCC=closed}$	indicator variable that equals 1 when DCC gate is closed, else equals 0
β_0, β_1	intercept and slope in logit model for $\theta(DCC)$, E[$logit(\theta(DCC))$]=$\beta_0 + \beta_1 I_{DCC=closed}$
$r_{Ry\rightarrow CI}$	Pr(fish released from Ryde survives to and is captured at Chipps Island)
$r_{Ry\rightarrow Oc}$	Pr(fish released from Ryde survives to and is captured in the ocean)
	Notation used in Interior BHM
θ	$S_{GS\rightarrow CI}/S_{Ry\rightarrow CI}$
$r_{Ry\rightarrow CI}$	Pr(fish released from Ryde survives to and is captured at Chipps Island)
$r_{Ry\rightarrow Oc}$	Pr(fish released from Ryde survives to and is captured in the ocean)
	Notation used in Delta Action 8 BHM
β_0, β_1	intercept and slope in logit model for θ (as a function of standardized exports), E[$logit(\theta)$]=$\beta_0 + \beta_1\left(\frac{(Exports-\overline{Exp})}{s_{Exp}}\right)$
	Notation used in VAMP BHM
$r_{JP\rightarrow A}$	Pr(fish released from JP survives to and is captured at Antioch)
$r_{JP\rightarrow CI}$	Pr(fish released from JP survives to and is captured at Chipps Island)
$r_{JP\rightarrow Oc}$	Pr(fish released from JP survives to and is captured in Ocean)
β	parameter(s) for E[logit($S_{DF\rightarrow MD}$)]
γ	parameter(s) for E[logit($S_{MD\rightarrow DR}$)]
ξ	parameter(s) for E[logit($S_{DR\rightarrow JP}$)]
ζ	parameter(s) for E[logit($S_{OR\rightarrow JP}$)]

TABLE 3. DCC: Release and recovery data. Recoveries at Chipps Island, in the ocean fisheries, and at the SWP and CVP fish salvage facilities are in the columns headed CI, Oc, and FF, respectively. Ryde releases were occasionally made at Isleton and some of the Port Chicago releases were actually at Benicia.

		Tag Codes			DCC	Courtland				Ryde				Pt.Chicago	
Year	Grp	Courtland	Ryde	Pt Chicago	Gate	R_{Ct}	CI	Oc	FF	R_{Ry}	CI	Oc	FF	R_{PC}	Oc
1983	1	06-62-24	06-62-23	06-62-30	closed	96,706	89	428	0	92,693	96	368	0	43,374	129
1987	2	06-62-53:54	06-62-55	NA	closed	100,302	73	1981	182	51,103	47	1607	0	NA	NA
1988	3	B6-14-02:03	06-31-01	B6-14-08	closed	107,249	151	1188	1075	52,741	104	1076	0	55,265	1115
1988	4	06-62-59:60	06-62-63	06-31-04	closed	106,901	37	1037	0	53,961	44	252	0	54,151	1022
1984	5	06-62-27	06-62-29,06-42-09	06-62-31,06-62-37	open	62,604	37	399	0	59,998	38	268	0	42,000	316
1985	6	06-62-38,06-62-41	06-62-35	06-62-45	open	100,626	38	313	0	107,161	89	926	0	48,143	465
1986	7	06-62-43	06-62-48	06-62-51	open	98,866	39	1692	8	101,320	75	1979	0	47,995	1377
1987	8	06-62-56:57	06-62-58	NA	open	100,919	43	1434	187	51,008	47	1039	0	NA	NA
1988	9	B6-14-04:05	06-31-02	B6-14-08	open	102,480	145	936	450	53,238	145	1324	0	55,265	1115
1988	10	06-62-50	06-31-03	06-31-04	open	99,827	5	70	0	53,942	38	285	0	54,151	1022
1989	11	06-31-11	06-31-12	NA	open	51,211	46	240	26	51,046	58	417	18	NA	NA
1989	12	06-31-08	06-31-07	06-31-09	open	50,659	19	41	0	50,601	26	82	0	45,446	181
1989	13	06-01-14-01-03,06-58-05	06-01-14-01-02	06-01-14-01-04	open	90,720	21	84	0	51,134	8	10	0	48,329	352

TABLE 4. Interior and DA 8: Release and recovery data. Recoveries at Chipps Island, in the ocean fisheries, at the SWP and CVP fish salvage facilities, and at Inland locations (expanded numbers) are in the columns headed CI, Oc, FF, and IL, respectively. Ryde releases were occasionally made at Isleton (denoted by asterisk by tag code) and some of the Port Chicago releases were actually at Benicia (denoted by asterisk by tag code). Exports are a three day average volume of water exported from SWP and CVP.

Release		Tag Codes			Georgiana Slough					Ryde						Pt.Chicago	
Date	Grp	Georg.Sl.	Ryde	Pt Chicago	R_{GS}	CI	Oc	FF	IL	R_{Ry}	CI	Oc	FF	IL	Exports	R_{PC}	Oc
12/02/93	1	06-45-21	06-45-22	NA	33,668	5	80	248	12	34,650	37	292	10	36	10,434	NA	NA
12/05/94	2	05-34-25	05-34-26*	NA	31,532	4	11	87	8	30,220	15	29	6	13	5,988	NA	NA
01/04-05/95	3	06-25-25	06-25-24*	NA	31,328	2	101	837	53	31,557	13	266	231	138	10,403	NA	NA
01/10-11/96	4	05-41-13	05-41-14	05-41-11	33,670	5	146	768	9	30,281	21	240	12	23	9,523	34,596	265
12/04-05/97	5	05-50-50	05-50-60	05-50-61	61,276	2	7	153	4	46,756	22	41	18	11	10,570	48,080	141
01/13-14/97	6	05-50-49	05-50-62	”	66,893	18	240	24	51	49,059	48	167	0	70	3,887	”	”
12/01-02/98	7	05-23-08	05-23-20	05-23-22	69,180	12	173	28	44	48,207	30	182	0	102	1,868	45,195	140
12/29-30/98	8	05-23-12	05-23-21	”	68,843	12	150	48	54	48,804	17	156	0	88	1,984	”	”
12/10-11/99	9	05-51-30	05-51-32*	05-51-34	65,517	3	43	24	9	53,426	16	128	0	20	3,237	49,208	274
12/20-21/99	10	05-51-31	05-51-33*	”	64,515	21	151	82	32	49,341	19	161	4	66	4,010	”	”
01/03-05/02	11	05-07-76	05-07-67	05-07-68	77,053	18	248	390	110	52,327	34	520	18	366	7,789	47,876	314
12/05-06/02	12	05-10-98,05-11-68	05-11-67	05-11-66	90,219	1	68	700	10	49,629	18	147	42	15	5,007	47,048	458
12/09-10/03	13	05-17-71:72	05-17-81:82	05-17-80*	68,703	5	50	306	2	45,981	13	128	24	12	4,016	24,785	156
12/08-09/04	14	05-22-92:93	05-22-80:81	05-22-82	72,082	10	NA	0	NA	50,397	28	NA	0	NA	6,092	25,132	NA
12/08-09/05	15	05-27-84:87	05-27-88:91	05-27-94,95	70,414	6	NA	165	NA	51,017	23	NA	12	NA	10,837	NA	NA

TABLE 5. VAMP: Release and recovery data from pre-VAMP (1985-1991, 1994-1999) and VAMP (2000-2006) studies. Recovery locations are Antioch (Ant), Chipps Island (CI), ocean fisheries (Oc), and the SWP and CVP fish salvage facilities (FF). Stock designations FRH and MRFF denote Feather River Hatchery and Merced River Fish Facility (excepting group 4, all releases in same group have same stock). Flow and Exports (Exp) column headings DF, MD, DR, and UOR are for Durham Ferry, Mossdale, Dos Reis, and Upper Old River. Flows, exports, p_{OR}, and temperature are defined in Table 6.

Group No.	Stock	Release Location	Release Date	Tag Codes	Release Number	Recovery Location Ant	CI	Oc	FF	HORB	DF Flow	MD Flow	DR Flow	UOR Flow	MD Exp	DR Exp	p_{OR}	Temp
1	MRFF	Dos Reis	4/30/85	Yellow	149968	—	94	—	4450	Out	—	—	384	—	—	5794	81	21.1
		Old River	4/29/85	Red	150048	—	99	—	37299		—	2475	—	1928	5257	5709		21.1
2	MRFF	Dos Reis	5/29/86	064658,B61101	95595	—	36	2068	2960	Out	—	—	2442	—	—	5626	73	20.0
		Old River	5/30/86	064659,B61102	100181	—	21	1139	62564		—	7140	—	4842	4096	5626		21.1
3	MRFF	Dos Reis	4/27/87	06450:3,4,5	92612	—	79	1219	5469	Out	—	—	391	—	—	5856	90	21.1
		Old River	4/27/87	06450:6,7,8	90952	—	17	500	24019		—	2480	—	2057	7370	5856		22.2
4	MRFF	Dos Reis	5/02/89	06011101:07,08,13	76073	—	12	78	428	Out	—	—	577	—	—	1798	66	21.7
		Old River	5/03/89	060111010:4-6	74341	—	4	16	1439		—	2500	—	1522	1797	1798		21.7
	FRH	Jersey Pt	5/05/89	06011101:09,10	56233	—	56	283	824		—	—	—	—	—	—		20.0
5	FRH	Dos Reis	4/20/89	063114	52962	—	11	34	2714	Out	—	—	-17	—	—	10212	104	20.6
		Old River	4/21/89	063113	51972	—	5	38	2916		—	1945	—	2049	10295	10212		19.5
		Jersey Pt	4/24/89	060111011:1-2	56816	—	53	180	144		—	—	—	—	—	—		17.8
6	FRH	Dos Reis	4/16/90	060114010:7-8	105742	—	4	23	1766	Out	—	—	48	—	—	9597	119	20.0
		Old River	4/17/90	060114010:5-6	106267	—	2	14	2613		—	1400	—	1060	9400	9597		21.1
		Jersey Pt	4/18/90	0601140109	52962	—	32	224	156		—	—	—	—	—	—		17.2
7	FRH	Dos Reis	5/02/90	060114011:0-1	103533	—	4	34	150	Out	—	—	431	—	—	2353	84	20.0
		Old River	5/03/90	060111011:2-3	103595	—	1	11	1346		—	1400	—	934	3276	2242		22.2
		Jersey Pt	5/04/90	063119	50143	—	56	204	62		—	—	—	—	—	—		20.0
8	FRH	Dos Reis	4/15/91	060114011:4-5	102999	—	17	86	7130	Out	—	—	-49	796	—	5990	126	15.6
		Jersey Pt	4/19/91	0601140206	52139	—	94	358	331		—	—	—	—	—	—		17.2
9	FRH	Mossdale	4/11/94	0601140315	51804	—	0	62	705	Out	—	1580	466	1018	2087	1725	67	17.2
		Jersey Pt	4/13/94	0601140403	50689	—	10	420	14		—	—	—	—	—	—		17.8
10	FRH	Mossdale	4/26/94	0601140404	50726	—	2	89	0	In	—	3115	2891	0	1120	1598	11	15.6

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Group No.	Stock	Release Location	Release Date	Tag Codes	Release Number	Recovery Location				HORB	DF Flow	MD Flow	DR Flow	UOR Flow	MD Exp	DR Exp	p_{OR}	Temp
						Ant	CI	Oc	FF									
		Jersey Pt	4/27/94	0601140408	53810	—	16	756	0		—	—	—	—	—	—		17.2
11	FRH	Mossdale	4/17/95	0601140:414,501	100969	—	20	461	2682	Out	—	18700	8267	9192	3707	3684	55	13.9
		Dos Reis	4/17/95	0601140412	50848	—	8	234	0		—	—	8267	—	—	3684		13.9
		Jersey Pt	4/19/95	0601140413	50779	—	26	280	0		—	—	—	—	—	—		15.6
12	FRH	Mossdale	5/05/95	06315:0-1	102562	—	13	392	1883	Out	—	21250	9316	9801	3770	3958	58	16.7
		Dos Reis	5/05/95	063147	52097	—	21	393	0		—	—	9316	—	—	3958		17.2
13	FRH	Mossdale	5/17/95	0601140504, 63148	1041245	—	8	353	1628	Out	—	23100	9545	10066	3507	4209	59	17.2
		Dos Reis	5/17/95	063149	51665	—	9	245	12		—	—	9545	—	—	4209		18.3
14	FRH	Mossdale	4/15/96	060106011:4-5	100742	—	2	100	1084	Out	—	6665	3296	3499	2040	1614	53	15.6
		Jersey Pt	4/18/96	0601060113	50041	—	25	332	0		—	—	—	—	—	—		16.7
15	FRH	Mossdale	4/30/96	060106020:1,5	99656	—	1	26	1432	Out	—	6565	3113	3378	1660	1629	52	17.8
		Dos Reis	5/01/96	0601060:110,203	98638	—	3	67	0		—	—	3113	—	—	1629		17.2
		Jersey Pt	5/03/96	0601060109	50820	—	24	311	12		—	—	—	—	—	—		17.8
16	MRFF	Dos Reis	5/01/96	0601110:412-415	107961	—	10	58	0	Out	—	—	3113	3378	—	1629	52	17.2
		Jersey Pt	5/03/96	0601110501	51737	—	39	186	0		—	—	—	—	—	—		18.9
17	FRH	Mossdale	4/28/97	060106030:2-3	48730	—	10	329	226	In	—	6135	4709	284	2330	2329	16	16.1
		Dos Reis	4/29/97	060106030:4-5	49784	—	10	259	125		—	—	4709	—	—	2329		15.6
		Jersey Pt	5/02/97	060106020:7-8	49815	—	55	697	12		—	—	—	—	—	—		17.2
18	MRFF	Dos Reis	4/29/97	06254:5,6	102431	—	16	348	394	In	—	—	4709	284	—	2329	16	15.6
		Jersey Pt	5/02/97	062547	51540	—	27	355	24		—	—	—	—	—	—		17.8
19	MRFF	Dos Reis	5/08/97	062548	46682	—	5	90	78	In	—	—	4740	268	—	2410	21	17.2
		Jersey Pt	5/12/97	062549	47208	—	18	192	14		—	—	—	—	—	—		19.4
20	MRFF	Mossdale	4/16/98	06011108:09-11	77430	—	88	157	48	Out	—	24950	9645	10356	805	1722	60	13.9
		Dos Reis	4/17/98	06011108:06-08	77180	—	93	145	0		—	—	9645	—	—	1722		15.0
		Jersey Pt	4/20/98	06011108:12-13	50050	—	187	201	0		—	—	—	—	—	—		17.2

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Group No.	Stock	Release Location	Release Date	Tag Codes	Release Number	Recovery Location				HORB	DF Flow	MD Flow	DR Flow	UOR Flow	MD Exp	DR Exp	p_{OR}	Temp
						Ant	CI	Oc	FF									
21	FRH	Mossdale	4/23/98	060106050:5-6	33800	—	7	13	192	Out	—	20250	8447	9404	1932	1926	57	18.9
		Dos Reis	4/24/98	060114060:6-7	47874	—	17	56	0		—	—	8447	—	—	1926		18.9
		Jersey Pt	4/28/98	060106050:3-4	31091	—	40	47	0		—	—	—	—	—	—		18.9
22	MRFF	Mossdale	4/19/99	06264:2-4	74646	—	36	395	2940	Out	—	6905	3180	3429	2683	3105	55	16.7
		Dos Reis	4/19/99	06264:5-6	49636	—	39	376	185		—	—	3180	—	—	3105		17.2
		Jersey Pt	4/21/99	062647, 0601110815	48907	—	59	715	60		—	—	—	—	—	—		17.2
23	MRFF	Durham F.	4/17/00	06040:1-2,64563	72094	27	28	693	521	In	6690	6995	5918	296	2265	2366	18	13.9
		Mossdale	4/18/00	06440:1-2	46111	30	18	381	457		—	6995	5918	—	2265	2366		13.3
		Jersey Pt	4/20/00	06440:3-4	51098	97	65	1353	0		—	—	—	—	—	—		17.8
24	MRFF	Durham F.	4/28/00	060106091:4-5, 601110814	74001	31	22	162	279	In	5665	5969	5062	560	2238	2196	11	17.2
		Jersey Pt	5/01/00	060106100:1-2	49871	152	78	589	6		—	—	—	—	—	—		17.2
25	MRFF	Durham F.	4/30/01	0644:29-31	68192	76	53	366	84	In	4125	4170	3630	687	1475	1482	12	21.7
		Mossdale	5/01/01	06443:2-3	44923	33	31	232	48		—	4170	3630	—	1475	1482		19.4
		Jersey Pt	5/04/01	06443:4-5	49161	329	111	1031	0		—	—	—	—	—	—		20.0
26	MRFF	Durham F.	5/07/01	06443:6-8	71744	29	9	92	39	In	4135	4145	3610	654	1566	1495	12	18.9
		Mossdale	5/08/01	0644:39-40	48888	19	8	52	36		—	4145	3610	—	1566	1495		21.1
		Jersey Pt	5/11/01	06444:1,2	51107	96	44	581	0		—	—	—	—	—	—		22.8
27	MRFF	Durham F.	4/18/02	06447:1-4	97318	63	21	270	207	In	3165	3255	2671	549	1536	1532	19	15.0
		Mossdale	4/19/02	06445:7-8	50411	42	13	145	234		—	3255	2671	—	1536	1532		13.9
		Jersey Pt	4/22/02	0644:59-60	48496	190	83	951	48		—	—	—	—	—	—		18.0
28	MRFF	Durham F.	4/25/02	0644:70,75-77	98082	18	15	58	175	In	3356	3356	2814	570	1523	1507	20	17.0
		Mossdale	4/26/02	06447:8-9	48924	7	5	40	129		—	3356	2814	—	1523	1507		17.5
		Jersey Pt	4/30/02	06448:0-1	46469	75	46	597	0		—	—	—	—	—	—		17.5
29		Durham F.	4/21/03	06028:2-3,62742	74377	6	3	19	51	In	3430	3345	2904	297	1494	1497	7	15.0
		Mossdale	4/22/03	06274:3,8	49827	4	5	8	0		—	3345	2904	—	1494	1497		15.2
		Jersey Pt	4/25/03	062744	24441	71	57	263	0		—	—	—	—	—	—		16.5
30	MRFF	Durham F.	4/28/03	06274:5-7	74491	0	0	10	24	In	3370	3370	3017	299	1481	1479	11	16.5
		Mossdale	4/29/03	0627:49-50	48317	0	1	5	12		—	3370	3017	—	1481	1479		15.7
		Jersey Pt	5/02/03	062751	25732	35	39	415	0		—	—	—	—	—	—		15.0
31	MRFF	Durham F.	4/22/04	06275:2-5	91867	2	3	3	96	In	3170	3160	2831	297	1483	1483	11	15.5

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Group	Stock	Release	Release	Tag	Release	Recovery Location				HORB	DF	MD	DR	UOR	MD	DR	p_{OR}	Temp
No.		Location	Date	Codes	Number	Ant	CI	Oc	FF		Flow	Flow	Flow	Flow	Exp	Exp		
		Mossdale	4/23/04	064670,06458:2-3	73258	1	3	2	30		—	3160	2831	—	1483	1483		17.0
		Jersey Pt	4/26/04	064580	22708	22	25	117	12		—	—	—	—	—	—		21.5
32	MRFF	Durham F.	5/02/05	06467:2-5	93833	6	12	—	1527	Out	8250	8195	3743	3934	1961	2293	56	16.0
		Dos Reis	5/03/05	064591,06469:7,8	69125	7	3	—	7		—	—	3743	—	—	2293		17.0
		Jersey Pt	5/06/05	064588	22767	31	32	—	0		—	—	—	—	—	—		18.0
33	MRFF	Durham F.	5/09/05	06458:4-6	91563	7	6	—	844	Out	8940	9085	4147	4529	2303	2300	55	14.9
		Dos Reis	5/10/05	0645:89-90, 064699	68646	7	6	—	6		—	—	4147	—	—	2300		15.0
		Jersey Pt	5/12/05	064700	23231	27	38	—	0		—	—	—	—	—	—		19.0
34	MRFF	Mossdale	5/04/06	06471:3-4	48828	9	9	—	18	Out	—	29350	10756	11130	1538	1544	61	18.0
		Dos Reis	5/05/06	064716	25463	3	7	—	0		—	—	10756	—	—	1544		17.5
		Jersey Pt	5/06/06	064715	26119	26	58	—	0		—	—	—	—	—	—		19.0
35	MRFF	Mossdale	5/19/06	0647:2-3	73764	0	8	—	48	Out	—	24650	10018	10423	6283	6046	59	19.5
		Jersey Pt	5/22/06	064724	24757	14	44	—	0		—	—	—	—	—	—		19.5

TABLE 6. VAMP: Definitions of covariates used in modeling (and listed in Table 5). DAYFLOW is a California Department of Water Resources (CDWR) database and DSM2 is a CDWR model; Yiguo Liang and Min Yu (personal communication) supplied the DSM2 model-based values. Vernalis is 6 miles upstream of Durham Ferry.

Covariate	Definition	Source
DF Flow	Mean flow at Vernalis for day of and day after release at Durham Ferry.	DAYFLOW
MD Flow	Mean flow at Vernalis for day of and day after release at Mossdale.	DAYFLOW
DR Flow	Median flow at Stockton for 8 days starting on day of release at Dos Reis. In absence of Dos Reis release, day of release = day of a Mossdale release or day after a Durham Ferry release.	
UOR Flow	Median (Vernalis Flow- Stockton Flow) starting on day of release at Upper Old River, Dos Reis, or Mossdale, in that order of priority. For group 24, started day after release at Durham Ferry	1985-1989: Vernalis Flow (DAYFLOW) Stockton Flow (DWR equ'ns) 1990-2006: Flows (DSM2)
MD Exp	Mean of combined CVP and SWP exports for the day of and day after release at Mossdale.	
DR Exp	Median of combined CVP and SWP exports for 8 days starting on day of release at Dos Reis.	
p_{OR}	Proportion of San Joaquin River flow diverted into Old River = 1-(Dos Reis or Stockton flow)/Vernalis flow calculated for day of Mossdale or upper Old River release, or day before a Dos Reis release, or day after a Durham Ferry release.	1985-1989: Dos Reis, Stockton Flows (DWR equ'ns Vernalis Flow (DAYFLOW) 1990-2006: Dos Reis, Stockton Flows (DSM2)
Temp	Temperature (in Celcius) in the river at the release site	

Table 7. VAMP: Year specific schematic of the release and recovery locations in the VAMP and related San Joaquin studies since 1985. Release locations (marked by R) are Durham Ferry (DF), Mossdale (MD), Old River (OR), Dos Reis (DR), and Jersey Point (JP). Recovery locations (marked by X) are Antioch (Ant), Chipps Island (CI), and ocean fisheries (Oc). X* denotes recoveries that are not yet available.

		Release Locations					Recovery Locations			
Group	Year	DF	MD	OR	DR	JP	Ant	CI	Oc	#Obs'ns
1	1985			R	R			X		2
2	1986			R	R			X	X	4
3	1987			R	R			X	X	4
4	1989			R	R	R		X	X	6
5	1989			R	R	R		X	X	6
6	1990			R	R	R		X	X	6
7	1990			R	R	R		X	X	6
8	1991				R	R		X	X	4
9	1994		R			R		X	X	4
10	1994		R			R		X	X	4
11	1994		R		R	R		X	X	6
12	1995		R		R			X	X	4
13	1995		R		R			X	X	4
14	1996		R			R		X	X	4
15	1996		R		R	R		X	X	6
16	1996				R	R		X	X	4
17	1997		R		R	R		X	X	6
18	1997				R	R		X	X	4
19	1997				R	R		X	X	4
20	1998		R		R	R		X	X	6
21	1998		R		R	R		X	X	6
22	1999		R		R	R		X	X	6
23	2000	R	R			R	X	X	X	9
24	2000	R				R	X	X	X	6
25	2001	R	R			R	X	X	X	9
26	2001	R	R			R	X	X	X	9
27	2002	R	R			R	X	X	X	9
28	2002	R	R			R	X	X	X	9
29	2003	R	R			R	X	X	X	9
30	2003	R	R			R	X	X	X	9
31	2004	R	R			R	X	X	X	9
32	2005	R			R	R	X	X	X*	6
33	2005	R			R	R	X	X	X*	6
34	2006		R		R	R	X	X	X*	6
35	2006		R			R	X	X	X*	4

Table 8. VAMP: Summary of analyses in 2005 Annual Technical Report for San Joaquin River Agreement. Response variable, $RR_{a/b \to c}$, denotes ratio of recovery fractions at location c from releases at location a and location b. Abbreviations are DF (Durham Ferry), MD (Mossdale), DR (Dos Reis), JP (Jersey Point), Ant (Antioch), CI (Chipps Island), and Oc (ocean fisheries). Sign refers to the slope coefficient. The P-value refers to a test that the slope coefficient equals 0.

Response variable	Covariate(s)	Sign	P-value	R^2	n
$RR_{(DF+MD)/JP \to Ant+CI}$	Vernalis Flow (HORB in)	+	< 0.01	0.50	15
$RR_{(DF+MD)/JP \to Ant+CI}$	Vernalis Flow (HORB out)	+	> 0.10	0.29	8
$RR_{(DF+MD)/JP \to Ant+CI}$	Vernalis Flow/Exports (HORB in)	+	< 0.02	0.30	18
$RR_{(DF+MD)/JP \to Ant+CI}$	CVP+SWP Exports (HORB out)	+	< 0.10	0.38	9
$RR_{(DF+MD)/JP \to Oc}$	Vernalis Flow (HORB in)	+	< 0.01	0.58	15
$RR_{(DF+MD)/JP \to Oc}$	Vernalis Flow (HORB out)	+	> 0.10	0.36	7
$RR_{(DF+MD)/JP \to Oc}$	Vernalis Flow/Exports (HORB in)	+	< 0.10	0.20	17
$RR_{(DF+MD)/JP \to Oc}$	CVP+SWP Exports (HORB out)	+	> 0.10	0.40	7
$RR_{MD/JP \to Ant+CI}$	Vernalis Flow/Exports (HORB out)	+	> 0.10	0.10	9
$RR_{MD/JP \to Oc}$	Vernalis Flow/Exports (HORB out)	+	> 0.10	0.08	6
$RR_{DR/JP \to Ant+CI}$	Modeled SJ Flow	+	> 0.10	0.19	12
$RR_{DR/JP \to Oc}$	Modeled SJ Flow	+	< 0.01	0.64	12

TABLE 9. DCC: Summary of BHMs fit and model selected for inference. Top table compares DIC values for several BHMs. Column headed $f(\theta)$ refers to the transformation used and column headed σ's refers to the priors used for standard deviations of random effects. The column headed by $\frac{\theta_{Open}}{\theta_{Closed}}$ gives the posterior median of the ratios. Bottom table contains summaries for the model selected for inference. The σ^2 values are the posterior medians for σ^2_θ, $\sigma^2_{\mu_{Ry\to CI}}$, and $\sigma^2_{\mu_{Ry\to Oc}}$.

Level 1 Dist'n	$f(\theta)$	σ's	DIC	$\frac{\theta_{Open}}{\theta_{Closed}}$
Negative Binomial	log	Uniform	567.3	0.73
Multinomial	logit	Uniform	649.8	0.94
Multinomial (correlated))	logit	Inv. Wishart	655.1	0.96

Negative Binomial, log θ, Uniform priors for σ

		Percentiles			
Parameter	Mean	0.025	0.50	0.975	σ^2
β_0	-0.62	-1.06	-0.62	-0.13	
β_1	0.32	-0.56	0.32	1.18	
θ (open)	0.69	0.13	0.54	2.20	0.62^2
θ (closed)	1.00	0.17	0.75	3.33	0.62^2
θ(open)/θ(closed)	1.32	0.09	0.73	5.67	
k_{CI}	492.9	17.1	492.1	974.7	
k_{Oc}	16.9	2.68	7.12	25.1	
$\mu_{Ry\to CI}$	-7.09	-7.49	-7.09	-6.71	0.67^2
$\mu_{Ry\to Oc}$	-4.82	-5.57	-4.82	-4.06	1.24^2
$r_{Ry\to CI}$	0.0011	0.0002	0.0008	0.0037	
$r_{Ry\to Oc}$	0.0195	0.0005	0.0081	0.1108	

TABLE 10. Interior: Summary of BHMs fit and model selected for inference. Top table compares DIC values for several BHMs and the mean posterior predicted survival of Georgiana Slough relative to Ryde survival ($\overline{\theta}$). Column headed $f(\theta)$ refers to the transformation of θ used and column headed σ's refers to the priors used for standard deviations of random effects (the inverse gamma is actually the gamma on the precision, inverse of σ^2). Bottom table contains summaries for the model selected for inference. The σ^2 values are the posterior medians for σ^2_θ, $\sigma^2_{\mu_{Ry\to CI}}$, and $\sigma^2_{\mu_{Ry\to Oc}}$.

Level 1 Dist'n	$f(\theta)$	σ's	DIC	$\overline{\theta}$
Multinomial	log	Uniform	427.6	0.44
Multinomial	log	Inv. Gamma	427.6	0.43
Multinomial	logit	Inv. Gamma	428.2	0.42
Multinomial	logit	Uniform	428.3	0.42
Multinomial (correlated)	logit	Inv. Wishart	428.8	0.41
Negative Binomial	log	Uniform	441.7	0.42

Multinomial, log θ, Uniform priors for σ

		Percentiles			
Parameter	Mean	0.025	0.50	0.975	σ^2
μ_θ	-1.02	-1.35	-1.02	-0.70	0.50^2
$\mu_{Ry\to CI}$	-7.72	-7.94	-7.72	-7.51	0.36^2
$\mu_{Ry\to Oc}$	-5.61	-6.11	-5.61	-5.12	0.88^2
θ	0.44	0.10	0.36	1.26	
$r_{Ry\to CI}$	0.0005	0.0002	0.0004	0.0009	
$r_{Ry\to Oc}$	0.0057	0.0006	0.0036	0.0226	

TABLE 11. DA 8: Posterior distribution summaries for the multinomial model (with log transformed θ and uniform priors on the σ's). The σ^2 values are the posterior medians of σ^2_θ, $\sigma^2_{r_{Ry\to CI}}$, and $\sigma^2_{r_{Ry\to Oc}}$.

		Percentiles			
Parameter	Mean	0.025	0.50	0.975	σ^2
β_0	-1.05	-1.38	-1.04	-0.75	
β_1	-0.29	-0.61	-0.28	0.02	0.54^2
$\mu_{Ry\to CI}$	-7.72	-7.94	-7.72	-7.65	0.36^2
$\mu_{Ry\to Oc}$	-5.61	-6.08	-5.61	-5.07	0.86^2
$r_{Ry\to CI}$	0.0005	0.0002	0.0004	0.0010	
$r_{Ry\to Oc}$	0.0057	0.0006	0.0036	0.0227	

TABLE 12. DA 8: Comparison of BHM and non-Bayesian estimates of release pair-specific θ, ratio of the Georgiana Slough survival probability to the Ryde survival probability. BHM values are mean and standard deviation of posterior distribution. Non-Bayesian values are the MLEs (maximum likelihood estimates) and standard errors (using the delta method). Ratio of survival indices is based upon the Chipps Island recoveries alone (Pat Brandes, personal communication).

	BHM		Non-Bayesian		Ratio of
Group	Mean	Std Dev	MLE	Std Error	Survival Indices
1	0.27	0.032	0.27	0.032	0.14
2	0.33	0.085	0.33	0.098	0.27
3	0.37	0.041	0.37	0.043	0.16
4	0.51	0.052	0.52	0.053	0.26
5	0.14	0.041	0.11	0.039	0.05
6	0.87	0.080	0.88	0.081	0.28
7	0.61	0.060	0.61	0.061	0.24
8	0.65	0.069	0.66	0.072	0.72
9	0.27	0.044	0.26	0.044	0.16
10	0.72	0.075	0.73	0.078	0.67
11	0.33	0.024	0.33	0.024	0.31
12	0.24	0.033	0.23	0.033	0.04
13	0.27	0.041	0.26	0.041	0.28
14	0.30	0.089	0.25	0.226	0.32
15	0.22	0.076	0.19	0.298	0.16

Table 13. VAMP: Comparison of DIC values for simple models with and without random effects. Only covariate is an indicator variable for HORB in a logit transformation of $S_{DR \to JP}$.

Model Class	DIC
No Random Effects	25,000
Recovery random effects	4,300
Survival and recovery random effects	1,500

Table 14. VAMP: Comparison of model results for p_{OR} known, multinomial distributions, logit θ's, and Uniform priors for σ's. When entries under S are decimals, the value shown is the posterior median probability of survival. When entries contain covariate names, the reported percentage is the posterior probability that the flow coefficient is positive or that the exports coefficient is negative.

Label	$S_{DF \to MD}$	$S_{DR \to JP}$	$S_{OR \to JP}$	DIC
Null.Null.Null	0.62	0.21	0.09	1499.1
Null.FE.FE	0.63	Flow: 89%+ Exports: 21%-	Flow: 65%+ Exports: 33%-	1474.8
Null.F.Null	0.63	Flow: 86%+	0.10	1491.4
Null.F.Null.Stk 0.63 (Stock, 100%+)	Flow: 90%+	0.10	1494.5	

Table 15. Recoveries from replicate releases made at Durham Ferry and χ^2 tests of homogeneity. χ^2 values are based on Antioch, Chipps Island, and Ocean recoveries. P-values were calculated by Monte Carlo simulations; P-values were calculated with Antioch, Chipps Island, and Ocean categories (w/ ocean) and with Antioch and Chipps Island categories (w/o ocean). Number in parentheses next to year is the release set number.

						P-Values	
Set	R	y_{Ant}	y_{CI}	y_{Oc}	χ^2	w/ ocean	w/o Oc
2000 (19)							
60401	23529	6	7	217			
60402	24177	10	10	232			
64563	24457	11	11	247	3.1	0.80	0.70
2001 (21)							
64429	23351	28	14	96			
64430	22720	30	22	159			
64431	22376	18	17	112	24.0	<0.01	0.27
2001 (22)							
64436	24029	8	2	17			
64437	23907	11	5	47			
64438	24054	10	2	28	17.8	<0.01	0.64
2002 (23)							
64471	23920	11	4	33			
64472	23920	20	9	96			
64473	23872	12	4	73			
64474	24747	20	4	68	34.6	<0.01	0.32
2002 (24)							
64470	24680	6	3	23			
64475	24659	2	5	22			
64476	24783	4	3	8			
64477	24381	6	4	6	19.6	0.02	0.78

TABLE 16. Estimated capture probabilities at Chipps Island for the DCC and Interior/DA 8 studies (based on ocean recoveries of Port Chicago releases).

DCC

Year	Tag Code	Ct	Ryde
83	6-62-24,6-62-23	0.00062	0.00078
87	6-62-53,6-62-54-6-62-55	NA	NA
88	B6-14-2,B6-14-3,6-31-1	0.00256	0.00195
88	6-62-59,6-62-60,6-62-63	0.00067	0.00328
84	6-62-27,6-62-29,6-42-09	0.00070	0.00107
85	6-62-38:6-62-41,6-62-35	0.00095	0.00093
86	6-62-43,6-62-48	0.00095	0.00093
87	6-62-56,6-62-57,6-62-58	NA	NA
88	B6-14-4,B6-14-5,6-31-2	0.00312	0.00222
88	6-62-50,6-31-3	0.00135	0.00251
89	6-31-11,6-31-12	NA	NA
89	6-31-8,6-31-7	0.00184	0.00126
89	6-1-14-1-3,6-58-5,6-1-14-1-2	0.00182	0.00579

Interior/DA 8

Year	Tag Code	GS	Ryde
1996	5-41-13,5-41-14	0.00026	0.00067
1998	5-50-50,5-50-60	0.00084	0.00157
1998	5-50-49,5-50-62	0.00022	0.00084
1999	5-23-08,5-23-20	0.00021	0.00051
1999	5-23-12,5-23-21	0.00025	0.00034
2000	5-51-30,5-51-32	0.00039	0.00070
2000	5-51-31,5-51-33	0.00077	0.00066
2002	5-07-76,5-07-67	0.00048	0.00043
2003	5-11-68,5-11-67	0.00020	0.00119
2004	5-17-71/72,5-17-81/82	0.00060	0.00065

TABLE 17. DA 8: Standard errors for $\hat{\beta}_1$, estimated slope coefficient, as a function of R (number released, $R_{GS} = R_{Ryde}$) and n (number of release pairs). Calculations are based upon simulations and regression of $logit(\hat{\theta})$ against standardized exports where the true value of β_1 was 0.57.

R	n		
	15	20	25
50,000	0.333	0.275	0.236
100,000	0.299	0.261	0.230
150,000	0.300	0.267	0.228

Table 18. VAMP: Interquartile range for parameter estimates for different stream sections as a function of number released ($R = R_{DF} = R_{MD} = R_{DR} = R_{JP}$) and number of release sets (n). Calculations are based upon 10,000 simulations and regressions of point estimates of survival probabilities (logit transformed) against the covariates. The true values are shown for each parameter. HORB is an indicator equal to 1 when the barrier is in.

Durham Ferry to Mossdale

		$\beta_1 = 1.0$	
		flow	
		n	
R	15	20	25
50,000	1.476	1.279	1.123
100,000	1.418	1.200	1.063
150,000	1.388	1.179	1.018

Mossdale to Dos Reis

		$\gamma_1 = 0.32$			$\gamma_2 = 5$			$\gamma_3 =$ -1.4	
		flow			HORB			exports×(1-HORB)	
		n			n			n	
R	15	20	25	15	20	25	15	20	25
50,000	1.347	1.097	0.965	3.048	2.529	2.244	1.264	1.077	0.896
100,000	1.270	1.060	0.898	2.868	2.429	2.135	1.230	1.029	0.877
150,000	1.209	1.030	0.873	2.778	2.415	2.087	1.184	0.997	0.854

Dos Reis to Jersey Point

		$\xi_1 = 0.71$			$\xi_2 = 5$			$\xi_3 =$ -0.5	
		flow			HORB			exports	
		n			n			n	
R	15	20	25	15	20	25	15	20	25
50,000	0.527	0.447	0.396	1.839	1.533	1.336	0.529	0.432	0.375
100,000	0.520	0.427	0.375	1.654	1.419	1.265	0.484	0.415	0.360
150,000	0.517	0.433	0.367	1.579	1.365	1.215	0.487	0.408	0.352

FIGURES

FIGURE 1. Map of release and recovery locations used by the USFWS for the multi-year studies.

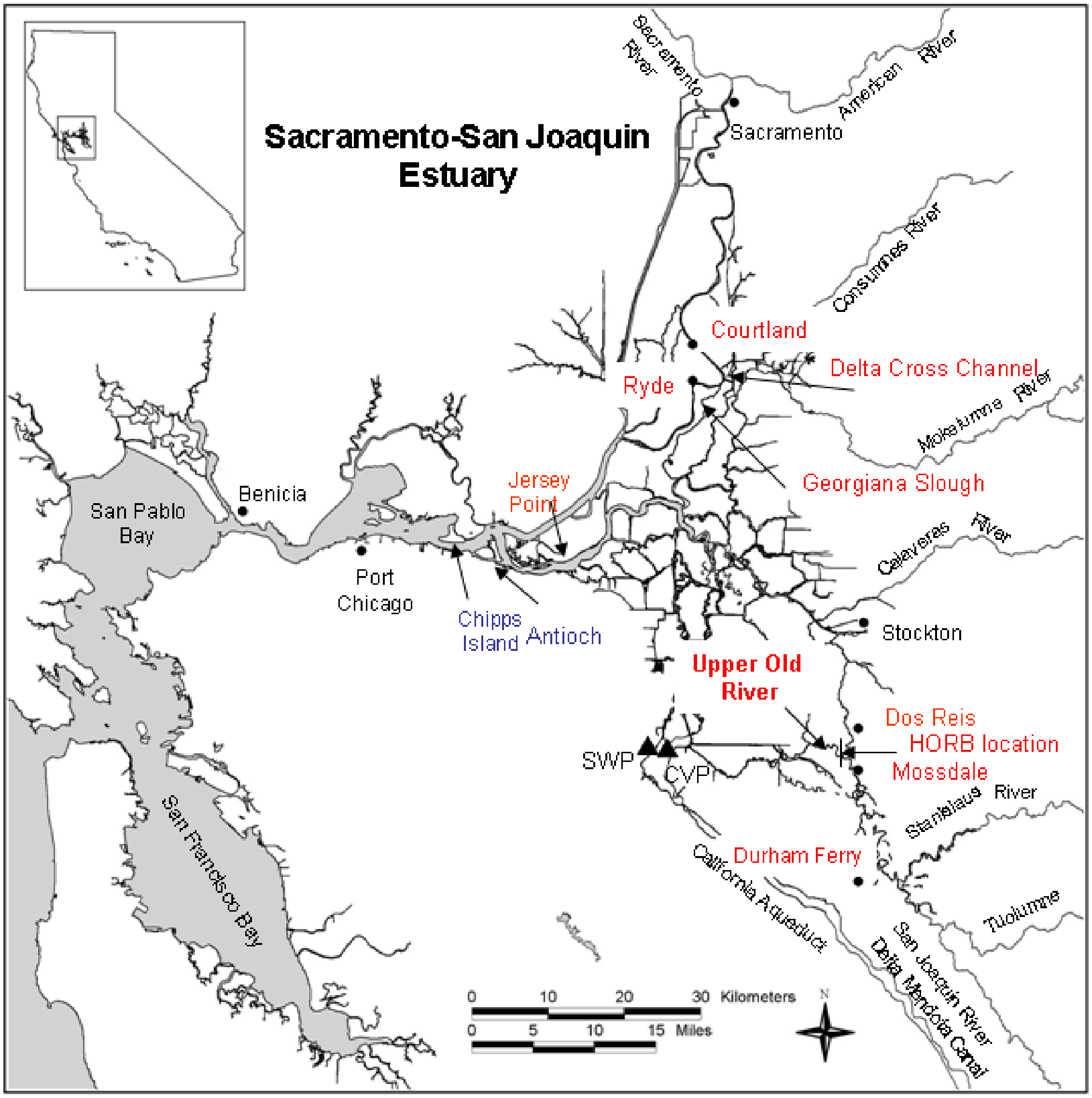


FIGURE 2. Schematics of release and recovery locations for the four multi-year studies. $S_{A\to B}$ is the survival probability between point A and point B, and p_C is the capture probability at location C.

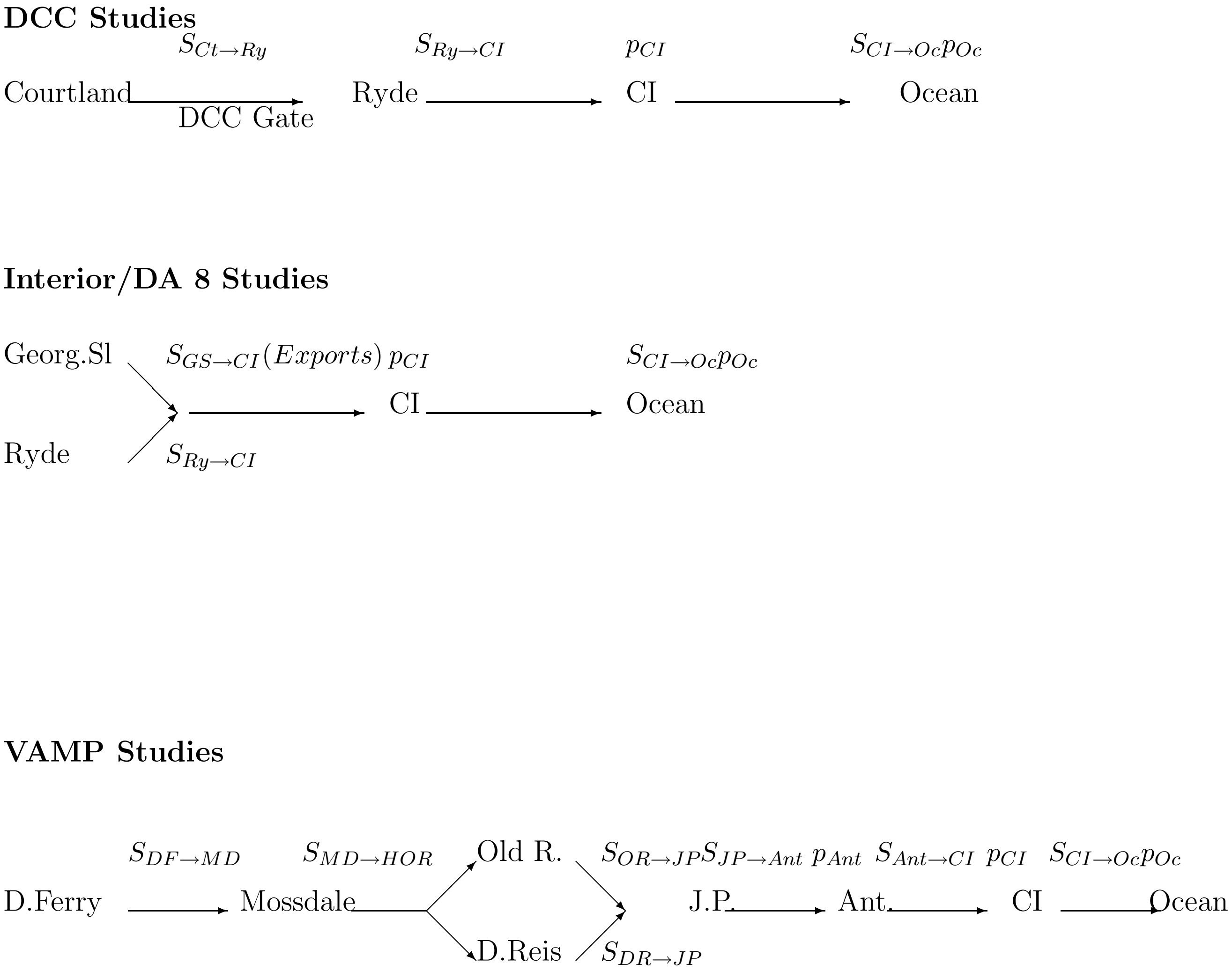


FIGURE 3. DCC: Recovery fractions for Courtland ($\hat{r}_{Ct\rightarrow CI+Oc}$) and Ryde ($\hat{r}_{Ry\rightarrow CI+Oc}$) releases by release pair. First four pairs are from releases that occurred when the gates were closed (with plotting character C), and the last nine are when the gates were open (plotting character O).

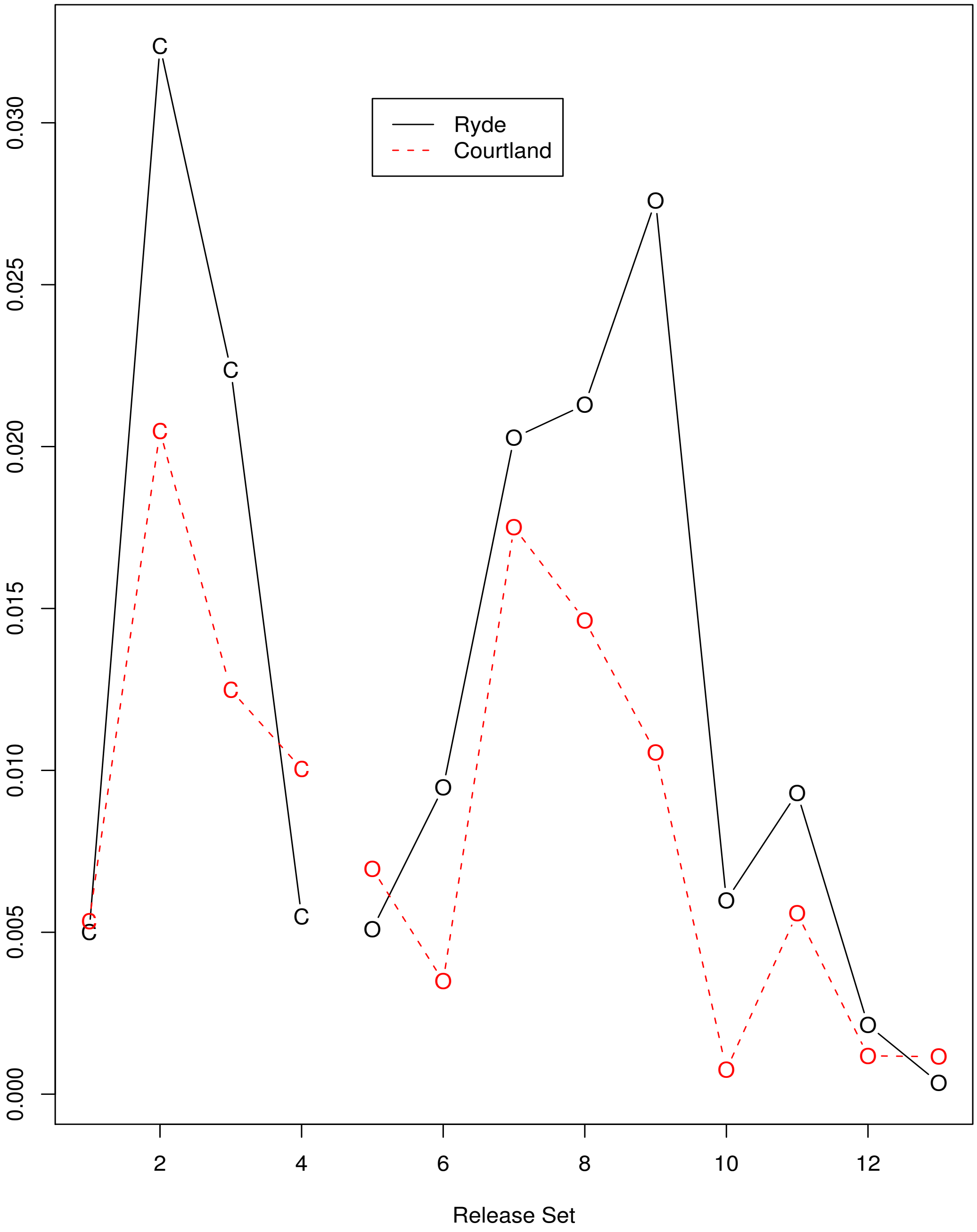


FIGURE 4. DCC: Boxplots of the ratio of recovery fractions for Courtland to Ryde releases, $\hat{r}_{Ct\to CI+Oc}/\hat{r}_{Ry\to CI+Oc}$, when the DCC gates were open and closed.

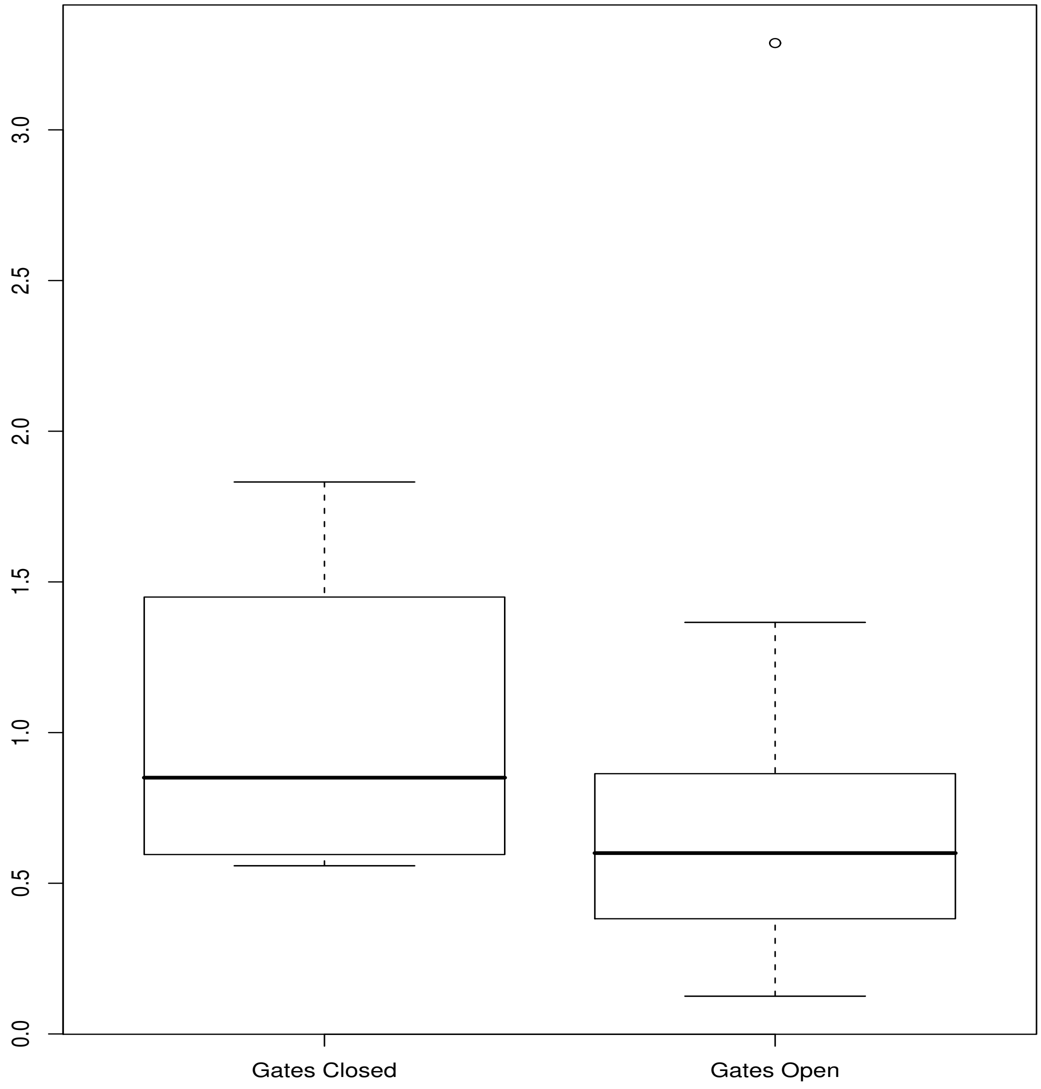


FIGURE 5. Interior/DA 8: Recovery fractions for Georgiana Slough ($\hat{r}_{GS\rightarrow CI+Oc}$) and Ryde ($\hat{r}_{Ry\rightarrow CI+Oc}$) releases by release pair.

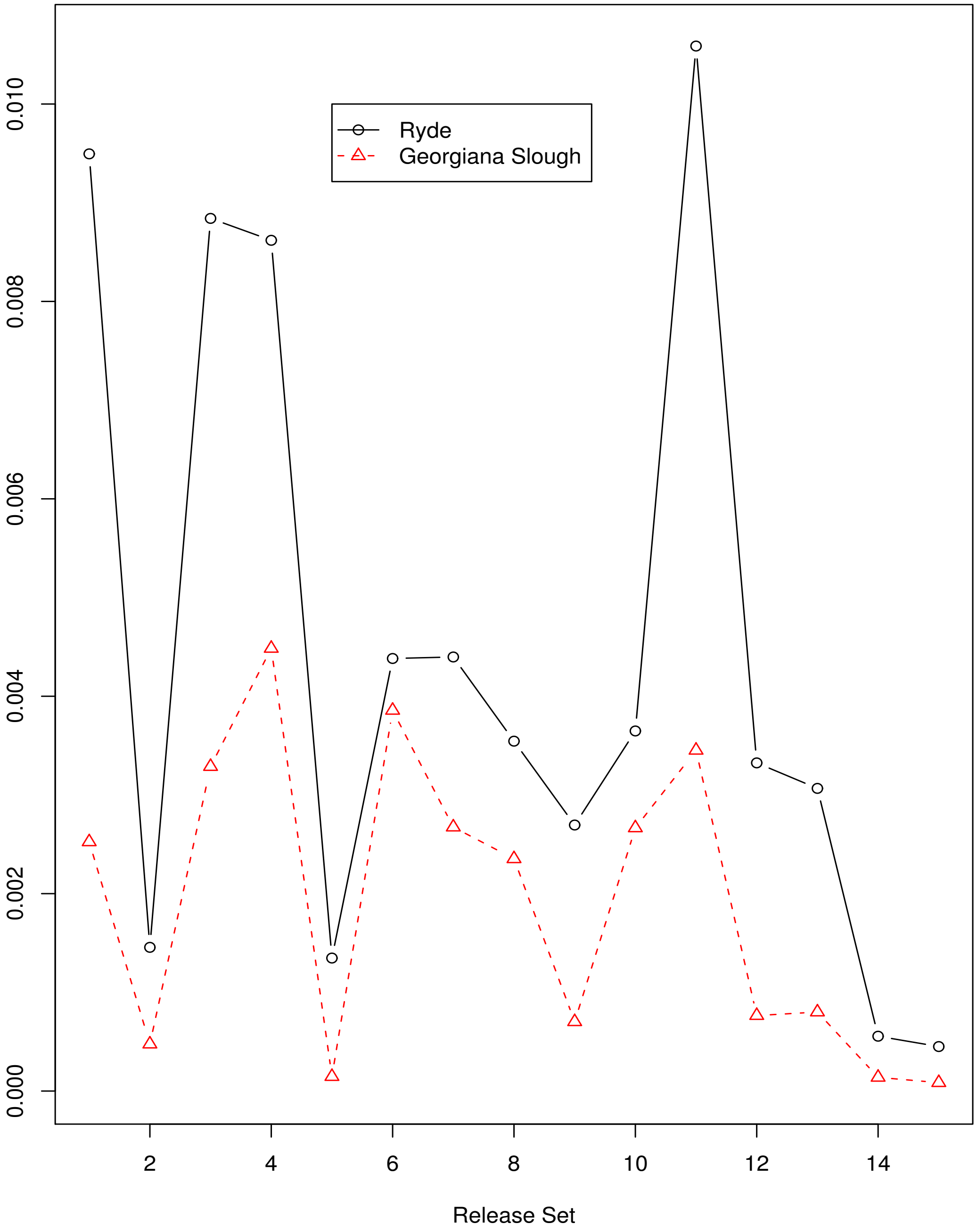


Figure 6. Interior/DA 8: Comparison of recovery fractions at Chipps Island, in the ocean fisheries, in fish facility salvage, and from inland recoveries for Georgiana Slough and Ryde releases by release pair. Straight lines on plots have slope equal to mean of the ratios of recovery fractions, with slope written below x-axis label.

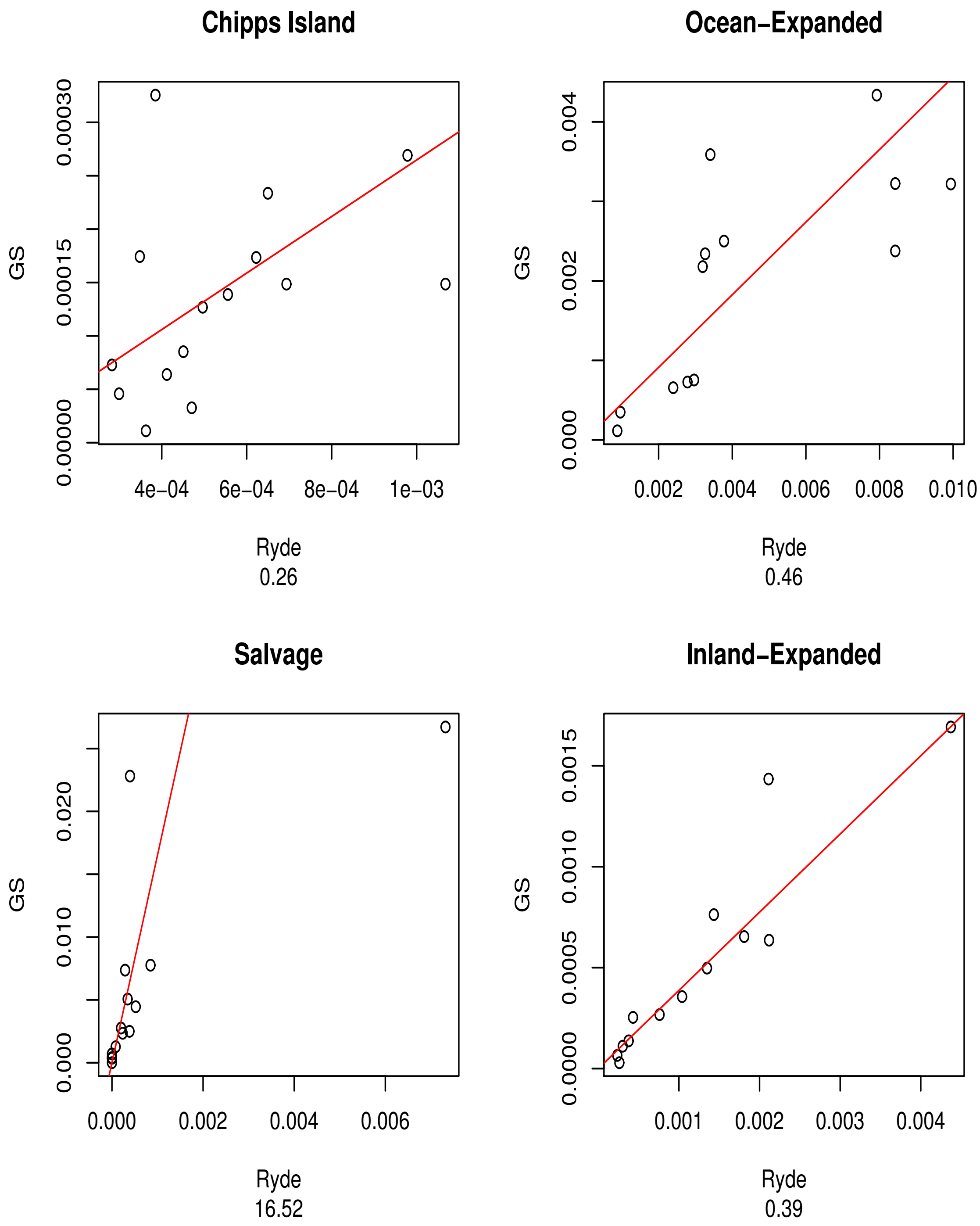


FIGURE 7. DA 8: Estimated fraction of the release that is salvaged at the SWP and CVP fish facilities plotted against the export level (for both Georgiana Slough and Ryde releases). Solid line and dashed line are scatterplot smooths of fraction salvaged for Georgiana Slough and Ryde releases, respectively.

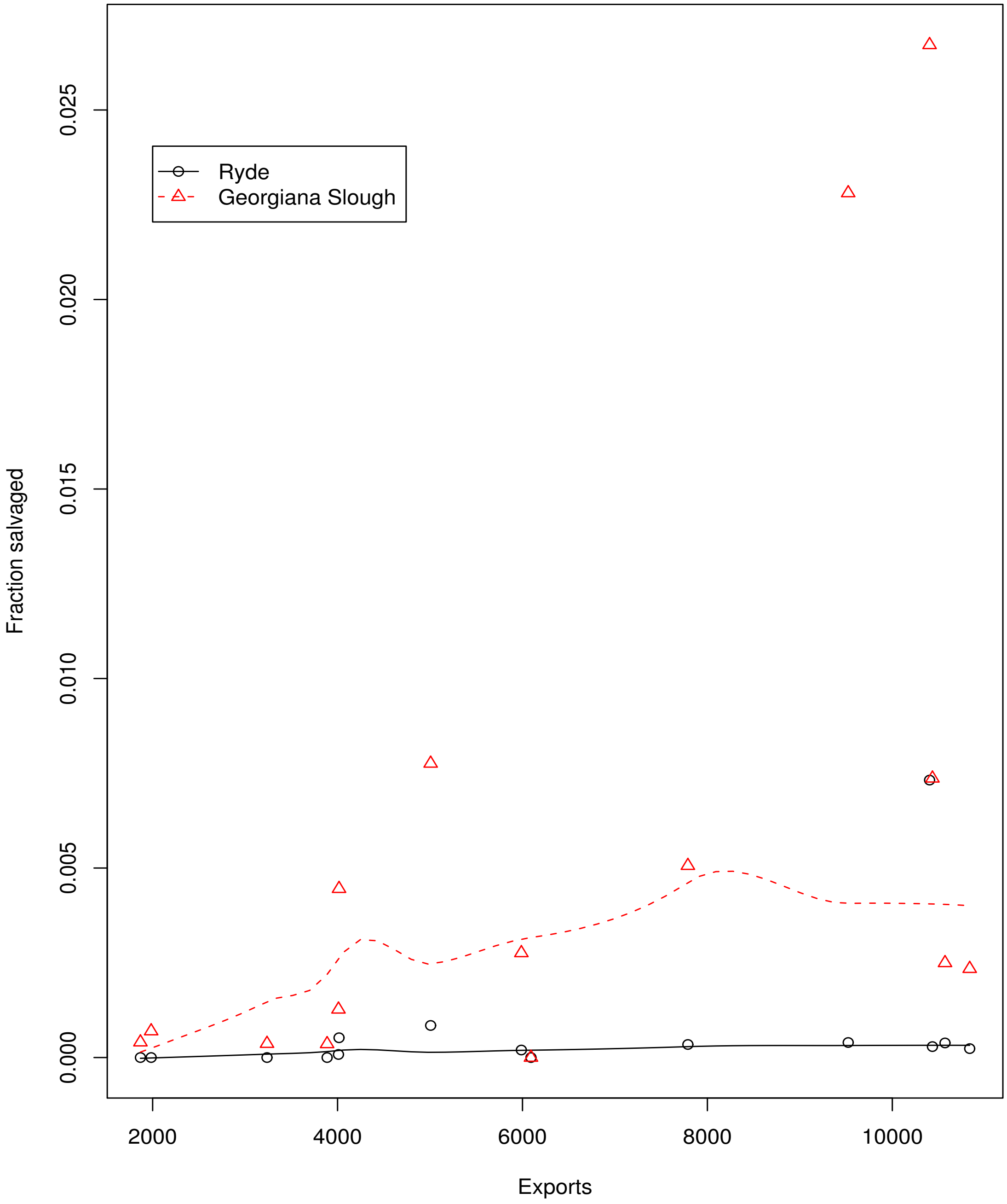


Figure 8. VAMP: Combinations of flow and export volumes when the HORB is in and when it is out. The flow and export measurements were those measured or estimated effective near Mossdale.

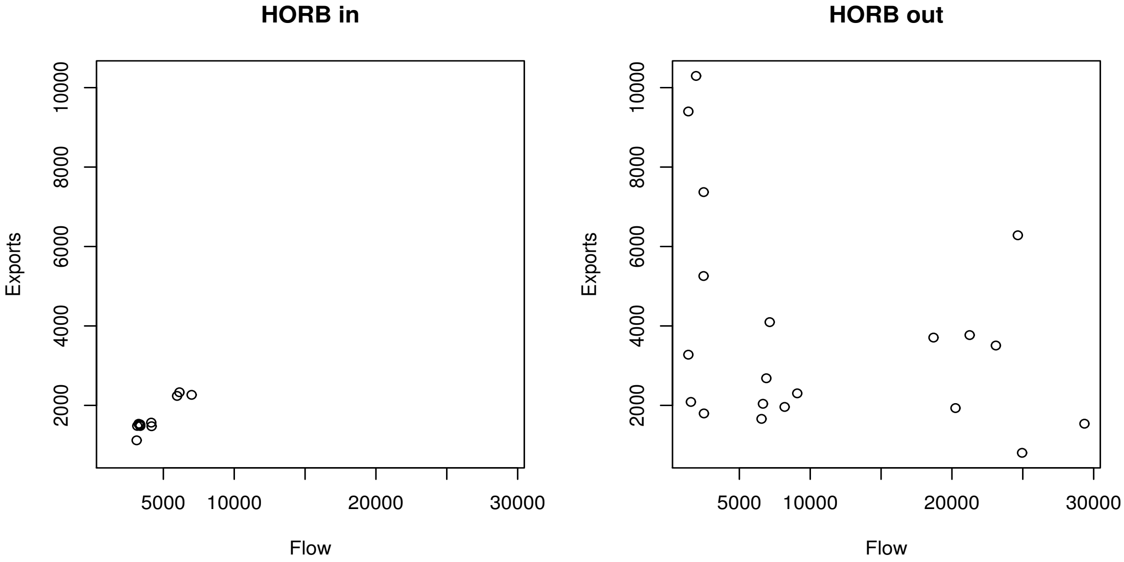


FIGURE 9. VAMP: Recovery fractions by release site; i.e., for release site x, $(y_{x \to Ant} + y_{x \to CI} + y_{x \to Oc})/R_x$.

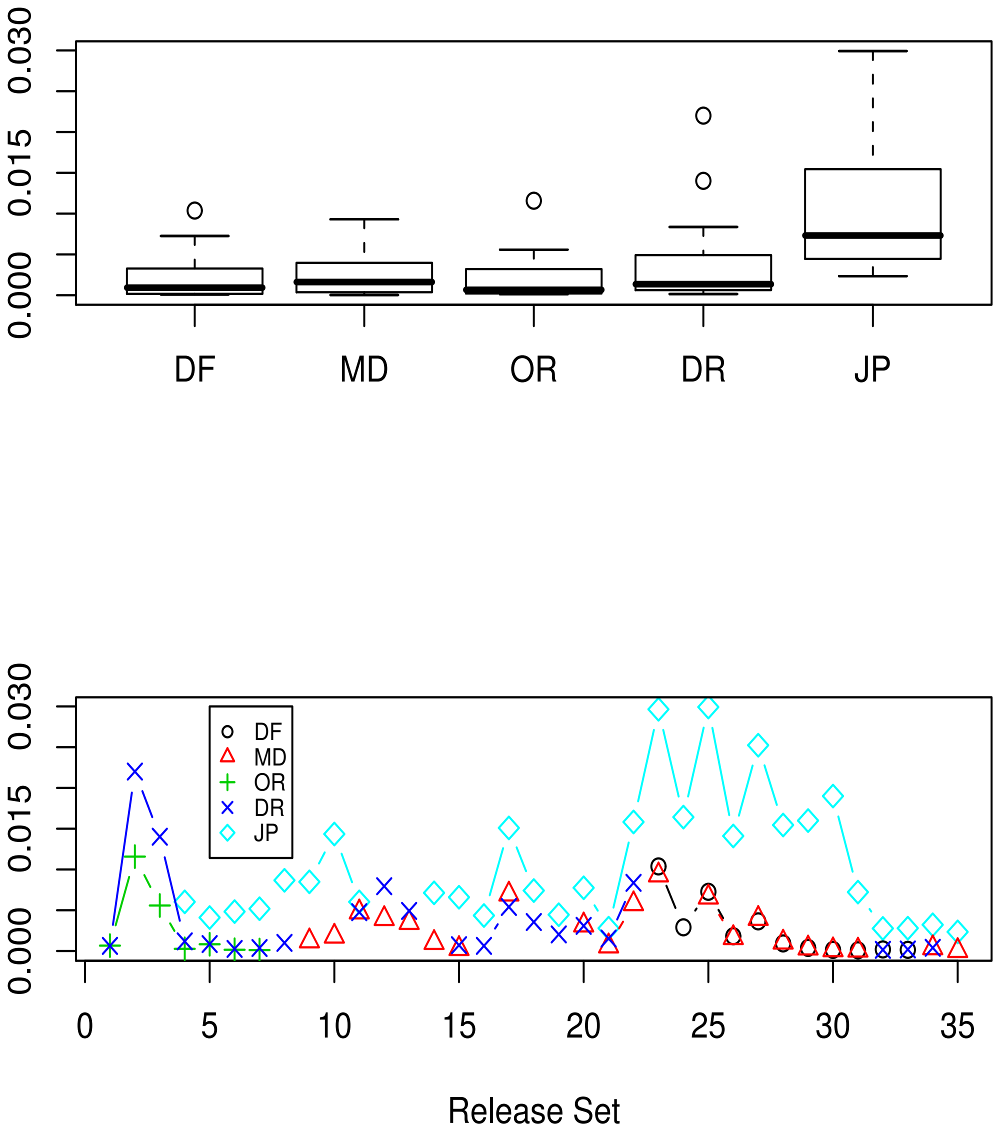


FIGURE 10. VAMP: Estimated fraction of releases salvaged at SWP and CVP fish salvage facilities when the HORB is in or out.

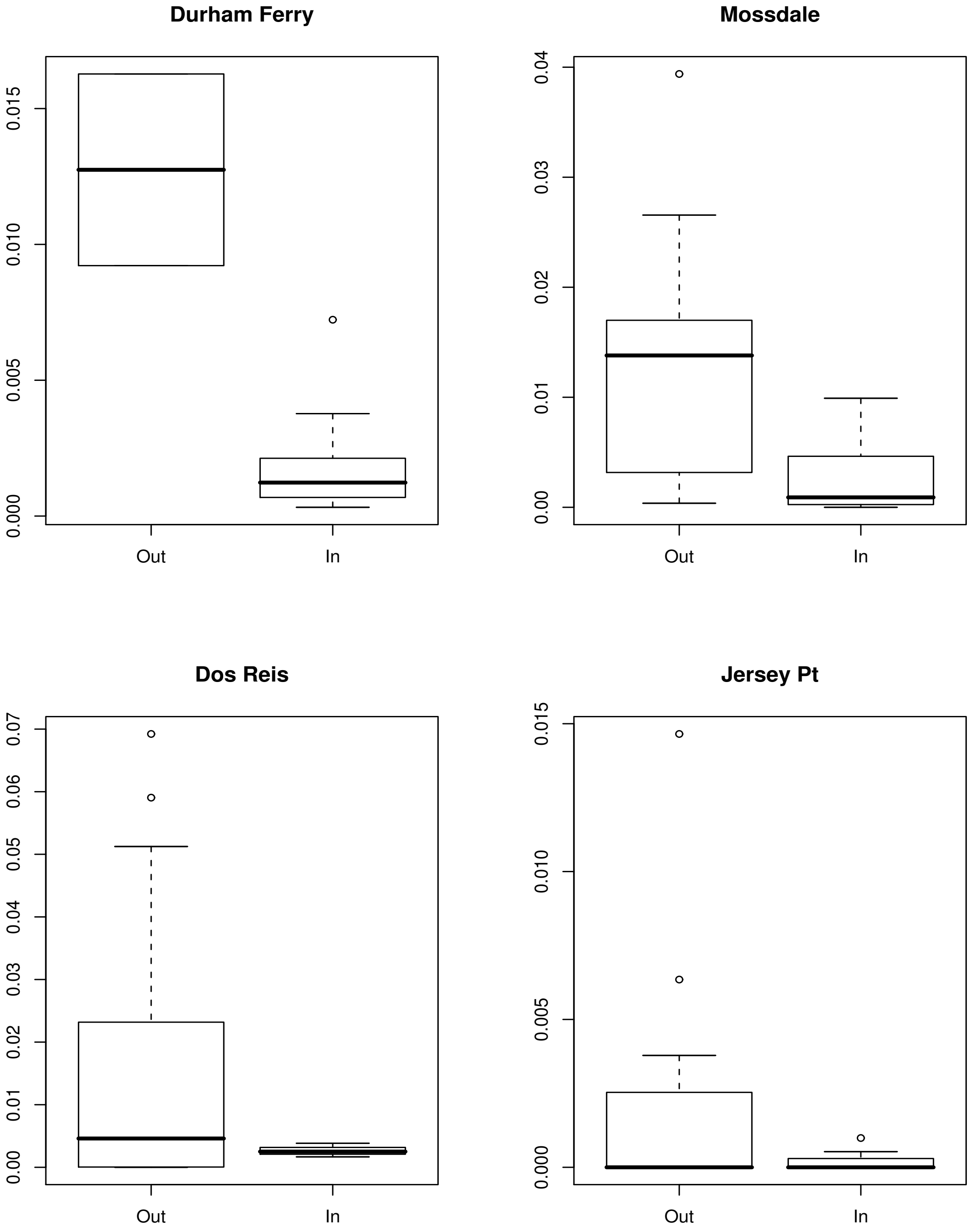


FIGURE 11. VAMP: Adult inland recovery fractions for Durham Ferry, Mossdale, Dos Reis, and Jersey Point releases by release pair.

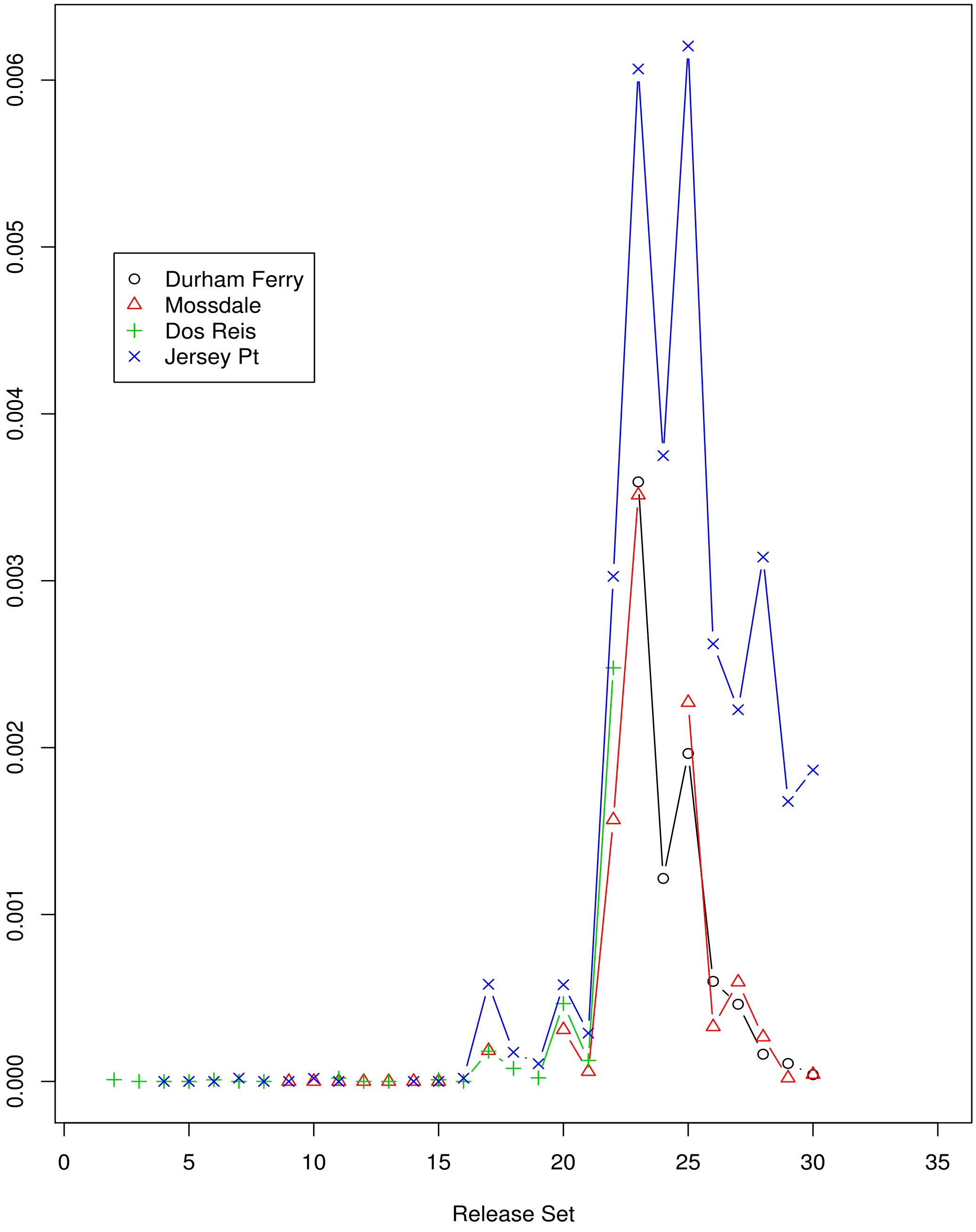
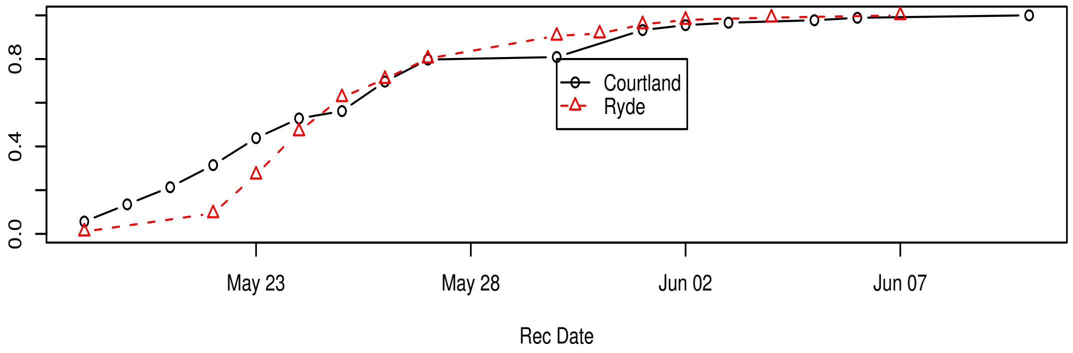
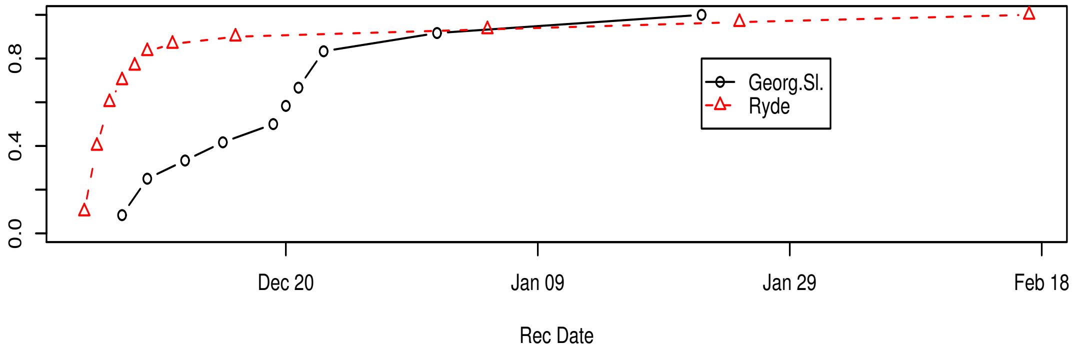


Figure 12. CWT recovery pattern by date at Chipps Island for examples taken from DCC, Interior/DA 8, and VAMP studies.

(c) 1983 DCC study



(b) 1999 DA 8 study



(c) 2000 VAMP study

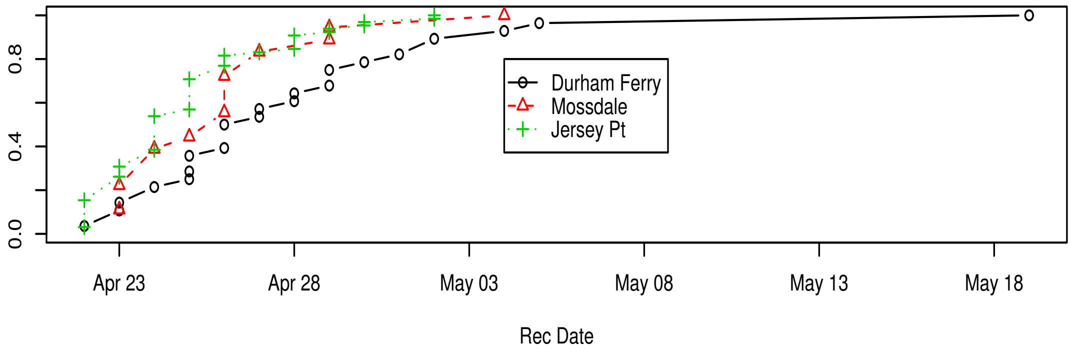


Figure 13. DCC: Bootstrap sample (B=10,000) of the estimated ratio, $\widehat{\left(\frac{\mu_{\theta(Open)}}{\mu_{\theta(Closed)}}\right)}$, equation (15). Vertical line marks the point estimate.

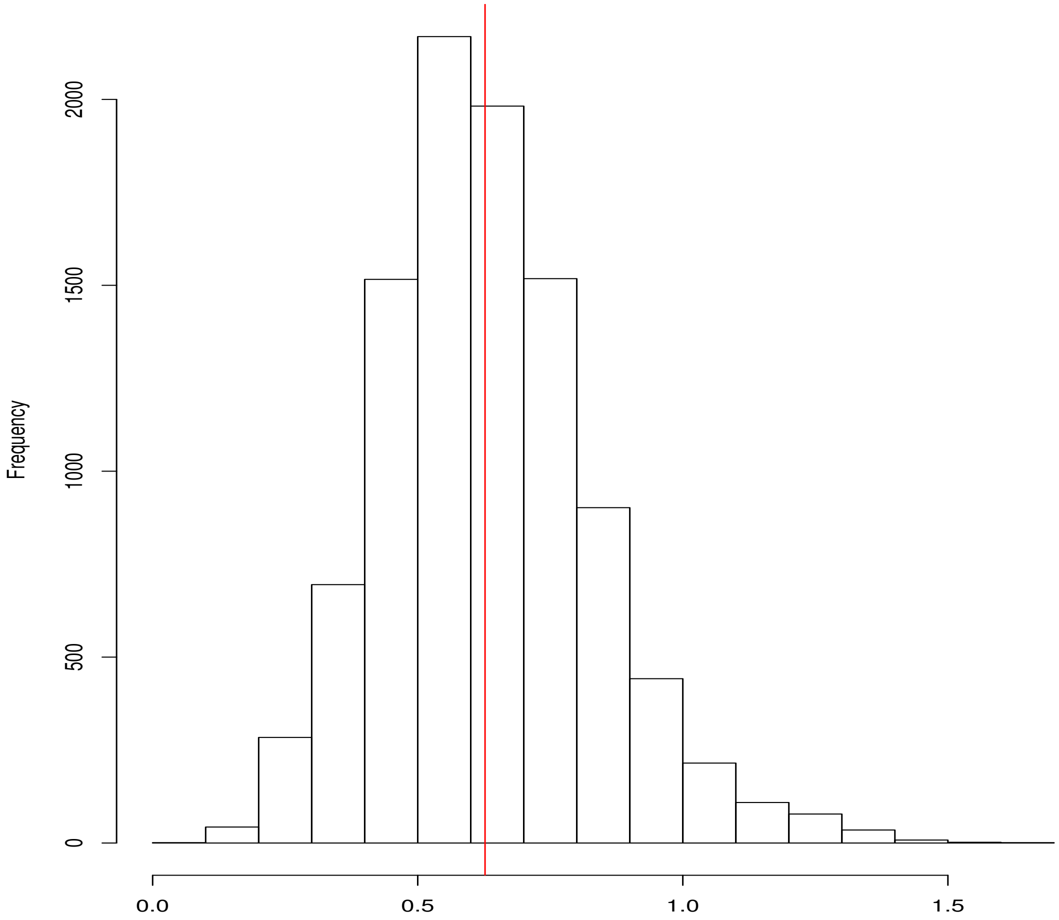


FIGURE 14. DCC: Predicted recoveries at Chipps Island of Ryde releases, $y_{Ry \to CI}$ (red vertical line), and Bayesian P-values.

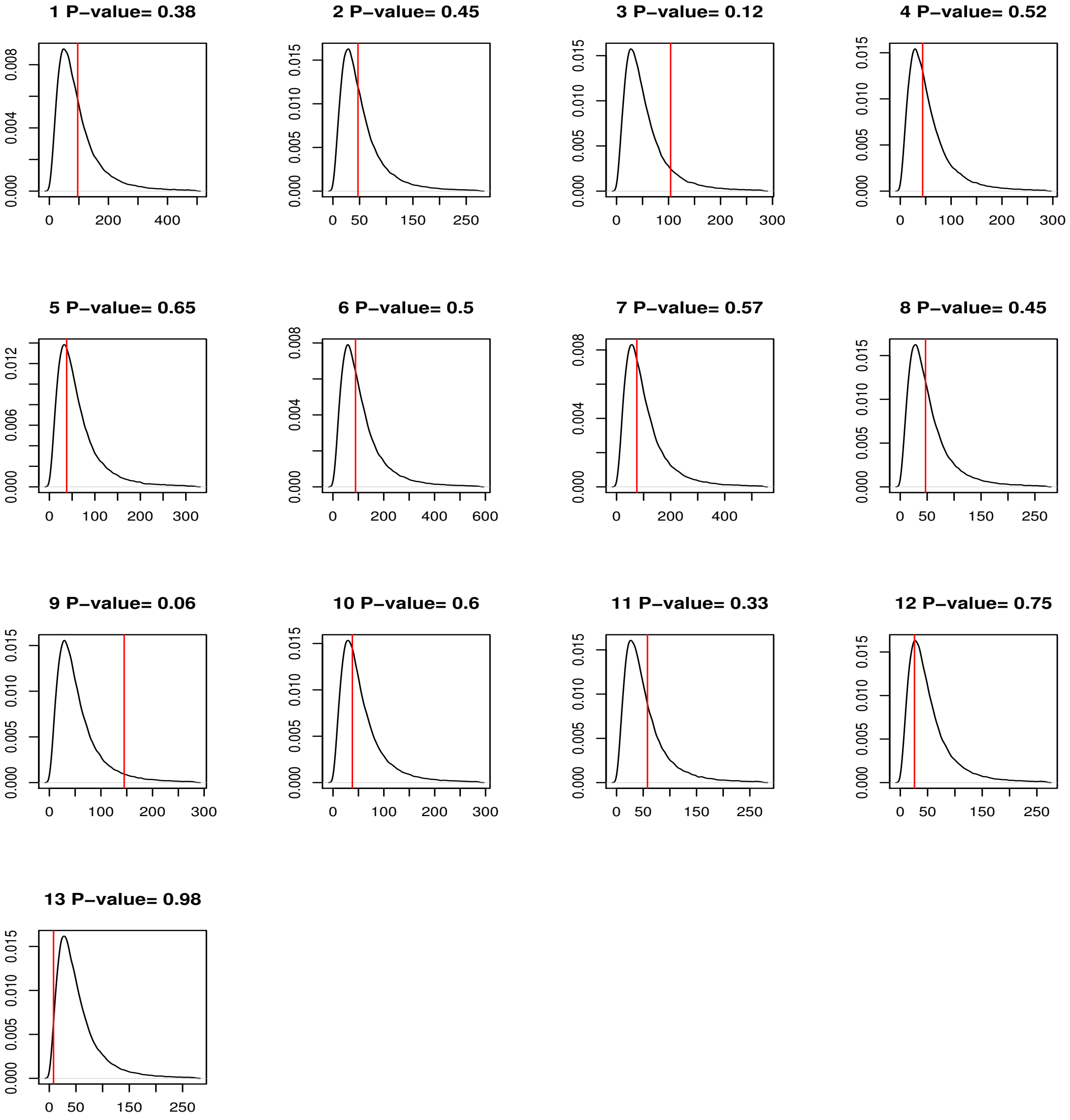


FIGURE 15. DCC: Predicted recoveries in Ocean fisheries of Ryde releases, $\hat{y}_{Ry\rightarrow Oc}$ (red vertical line), and Bayesian P-values.

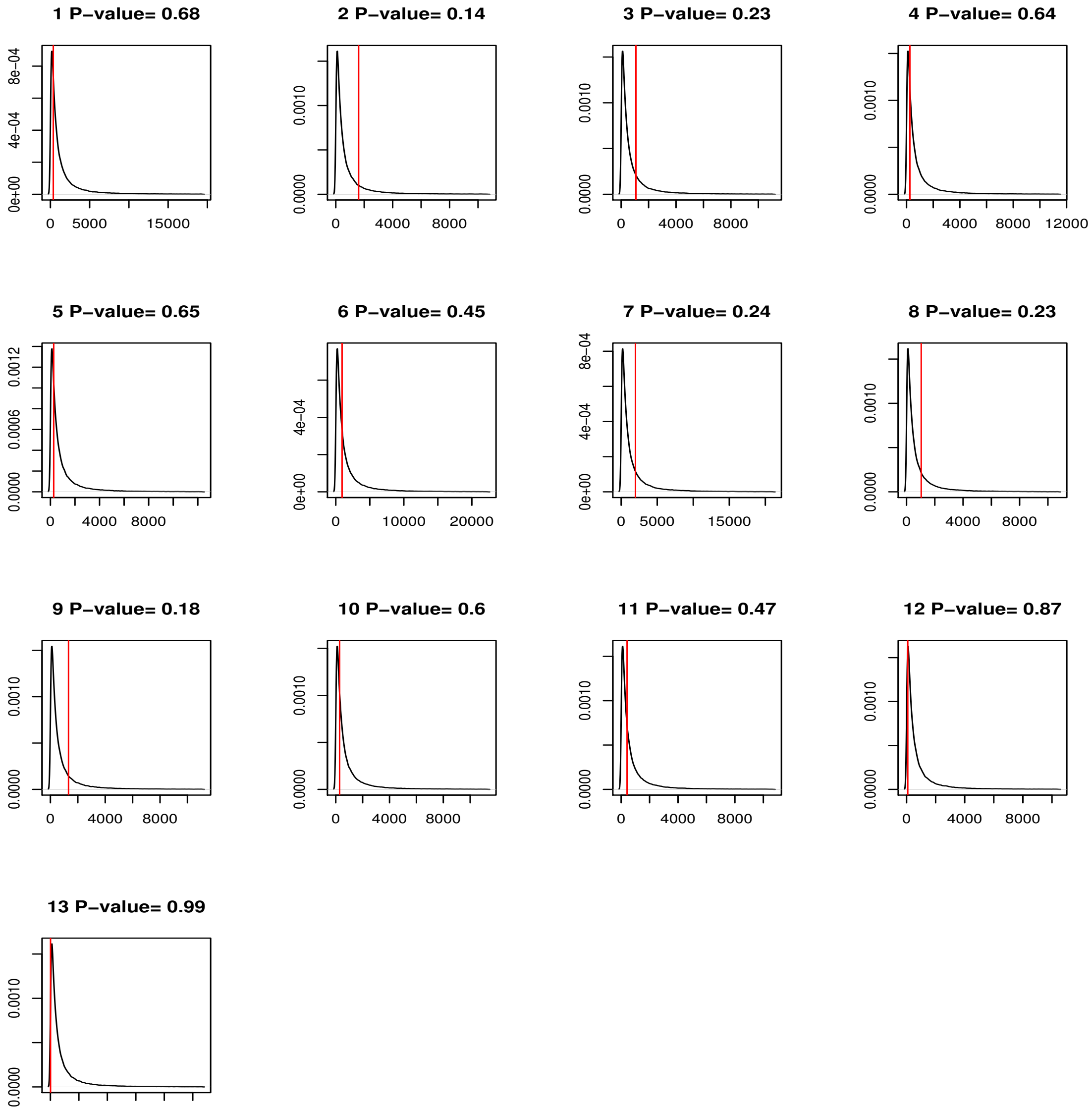
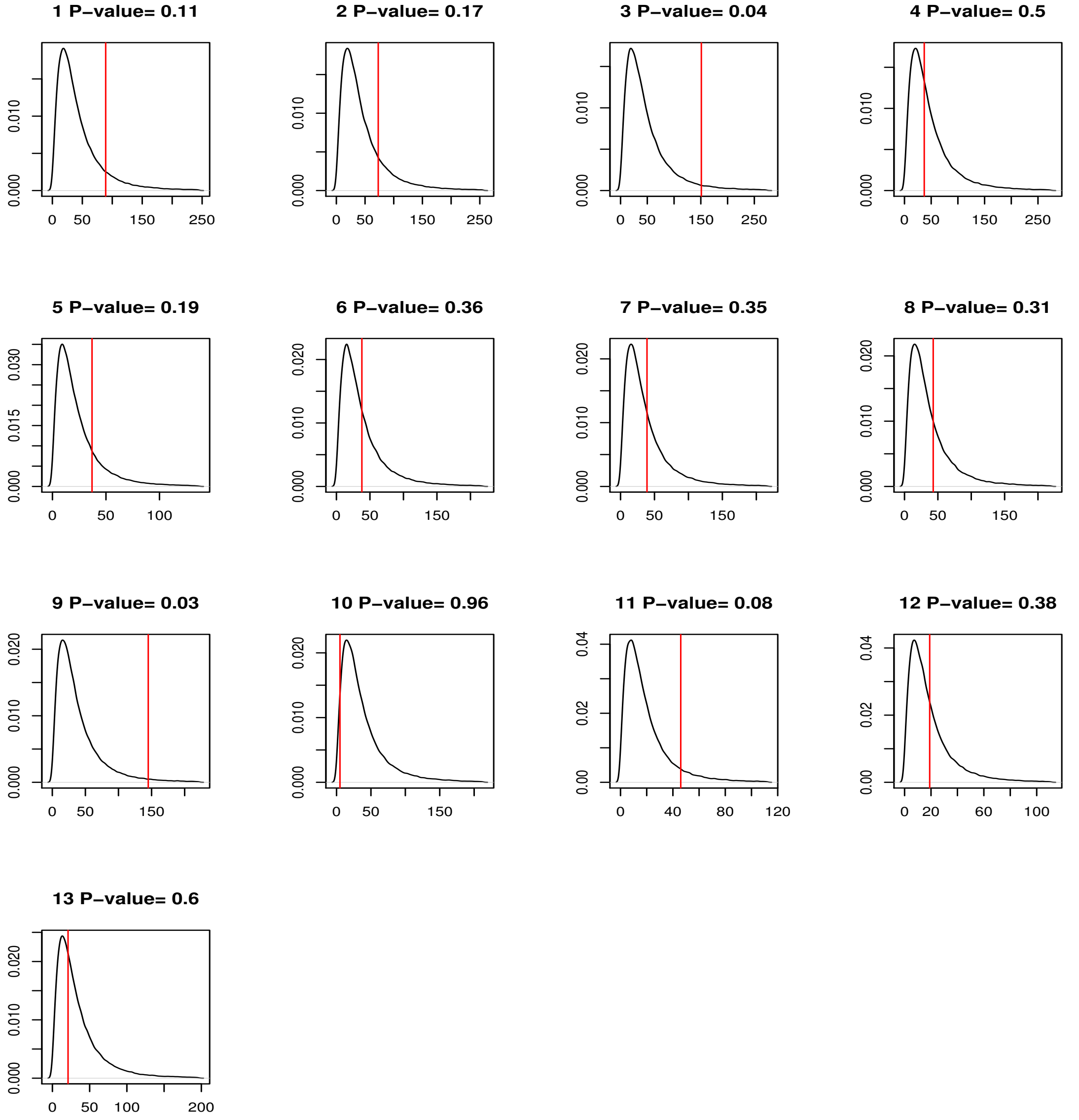


FIGURE 16. DCC: Predicted recoveries at Chipps Island of Courtland releases, $y_{Ct \rightarrow CI}$ (red vertical line), and Bayesian P-values.



1 P−value= 0.11

2 P−value= 0.17

3 P−value= 0.04

4 P−value= 0.5

5 P−value= 0.19

6 P−value= 0.36

7 P−value= 0.35

8 P−value= 0.31

9 P−value= 0.03

10 P−value= 0.96

11 P−value= 0.08

12 P−value= 0.38

13 P−value= 0.6

FIGURE 17. DCC: scaled residuals plotted against predicted values.

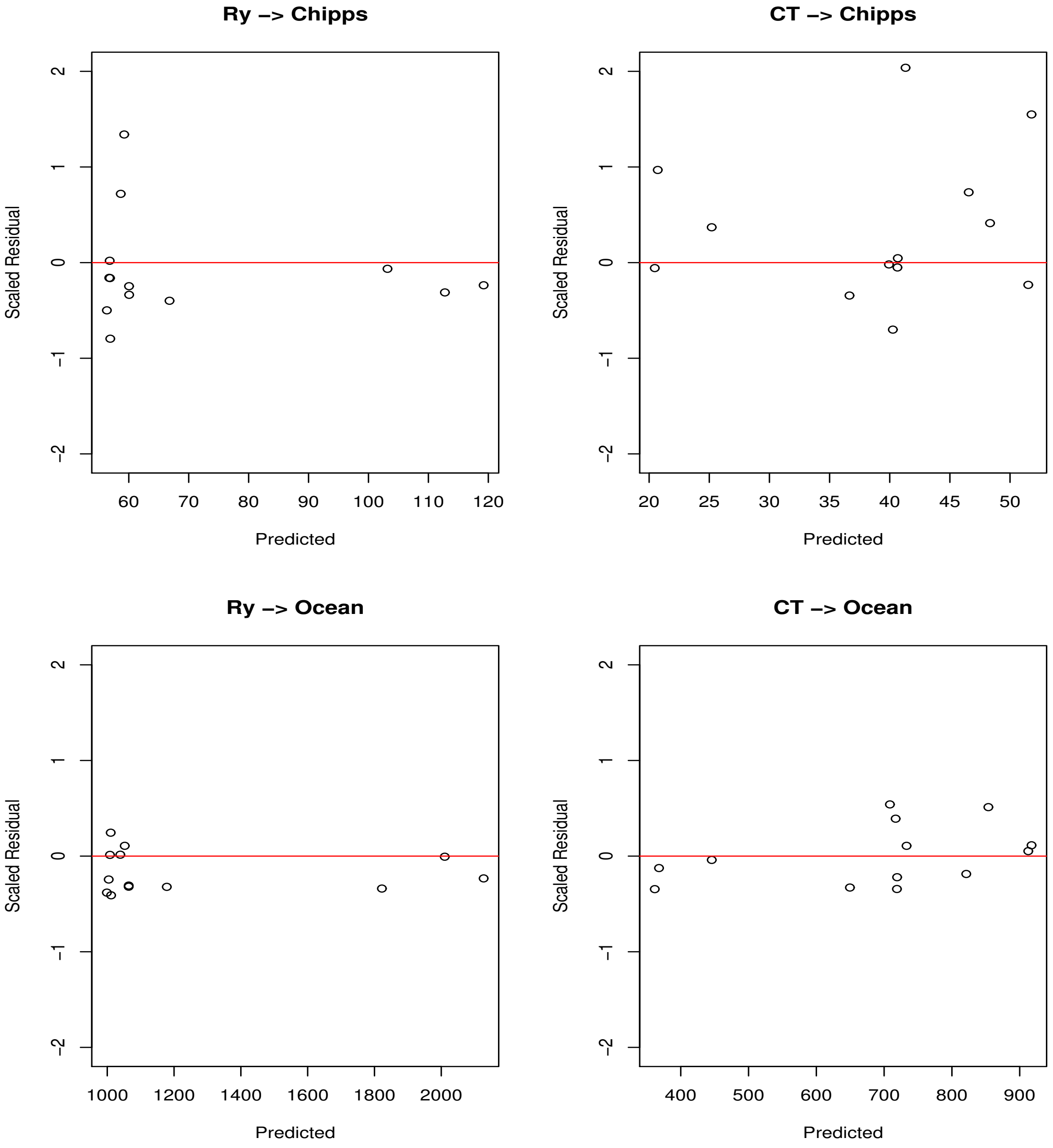


FIGURE 18. DCC: scaled residuals plotted against predicted values for model without random effects.

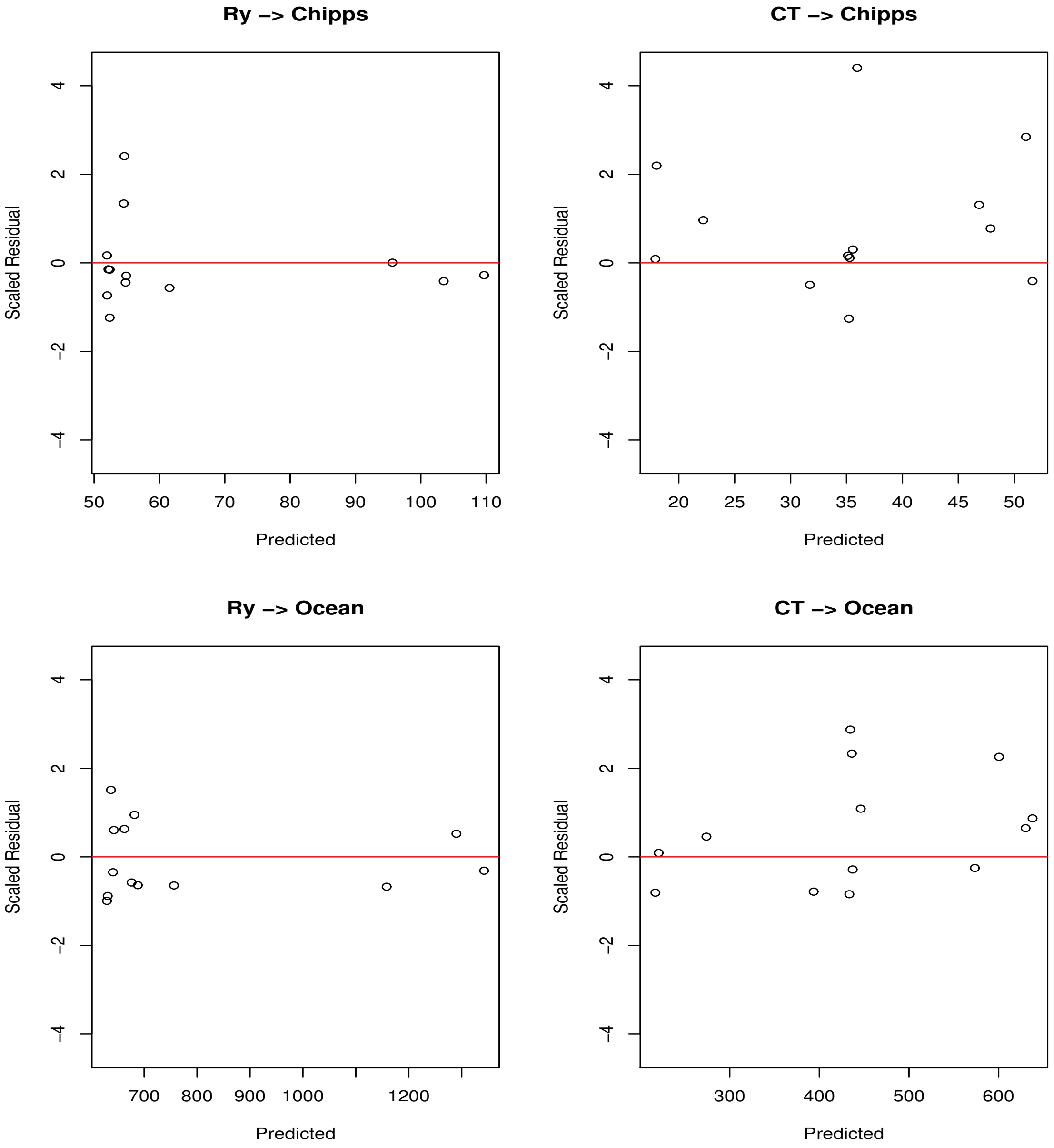


FIGURE 19. Interior: Predicted recoveries at Chipps Island of Ryde releases, $y_{Ry \to CI}$ (red vertical line), and Bayesian P-values.

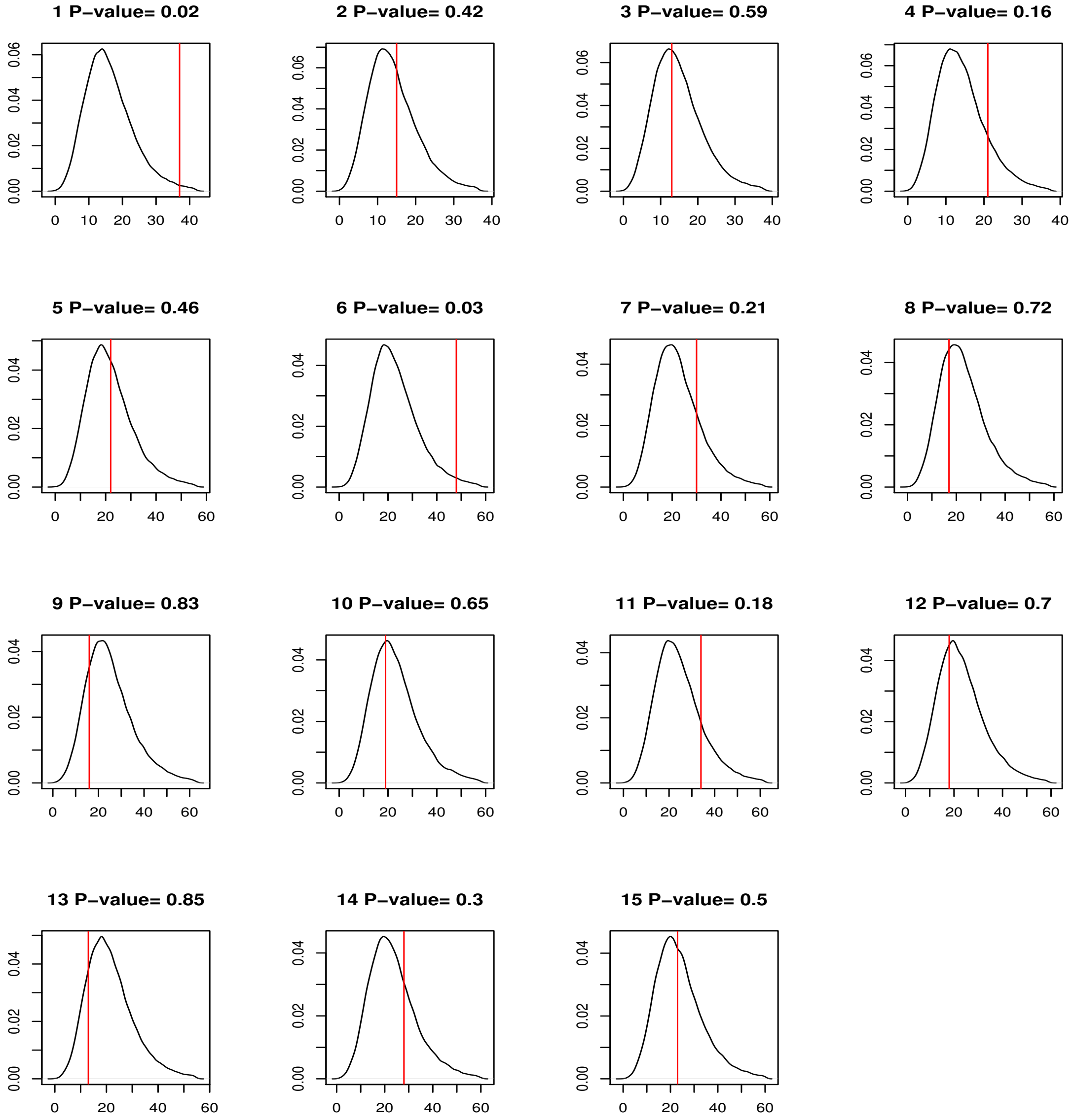


Figure 20. Interior: scaled residuals plotted against predicted values.

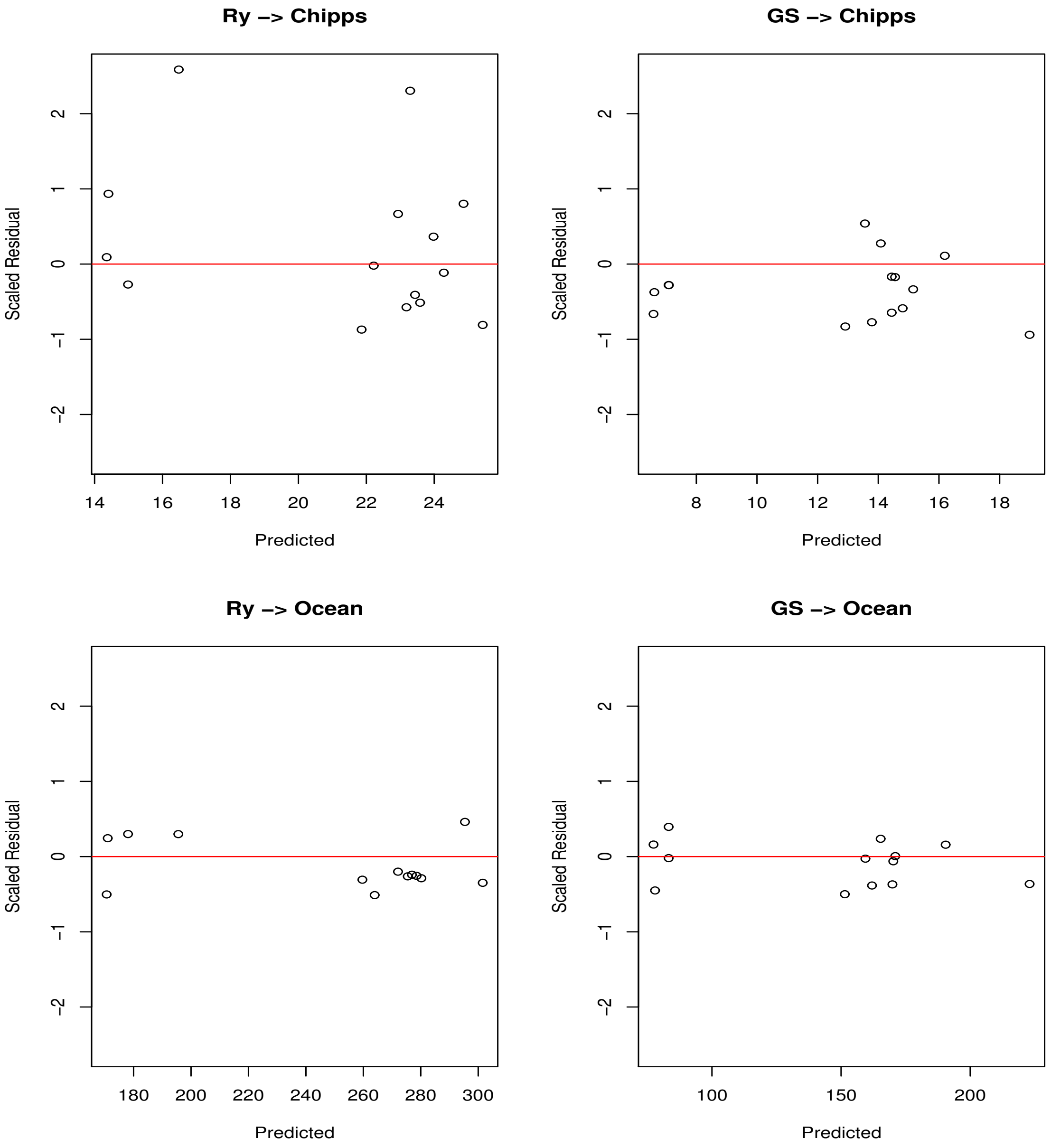


Figure 21. Interior: scaled residuals plotted against predicted values for model without random effects.

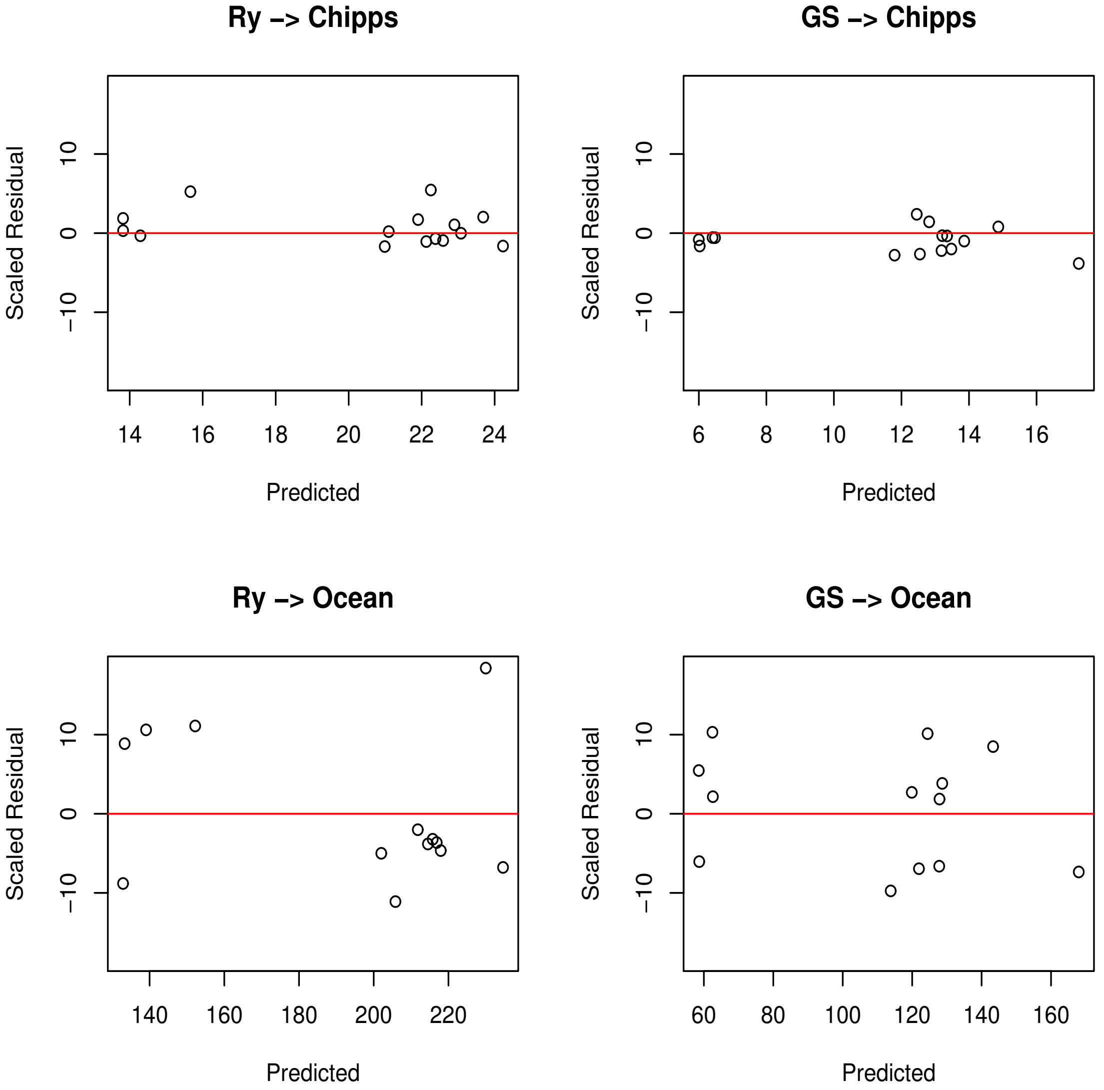
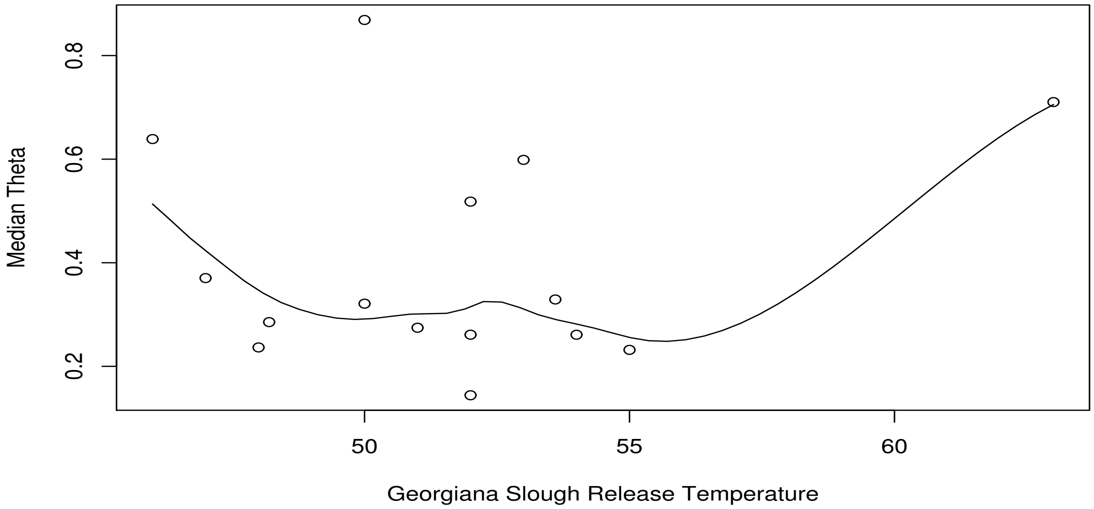


Figure 22. Interior: Posterior median θ's plotted against secondary covariates, Georgiana Slough release temperatures and mean fish lengths at time of release.



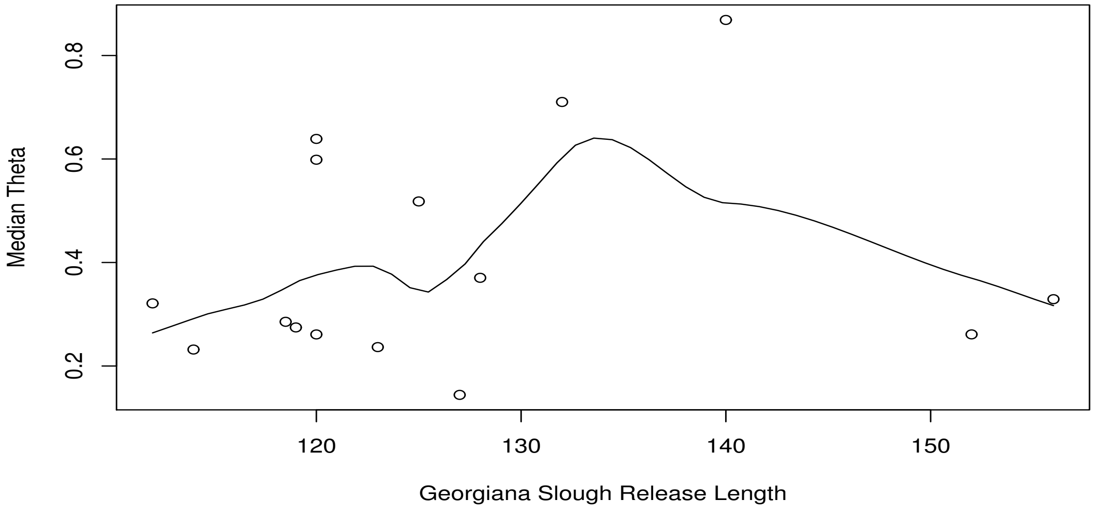


FIGURE 23. DA 8: $\hat{\theta}$ ($=\hat{r}_{GS\to CI+Oc}/\hat{r}_{Ry\to CI+Oc}$) plotted against export levels. Vertical lines extend up and down one standard error. Fitted line is a nonparametric weighted regression using the supersmoother function in `R` with weights being the inverse of the standard errors squared.

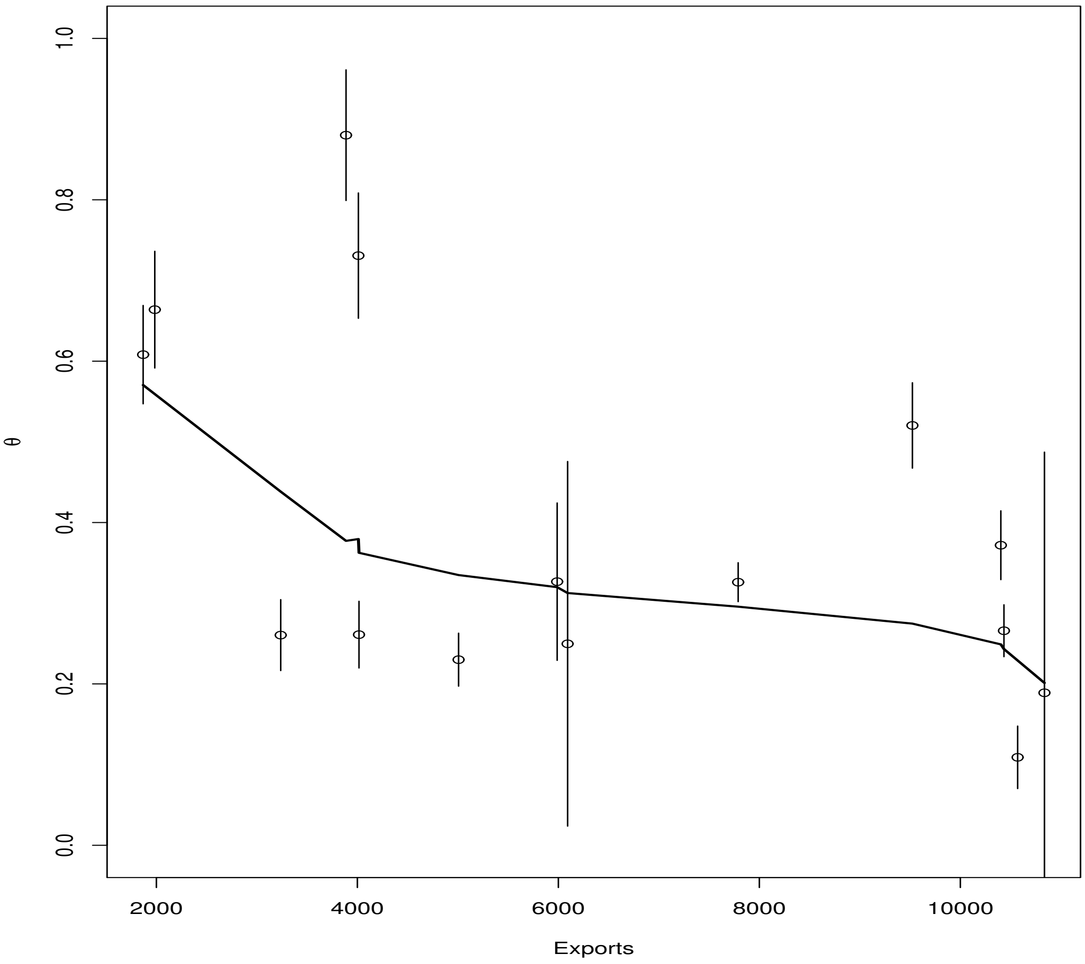


Figure 24. DA 8: Posterior means (solid) and medians (dashed line) for θ from the BHM (with log transformed θ and uniform priors on standard deviations of random effects) plotted against export levels. The 2.5% and 97.5% intervals are indicated by vertical lines.

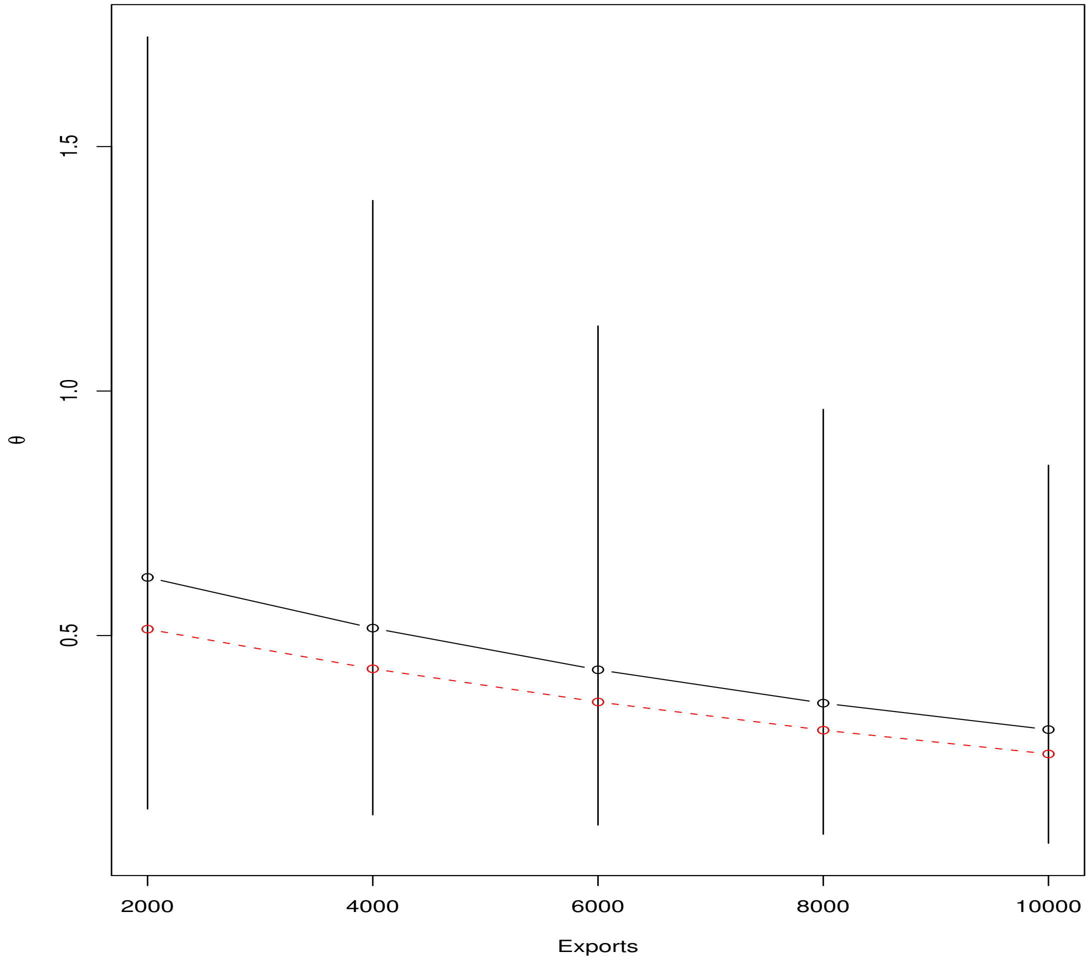


FIGURE 25. DA 8: Predicted θ ($S_{GS\to CI}/S_{Ry\to CI}$) values for different levels of exports for three different models, M1, M2, and M3. M1 is a linear regression of $\hat{r}_{GS\to CI}/\hat{r}_{Ry\to CI}$ on exports. The M2 values are the exponentiated values of a linear regression of $\log(\hat{r}_{GS\to CI+Oc}/\hat{r}_{Ry\to CI+Oc})$ on exports. M3 is a BHM (with log transformed θ and uniform priors on standard deviations of random effects). Also plotted are the non-BHM point estimates $\hat{r}_{GS\to CI+Oc}/\hat{r}_{Ry\to CI+Oc}$ for the individual releases (denoted by X).

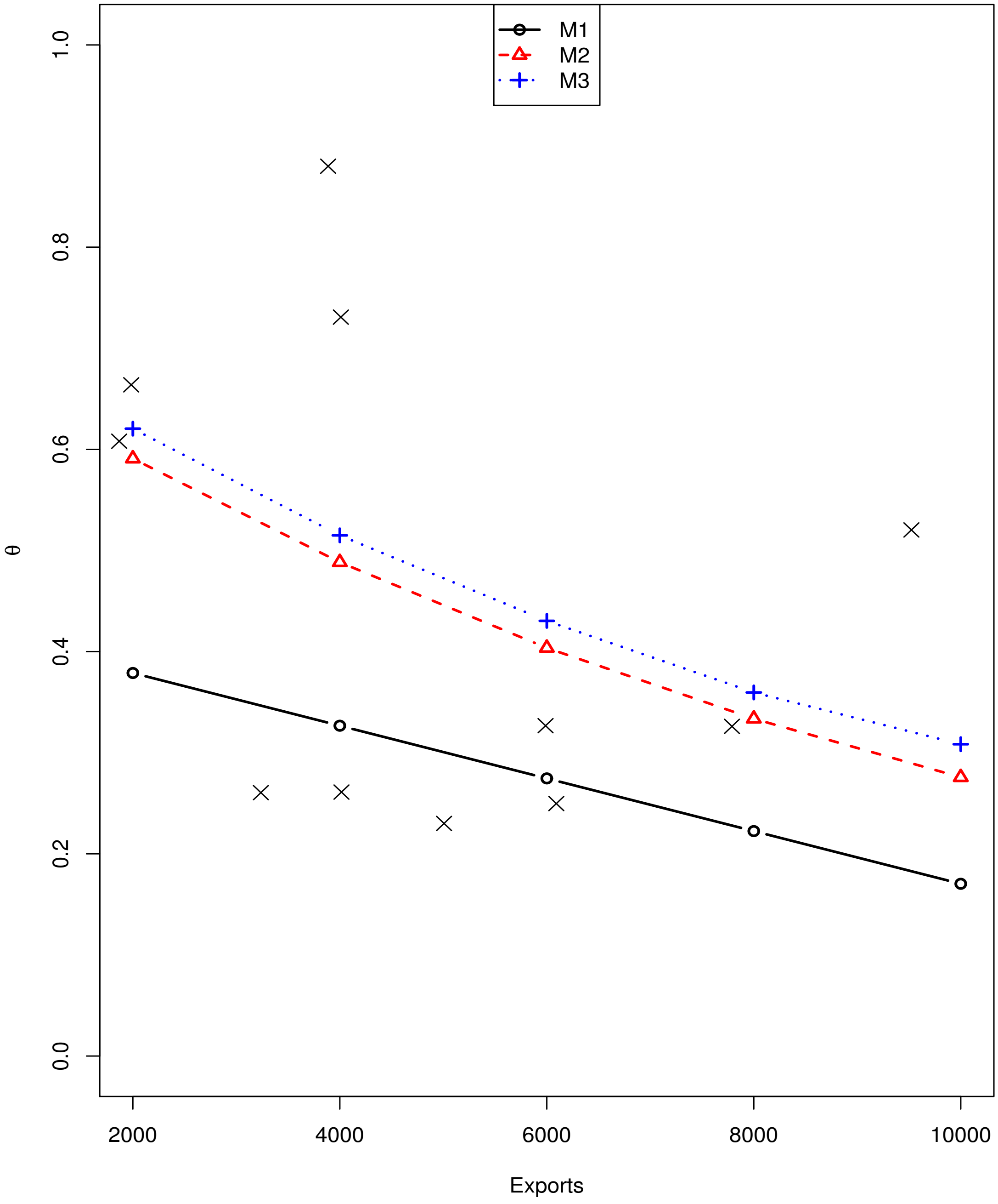


Figure 26. VAMP: Histograms of posterior distributions for coefficients, ξ_1, ξ_2, ζ_1, ζ_2, corresponding to flow at Dos Reis and exports following the time of releases from Dos Reis, and flow in Upper Old River and exports following the time of releases from Upper Old River (or Mossdale). (Based on Null.FE.FE model.)

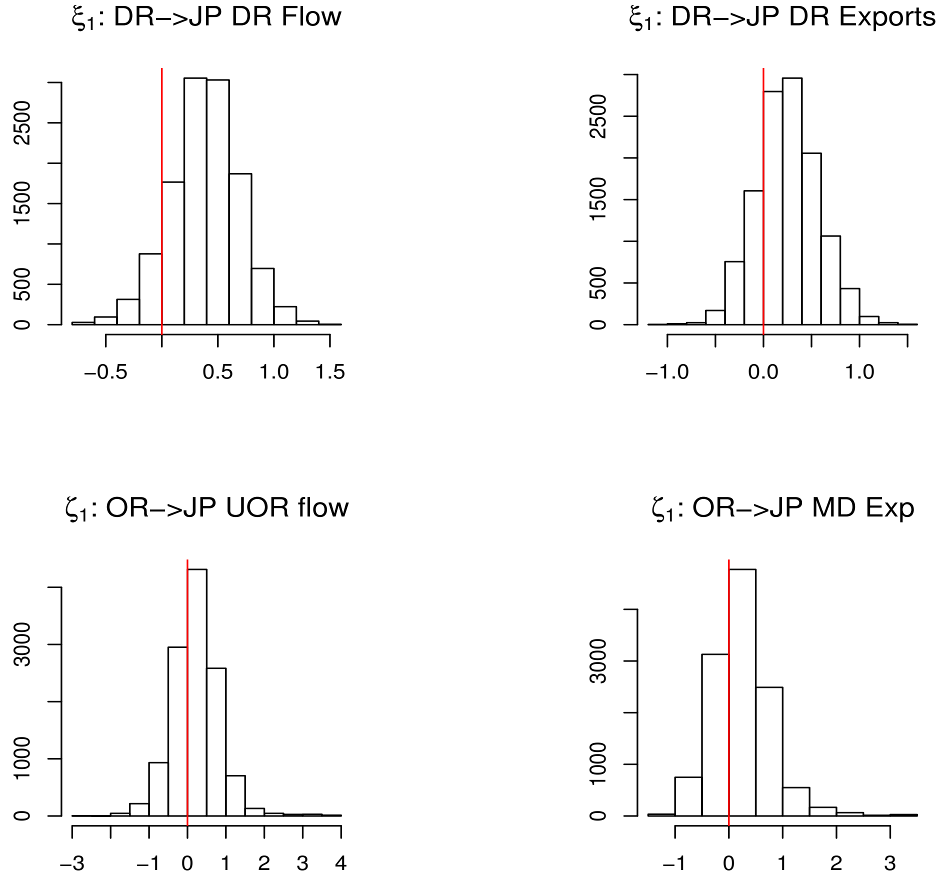


Figure 27. VAMP: Posterior mean survival probabilities for each of the release sets through the Dos Reis to Jersey Point reach, the Upper Old River to Jersey Point "reach". Blue vertical bars on x-axis denote when the HORB was in place. (Based on Null.FE.FE model.)

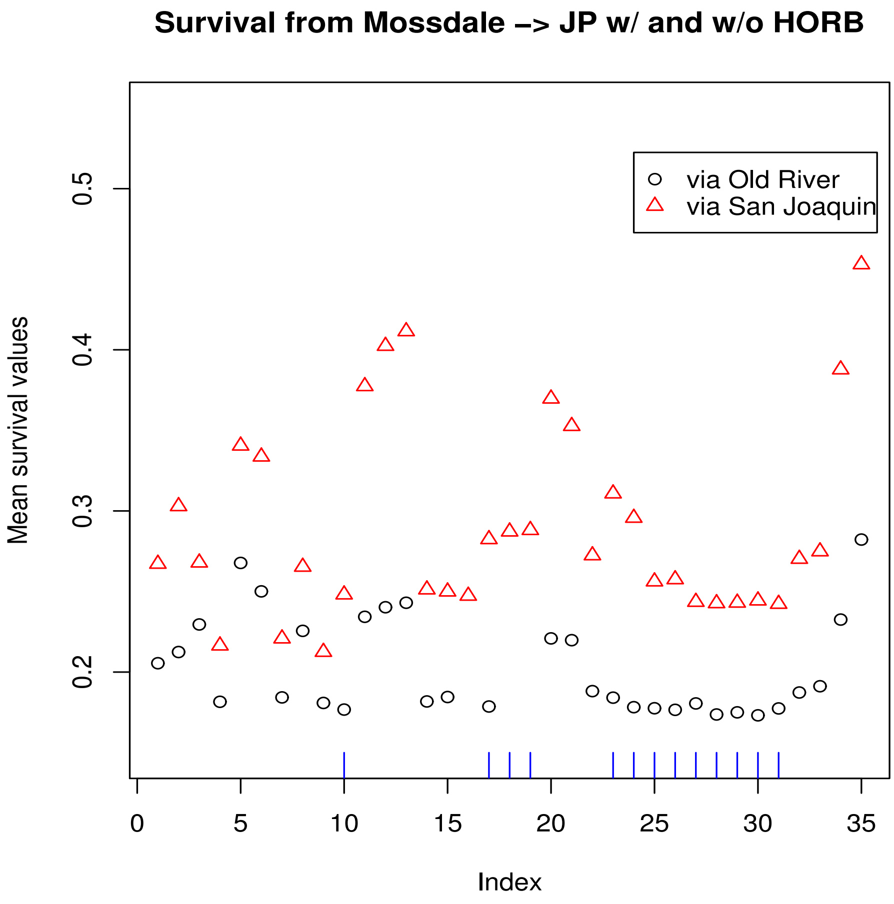


Figure 28. VAMP: Posterior predictive distribution and Bayesian P-values for recoveries at Antioch of releases from Mossdale. P-values are the minimum of the two tail probabilities. (Based on Null.FE.FE model.)

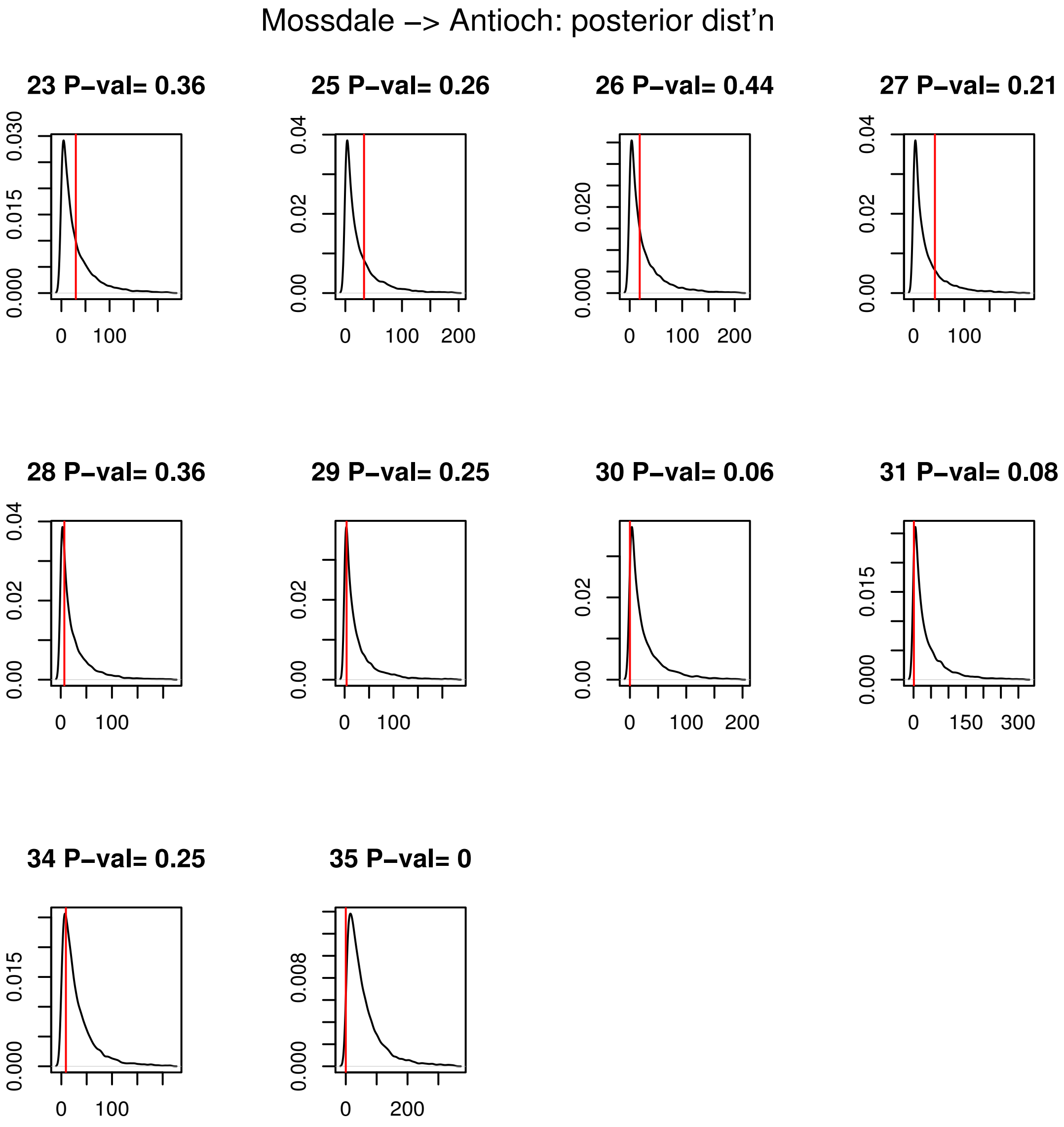


FIGURE 29. VAMP: Scaled residuals versus posterior predictive means. (Based on Null.FE.FE model.)

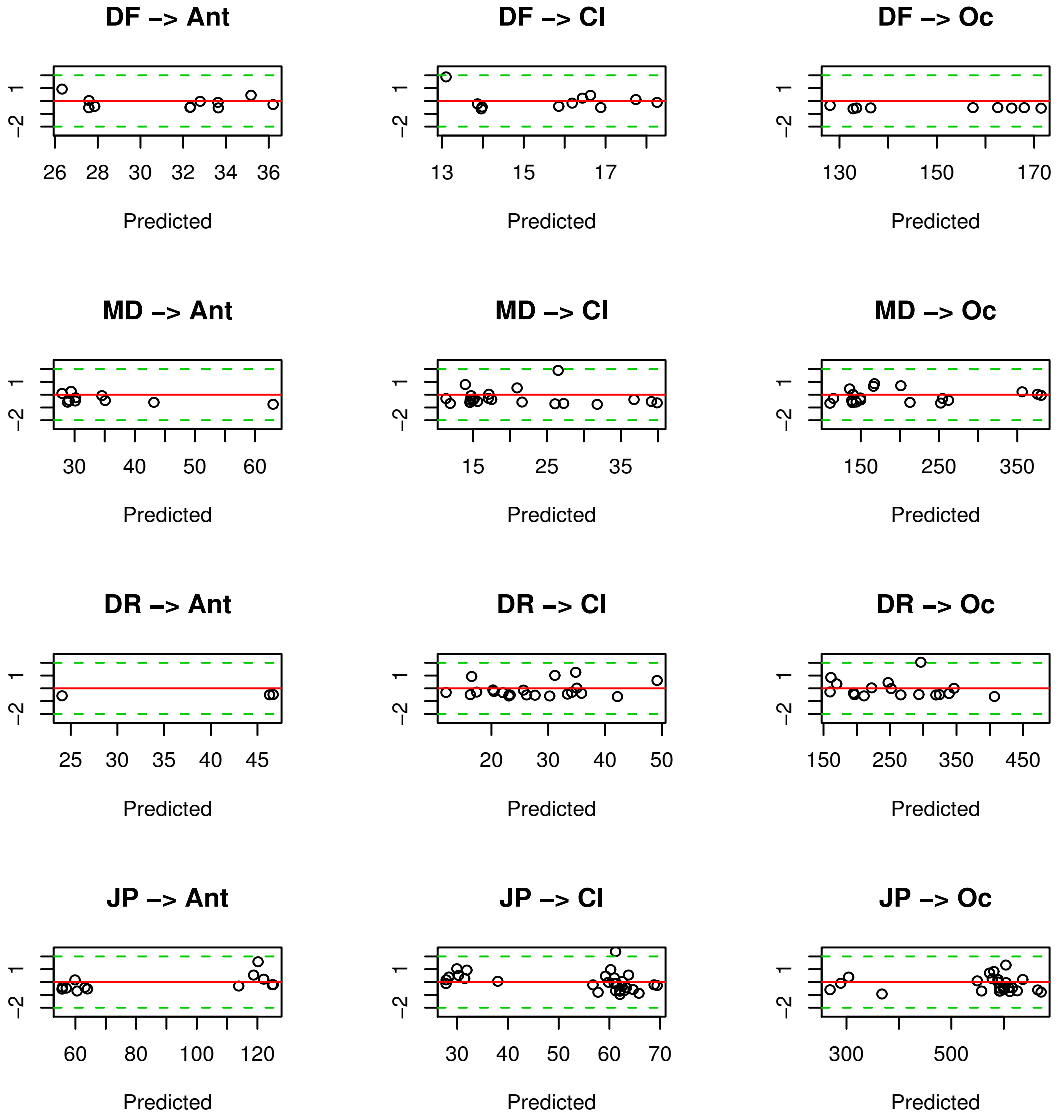


FIGURE 30. VAMP: Random effects residuals, by stream section, for logit of survival plotted against water temperature at release with supersmoother fit superimposed. The effects for Jersey Point are for the logit of Chipps Island recovery rate, either $r_{JP \to Ant \to CI}$ or $r_{JP \to CI}$. (Based on Null.FE.FE model.)

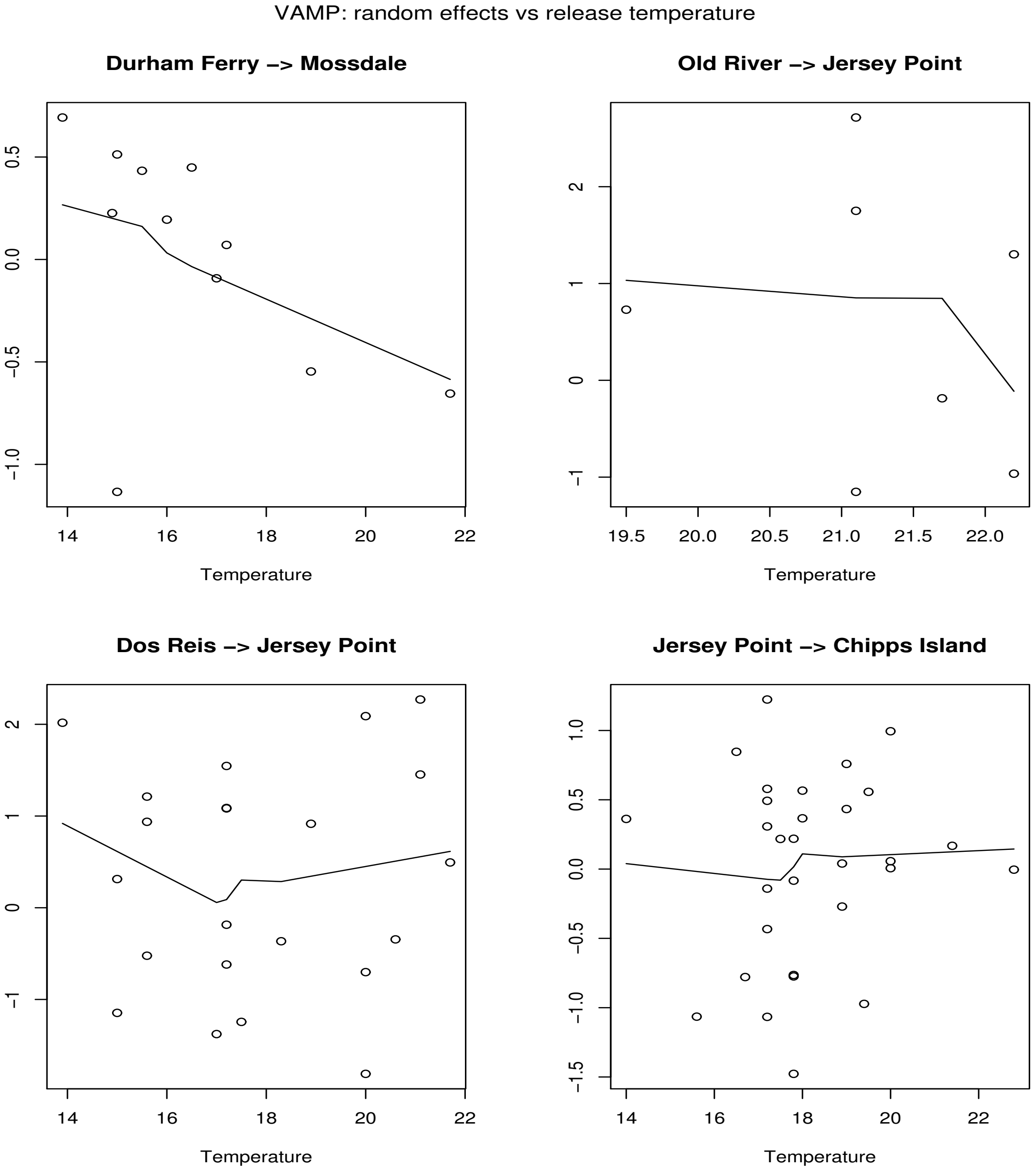


FIGURE 31. VAMP: Random effects residuals, by stream section, for logit of survival plotted against stock origin (FRH=Feather River Hatchery, MRFF=Merced River Fish Facility). The effects for Jersey Point are for the logit of Chipps Island recovery rate, $r_{JP \rightarrow CI}$. (Based on Null.FE.FE model.)

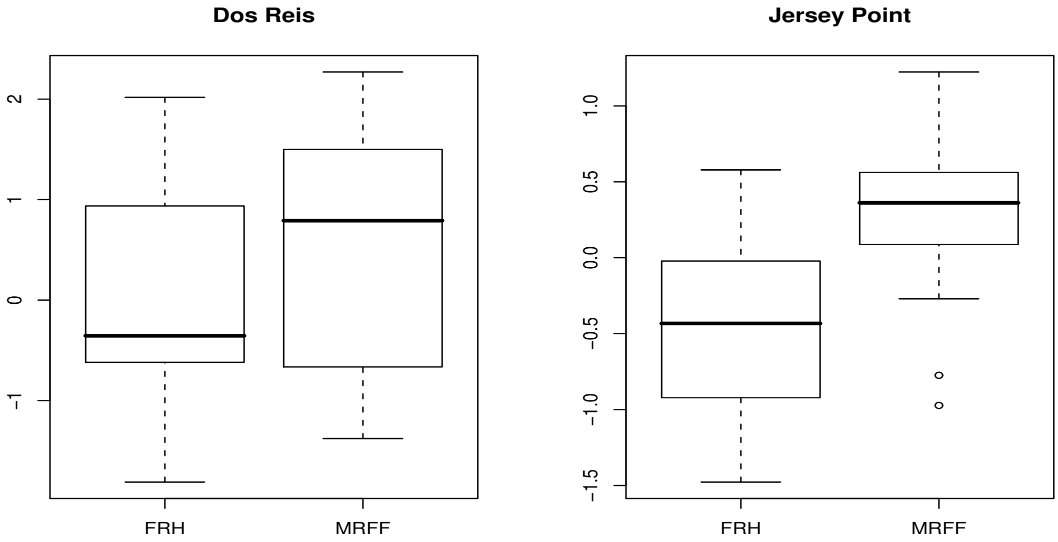
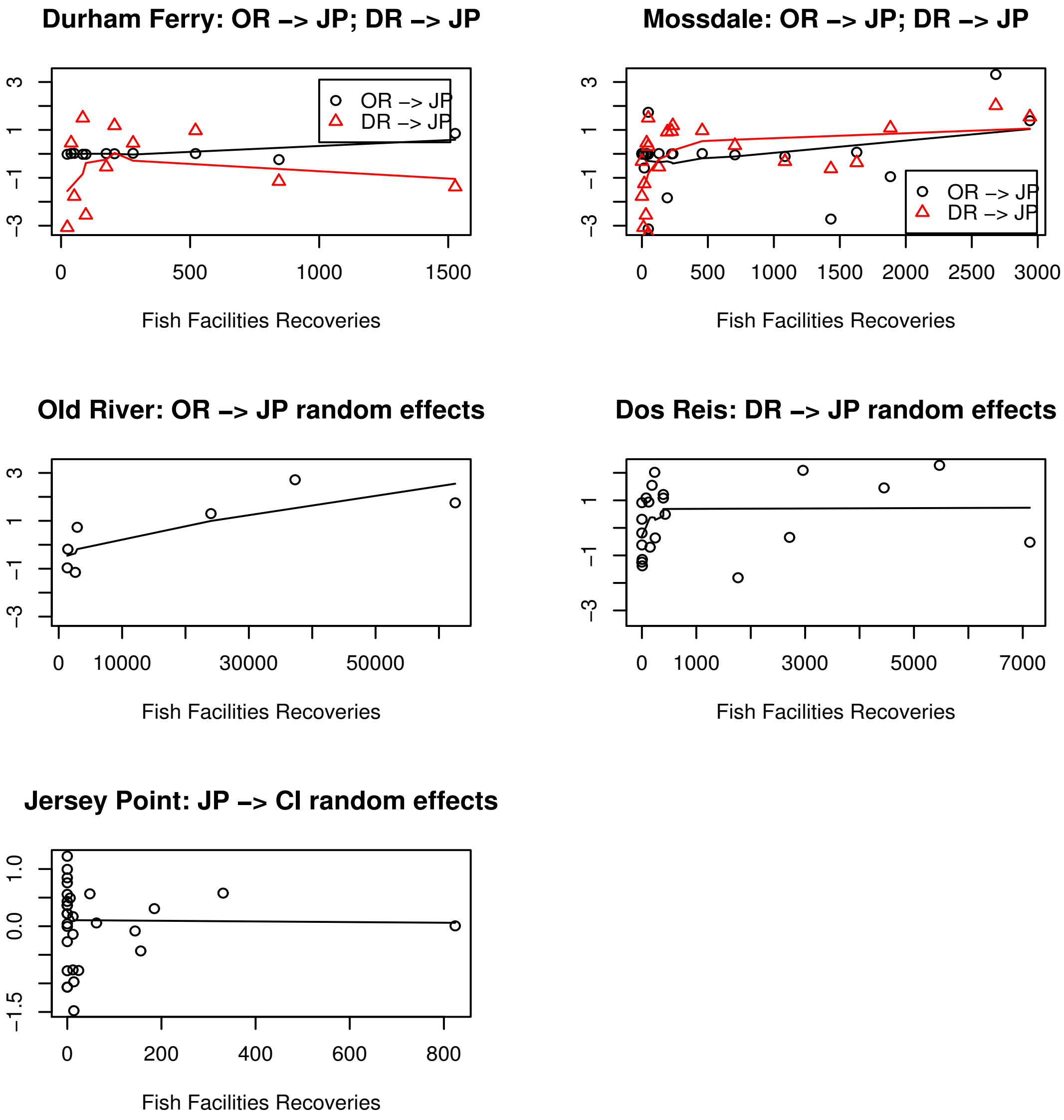


Figure 32. VAMP: Random effects residuals, by stream section, for logit of survival plotted against the estimated number of salmon salvaged at the fish facilities at CVP and SWP. The effects for Jersey Point are for the logit of Chipps Island recovery rate, $r_{JP \to CI}$. (Based on Null.FE.FE model.)



Durham Ferry: OR –> JP; DR –> JP

Mossdale: OR –> JP; DR –> JP

Old River: OR –> JP random effects

Dos Reis: DR –> JP random effects

Jersey Point: JP –> CI random effects

FIGURE 33. DCC: Bootstrap standard errors for $\widehat{\frac{\mu_{\theta(Open)}}{\mu_{\theta(Closed)}}}$ as a function of the number of replications. The number of replications on the x-axis refer to the total number of replications, with half being gates open and half with gates closed; e.g., 10 means 5 experiments with DCC gate open and 5 experiments with DCC gate closed. Number of fish released at each site was fixed at 100,000, R_{Ct}=R_{Ry}=100,000. An extreme value of 62, for n=10 was deleted before plotting.

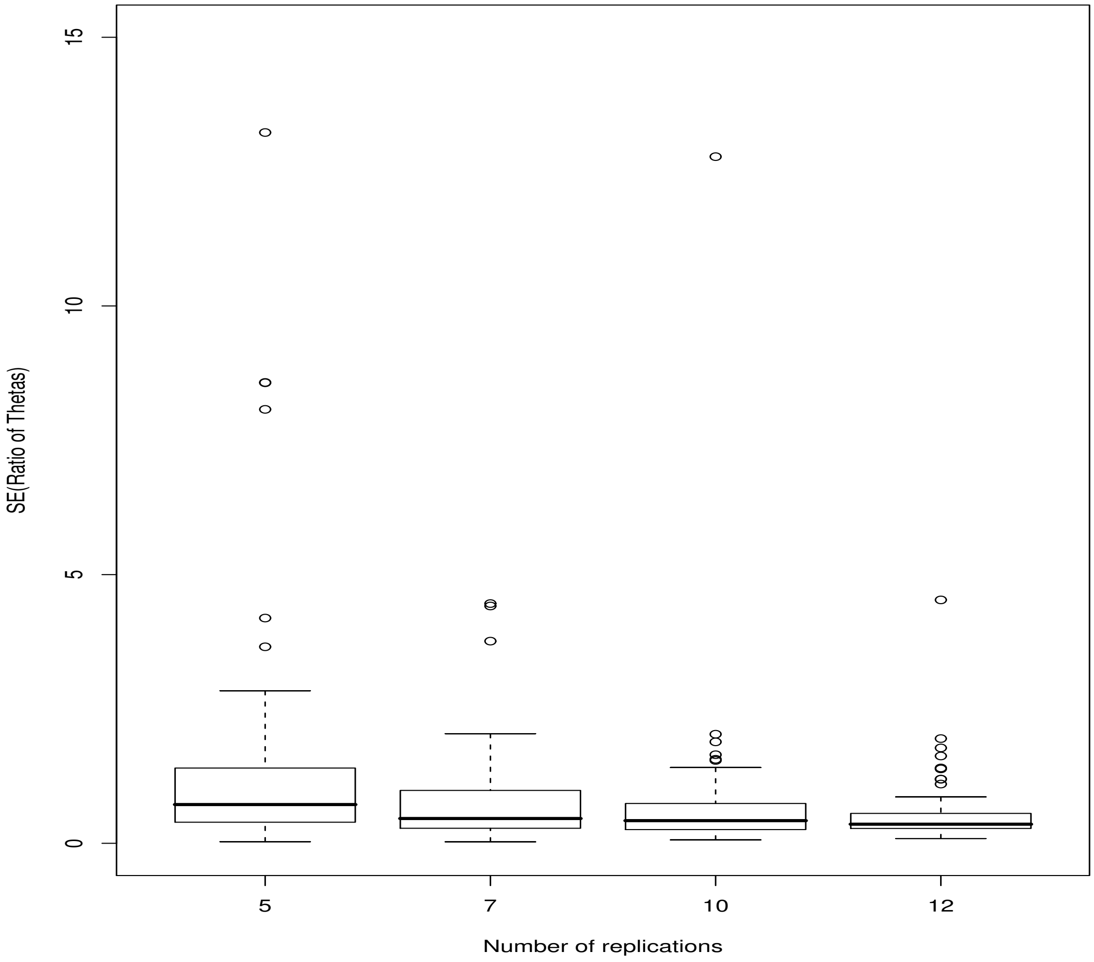
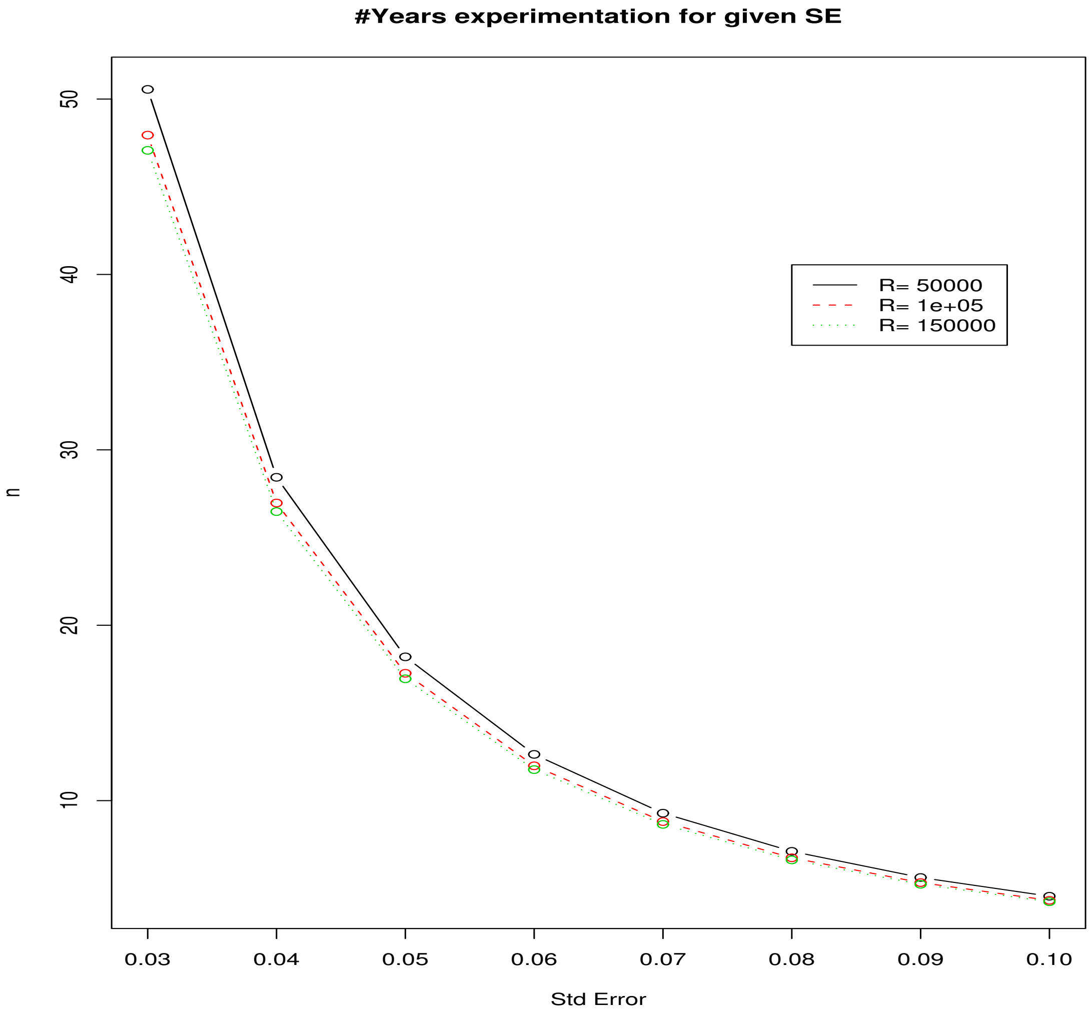


FIGURE 34. Interior: Number of years of experimentation (n) to achieve a specified standard error for $\hat{\mu}_\theta$ for expected numbers of recoveries plotted against observed numbers of recoveries, by release site and recovery location. (μ_θ=0.8.)



APPENDICES

APPENDIX A. DCC AND INTERIOR: THEORETICAL VARIANCE OF $\hat{\mu}_\theta$

The expected value of the ratio of the survival probabilities for two "upstream" releases, μ_θ, can be estimated by averaging year specific estimates of θ_t:

$$\begin{aligned}\hat{\mu}_\theta &= \sum_{t=1}^{n} w_t \hat{\theta}_t \\ &= \sum_{t=1}^{n} w_t \frac{(y_{13,t} + y_{14,t})/R_{1t}}{(y_{23,t} + y_{24,t})/R_{2t}},\end{aligned}$$

where w_t are weights, $\sum_{t=1}^{n} w_t = 1$. Variation in this estimate arises from between year variation in the survival and capture probabilities and within year sampling variation. The following standard result from probability theory reflects these two levels of variation and is used to calculate the variance of $\hat{\mu}_\theta$:

$$V(\hat{\mu}_\theta) = E\left[V\left(\hat{\mu}_\theta|\theta_t, S_{23,t}, p_t, \pi_t\right)\right] + V\left[E\left(\hat{\mu}_\theta|\theta_t, S_{23,t}, p_t, \pi_t\right)\right]. \tag{57}$$

A.1. $V[E]$ **calculation.** Regarding the second term on the righthand side of (57), the expectation portion can be written:

$$E[\hat{\mu}_\theta|\theta_t, S_{23,t}, p_t, \pi_t] = \sum_{t=1}^{n} w_t E[\hat{\theta}_t|\theta_t, S_{23,t}, p_t, \pi_t] \approx \sum_{t=1}^{n} w_t \theta_t,$$

assuming that $\hat{\theta}_t$ is unbiased for θ_t. Then

$$V\left[E(\hat{\mu}_\theta|\theta_t, S_{23,t}, p_t, \pi_t)\right] \approx \sum_{t=1}^{n} w_t^2 V(\theta_t) = \sum_{t=1}^{n} w_t^2 \sigma_\theta^2. \tag{58}$$

If each of the yearly estimates of θ are given equal weight (as would be the case with equal release numbers per year), this component reduces to

$$V\left[E(\hat{\mu}_\theta)|\theta_t, S_{23,t}, p_t, \pi_t)\right] \approx \frac{\sigma_\theta^2}{n}.$$

A.2. $E[V]$ **calculation.** For the first term on the righthand side of (57), the delta approximation (Stuart and Ord, 1987, p. 324) is used to calculate $V(\hat{\mu}_\theta|\theta_t, S_{23,t}, p_t, \pi_t)$:

$$V(\hat{\mu}_\theta|\mu_\theta, S_{23,t}, p_t, \pi_t) = \sum_{t=1}^{n} w_t^2 V(\hat{\theta}_t), \tag{59}$$

where

$$\begin{aligned} V(\hat{\theta}_t) &\approx d_1^2\left(v(y_{13,t}) + v(y_{14,t}) + 2cov(y_{13,t}, y_{14,t})\right) + \\ &\quad d_2^2\left(v(y_{23,t}) + v(y_{24,t}) + 2cov(y_{23,t}, y_{24,t})\right), \end{aligned}$$

and

$$\begin{aligned} d_1 &= \frac{R_{2t}}{R_{1t}}\frac{1}{E[y_{23,t}] + E[y_{24,t}]} = \frac{R_{2t}}{R_{1t}}\frac{1}{R_{2t}S_{23,t}(p_t + (1-p_t)\pi_t)} \\ &= \frac{1}{R_{1t}S_{23,t}(p_t + (1-p_t)\pi_t)} \\ v(y_{13,t}) &= R_{1t}\theta_t S_{23,t}p_t\left(1 - \theta_t S_{23,t}p_t\right) \\ v(y_{14,t}) &= R_{1t}\theta_t S_{23,t}(1-p_t)\pi_t\left(1 - \theta_t S_{23,t}(1-p_t)\pi_t\right) \\ cov(y_{13,t}, y_{14,t}) &= -R_{1t}\theta_t S_{23,t}p_t * \theta_t S_{23,t}(1-p_t)\pi_t \\ d_2 &= \frac{R_{2t}}{R_{1t}}\frac{E[y_{13,t}] + E[y_{14,t}]}{(E[y_{23,t}] + E[y_{24,t}])^2} = \frac{\theta_t S_{23,t}(p_t + (1-p_t)\pi_t)}{R_{2t}\left(S_{23,t}(p_t + (1-p_t)\pi_t)\right)^2} \\ v(y_{23,t}) &= R_{2t}S_{23,t}p_t\left(1 - S_{23,t}p_t\right) \\ v(y_{24,t}) &= R_{2t}S_{23,t}(1-p_t)\pi_t\left(1 - S_{23,t}(1-p_t)\pi_t\right) \\ cov(y_{23,t}, y_{24,t}) &= -R_{2t}S_{23,t}p_t * S_{23,t}(1-p_t)\pi_t \end{aligned}$$

The expected value, $E\left[V(\hat{\mu}_\theta)|\theta_t, S_{23,t}, p_t, \pi_t)\right]$, is also approximated using the delta method (with a second order approximation, Stuart and Ord (1987, p 342)[9]). Assuming independence between θ_t and the survival and capture probabilities, the approximation has the following form:

$$\begin{aligned} E\left[V(\hat{\mu}_\theta)|\theta_t, S_{23,t}, p_t, \pi_t)\right] &\approx \sum_{t=1}^{n} w_t^2\, V(\hat{\theta}_t)\Big|_\mu + \\ (60) \qquad &\quad 0.5\sum_{t=1}^{n} w_t^2\left[\frac{d^2V}{d\theta_t^2}\bigg|_\mu \sigma_{\theta_t}^2 + \frac{d^2V}{dS_{23,t}^2}\bigg|_\mu \sigma_{S_{23,t}}^2 + \frac{d^2V}{dp_t^2}\bigg|_\mu \sigma_{p_t}^2 + \frac{d^2V}{d\pi_t^2}\bigg|_\mu \sigma_{\pi_t}^2\right] \end{aligned}$$

where μ denotes the expected values μ_θ, $\mu_{S_{23}}$, μ_p, and μ_π.

---

[9] Note: simply substituting $(\mu_\theta, \mu_{S_{23}}, \mu_p, \mu_\pi)$ for $(\theta_t, S_{23,t}, p_t, \pi_t)$ into $V(\hat{\theta}_t)$ is relatively inaccurate. Simulations using beta distributions for the survival and capture probabilities indicated that such an approximation was biased low.

Formulae for second derivatives. The formulae for the second derivatives are shown below; to reduce notation the t subscripts have been dropped and $S_{23,t}$ is simply written as S. Furthermore, let

$$\begin{aligned}
N_1 &= \theta p(1-\theta Sp) + \theta(1-p)\pi(1-\theta S(1-p)\pi) - 2\theta^2 pS(1-p)\pi \\
N_2 &= \theta^2 p(1-Sp) + \theta^2(1-p)\pi(1-S(1-p)\pi) - 2\theta^2 pS(1-p)\pi \\
D_1 &= R_1 S(p+(1-p)\pi)^2 \\
D_2 &= R_2 S(p+(1-p)\pi)^2
\end{aligned}$$

Then

$$\frac{d^2V}{d\theta^2} = \frac{d^2N_1}{d\theta^2}D_1^{-1} + \frac{d^2N_2}{d\theta^2}D_2^{-1},$$

where

$$\begin{aligned}
\frac{d^2N_1}{d\theta^2} &= -2Sp^2 - 2S(1-p)^2\pi^2 - 4Sp(1-p)\pi \\
\frac{d^2N_2}{d\theta^2} &= 2p - 2Sp^2 + 2(1-p)\pi - 2S(1-p)^2\pi^2 - 4Sp(1-p)\pi
\end{aligned}$$

And

$$\begin{aligned}
\frac{d^2V}{dS^2} = {} & 2\left[\theta^2p^2 + \theta^2(1-p)^2\pi^2 + 2\theta^2p(1-p)\pi\right] D_1^{-2} R_1(p+(1-p)\pi)^2 + \\
& 2N_1D_1^{-3}\left(R_1(p+(1-p)\pi)^2\right)^2 + \\
& 2\left[\theta^2p^2 + \theta^2(1-p)^2\pi^2 + 2\theta^2p(1-p)\pi\right] D_2^{-2} R_2(p+(1-p)\pi)^2 + \\
& 2N_2D_2^{-3}\left(R_2(p+(1-p)\pi)^2\right)^2.
\end{aligned}$$

And

$$\begin{aligned}
\frac{d^2V}{dp^2} = {} & \frac{d^2N_1}{dp^2}D_1^{-1} - 2\frac{dN_1}{dp}D_1^{-2}\frac{dD_1}{dp} + 2N_1D_1^{-3}\left(\frac{dD_1}{dp}\right)^2 - N_1D_1^{-2}R_1S(2-4\pi+2\pi^2) + \\
& \frac{d^2N_2}{dp^2}D_2^{-1} - 2\frac{dN_2}{dp}D_2^{-2}\frac{dD_2}{dp} + 2N_2D_2^{-3}\left(\frac{dD_2}{dp}\right)^2 - N_2D_2^{-2}R_2S(2-4\pi+2\pi^2),
\end{aligned}$$

where

$$\begin{aligned}
\frac{dN_1}{dp} &= \theta - 2\theta^2 Sp - \theta\pi - \theta^2 S(-2+2p)\pi^2 - 2\theta^2 S(1-2p)\pi \\
\frac{d^2N_1}{dp^2} &= -2\theta^2 S - 2\theta^2 S\pi^2 + 4\theta^2 S\pi \\
\frac{dD_1}{dp} &= R_1 S(2p + 2\pi - 4p\pi + (-2+2p)\pi^2) \\
\frac{dN_2}{dp} &= \theta^2 - 2\theta^2 Sp - \theta^2\pi - \theta^2 S(-2+2p)\pi^2 - 2\theta^2 S(1-2p)\pi \\
\frac{d^2N_2}{dp^2} &= -2\theta^2 S - 2\theta^2 S\pi^2 + 4\theta^2 S\pi \\
\frac{dD_2}{dp} &= R_2 S(2p + 2\pi - 4p\pi + (-2+2p)\pi^2).
\end{aligned}$$

Lastly,

$$\begin{aligned}
\frac{d^2V}{d\pi^2} &= \frac{d^2N_1}{d\pi^2}D_1^{-1} - 2\frac{dN_1}{d\pi}D_1^{-2}\frac{dD_1}{d\pi} + 2N_1D_1^{-3}\left(\frac{dD_1}{d\pi}\right)^2 - 2N_1D_1^{-2}R_1S(1-p)^2 + \\
&\quad \frac{d^2N_2}{d\pi^2}D_2^{-1} - 2\frac{dN_2}{d\pi}D_2^{-2}\frac{dD_2}{d\pi} + 2N_2D_2^{-3}\left(\frac{dD_2}{d\pi}\right)^2 - 2N_2D_2^{-2}R_2S(1-p)^2,
\end{aligned}$$

where

$$\begin{aligned}
\frac{dN_1}{d\pi} &= \theta(1-p) - 2\theta^2 S(1-p)^2\pi - 2\theta^2 Sp(1-p) \\
\frac{d^2N_1}{d\pi^2} &= -2\theta^2 S(1-p)^2 \\
\frac{dD_1}{d\pi} &= 2R_1 S(1-p)(p + (1-p)\pi) \\
\frac{dN_2}{d\pi} &= \theta^2(1-p) - 2\theta^2 S(1-p)^2\pi - 2\theta^2 Sp(1-p) \\
\frac{d^2N_2}{d\pi^2} &= -2\theta^2 S(1-p)^2 \\
\frac{dD_2}{d\pi} &= 2R_2 S(1-p)(p + (1-p)\pi).
\end{aligned}$$

Each of the above second derivatives is then evaluated at the expected values for θ_t, $S_{23,t}$, p_t, and π_t.

A.3. **Summary.** Thus equation (57), which is found by adding equations (58) and (60), yields an approximate theoretical variance. This is what is needed for determining sample sizes and making power calculations. One must put in assumed known parameter values, particularly the means and variances of θ_t, $S_{23,t}$, p_t, and π_t. `R` code has been written that calculates the theoretical variance approximation (Appendix D.1).

The quality of the approximation to the theoretical variance was evaluated using simulations. The simulation code (in `R` code) is listed in Appendix D.2. The results based on 30,000 simulations (example code also given in Appendix D.2) are summarized below; R_1=R_2=50,000 in each case and σ_θ was fixed at 0.1, and E[S_{23}]= 0.9 $\sigma_{S_{23}}$=0.15, E[p_3]=0.002, σ_{p_3}=0.0002, E[π]=0.0079, σ_π=0.00627.

θ	n	Theoretical Std Error	Simulated SE Std Error	Relative Error (%)
0.6	5	0.05117	0.05202	-1.7%
0.6	10	0.03618	0.03685	-1.8%
0.8	5	0.05408	0.05663	-4.7%
0.8	10	0.03824	0.03875	-1.3%
0.95	5	0.05646	0.05795	-2.6%
0.95	10	0.03992	0.04092	-2.5%

The theoretical standard error approximation appears to be biased low, with a negative bias from 1 and 5%.

APPENDIX B. DCC AND INTERIOR: BOOTSTRAP ESTIMATE OF VARIANCE OF $\hat{\mu}_\theta$

To calculate confidence intervals or carry out hypothesis tests in practice, the standard error must be calculated using the data, not hypothesized values for the parameters. Estimates of unknown parameters can be substituted in some cases, but the calculations can be involved. A simpler approach is to use a bootstrap procedure. The general procedure for bootstrapping hierarchical models is described by Davison and Hinkley (1997, pp 100-102).

The gist of the bootstrap procedure is to mimic the original data generation procedure: first, generate samples of the "annual" studies, then generate observations within each generated study. To generate samples of the studies, the release pairs are resampled with replacement; this then reflects between release pair variation. To generate observations, samples are generated from trinomial distributions for recoveries using the observed recovery *rates* for each sampled group. Thus the recoveries within a group are resampled with replacement. An alternative is to sample without replacement, however, with large release numbers the results will be essentially equivalent.

Bootstrap code has been written in `R` (Appendix D.3) that is applicable to the Interior studies and the problem of estimating μ_θ. The quality of the bootstrap standard errors, and 95% confidence intervals based on ± 2 standard errors, was evaluated by simulation study. The bootstrap standard errors compared favorably to empirical standard errors and the confidence intervals were reasonably accurate for the values of μ_θ tried. For example, with θ=0.6, R_1=R_2=50,000, the median bootstrap standard error was 0.03808 compared to an empirical standard error of 0.03641. The percentage of bootstrap based 95% confidence intervals that included μ_θ was 95.16%, thus accurate coverage.

Appendix C. Interior: Sample size determination

There are two sample sizes that can be manipulated to achieve a specified level of precision (standard error) and these are n, the number of replications of paired releases, and R_1 and R_2, the number of fish released. The variance formula for $\hat{\mu}_\theta$ given in Appendix A can be used to solve for R_1, R_2, and n to achieve a specified standard error. For any given standard error there are multiple combinations of R_1, R_2, and n that will work. For simplicity assume that R_1=R_2=R and that the annual weights, w_t, are thus $1/n$. The variance formula (see equations (59) and (60)) can be written:

$$(61)\quad V[\hat{\mu}_\theta] \approx \frac{\sigma_\theta^2}{n} + \frac{1}{n}\left[V(\hat{\theta}_t) + 0.5\left(\left.\frac{d^2V}{d\theta_t^2}\right|_\mu \sigma_{\theta_t}^2 + \left.\frac{d^2V}{dS_{23,t}^2}\right|_\mu \sigma_{S_{23,t}}^2 + \left.\frac{d^2V}{dp_t^2}\right|_\mu \sigma_{p_t}^2 + \left.\frac{d^2V}{d\pi_t^2}\right|_\mu \sigma_{\pi_t}^2\right)\right]$$

The term $V(\hat{\theta}_t)$ and the second derivative terms each have release number, R, in the denominator and the variance formula can be rewritten as:

$$(62)\quad V[\hat{\mu}_\theta] \approx \frac{\sigma_\theta^2}{n} + \frac{1}{n}\left[\frac{A}{R} + 0.5\frac{B}{R}\right]$$

where A and B are constants involving the means and standard deviations of θ_t, $S_{23,t}$, p_t, and π_t (as in equation (61)). One can then solve for n given $V[\hat{\mu}_\theta]$ and R, or for R given n and $V[\hat{\mu}_\theta]$:

$$\begin{aligned} n &= \frac{\sigma_\theta^2 + \frac{1}{R}[A + 0.5B]}{V[\hat{\mu}_\theta]} \\ R &= \frac{A + 0.5B}{nV[\hat{\mu}_\theta] - \sigma_\theta^2}. \end{aligned}$$

`R` code has been written for both of these cases (Appendix D.5).

APPENDIX D. R CODE

D.1. **Interior: Theoretical variance calculation.** The `R` function, `theory.exp.var`, estimates the variance of $\hat{\mu_\theta}$ (the non-Bayesian estimate, see Equation (57)) based on number released, number of replicates (years of experimentation), and parameter values.

```
theory.exp.var <- function(R1,R2,n,mu.theta,sigma2.theta,mu.S,sigma2.S,
  mu.p,sigma2.p,mu.pi,sigma2.pi) {
  # Calculates variance of mu.theta.hat using double variance formula
  # Var() = E[V] + V[E]
  # - delta approximations used for conditional variance and unconditional
  #   expectation

  # Input parameters:
  #  R1, R2   = number released in each group (group 1 is the "upstream" grp)
  #  n        = number of years of experimentation
  #  mu.theta = expected value of theta, the ratio of survival rates
  # sigma2.theta = variance of theta
  #  mu.S        = expected value of S_{23}, survival from location 2 to 3
  # sigma2.S     = variance of S_{23}
  #  mu.p        = expected probability of capture at location 3
  # sigma2.p     = variance of p
  #  mu.pi       = expected probability of recovery (S_{34}*p_4) at loc. 4
  # sigma2.pi    = variance of pi

  theta <- mu.theta; S<-mu.S; p <- mu.p; opi <- mu.pi #saves typing

  N1 <- theta*p*(1-theta*S*p)+theta*(1-p)*opi*
        (1-theta*S*(1-p)*opi)-2*theta^2*p*S*(1-p)*opi

  D1 <- R1*S*(p+(1-p)*opi)^2

  N2 <- theta^2*p*(1-S*p)+theta^2*(1-p)*opi*
        (1-S*(1-p)*opi)-2*theta^2*p*S*(1-p)*opi

  D2 <- R2*S*(p+(1-p)*opi)^2

  #-------- 2nd Derivative wrt Theta -------------
  d2N1     <- -2*S*p^2 - 2*S*(1-p)^2*opi^2- 4*S*p*(1-p)*opi
  d2N2     <- 2*p-2*S*p^2+2*(1-p)*opi- 2*S*(1-p)^2*opi^2- 4*S*p*(1-p)*opi
  d2.theta <- d2N1*D1^(-1) + d2N2*D2^(-1)
```

```
  #-------- 2nd Derivative wrt S_{23} -------------
  d1N1     <- d1N2 <-
              -theta^2*p^2-theta^2*(1-p)^2*opi^2- 2*theta^2*p*(1-p)*opi
  d1D1     <- R1*(p+(1-p)*opi)^2
  d1D2     <- R2*(p+(1-p)*opi)^2
  d2.S23   <- -2*d1N1*D1^(-2)*d1D1 + 2*N1*D1^(-3)*d1D1^2 +
              -2*d1N2*D2^(-2)*d1D2 + 2*N2*D2^(-3)*d1D2^2

  #-------- 2nd Derivative wrt p -------------
  d1N1    <- theta - 2*theta^2*S*p - theta*opi -
              theta^2*S*(-2+2*p)*opi^2 - 2*theta^2*S*(1-2*p)*opi
  d1N2    <- theta^2 - 2*theta^2*S*p - theta^2*opi -
              theta^2*S*(-2+2*p)*opi^2 - 2*theta^2*S*(1-2*p)*opi
  d2N1    <- d2N2  <- -2*theta^2*S*(1+opi^2-2*opi)
  d1D1    <- R1*S*(2*p+2*opi-4*p*opi+(-2+2*p)*opi^2)
  d1D2    <- R2/R1*d1D1

  d2.p     <- (d2N1 * D1^(-1) - 2*d1N1*D1^(-2)*d1D1 +
               2*N1*D1^(-3)*d1D1^2 - N1*D1^(-2)*R1*S*(2-4*opi+2*opi^2))  +
              (d2N2 * D2^(-1) - 2*d1N2*D2^(-2)*d1D2 +
               2*N2*D2^(-3)*d1D2^2 - N2*D2^(-2)*R2*S*(2-4*opi+2*opi^2))

  #-------- 2nd Derivative wrt pi -------------
  d1N1     <- theta*(1-p)   - 2*theta^2*S*(1-p)^2*opi - 2*theta^2*S*p*(1-p)
  d1N2     <- theta^2*(1-p) - 2*theta^2*S*(1-p)^2*opi - 2*theta^2*S*p*(1-p)
  d2N1     <- d2N2 <- -2*theta^2*S*(1-p)^2
  d1D1     <- R1*S*2*(1-p)*(p+(1-p)*opi)
  d1D2     <- R2/R1*d1D1

  d2.pi     <- (d2N1*D1^(-1) - 2*d1N1*D1^(-2)*d1D1 + 2*N1*D1^(-3)*d1D1^2 -
                2*N1*D1^(-2)*R1*S*(1-p)^2) +
               (d2N2*D2^(-1) - 2*d1N2*D2^(-2)*d1D2 + 2*N2*D2^(-3)*d1D2^2 -
                2*N2*D2^(-2)*R2*S*(1-p)^2)

 #----output ----------
 out       <-  (N1/D1+N2/D2) +
                0.5*(d2.theta*sigma2.theta + d2.S23*sigma2.S +
                     d2.p*sigma2.p         + d2.pi*sigma2.pi)
 SE        <- sqrt((1/n)*(out + sigma2.theta))
 return(SE)
}}
```

D.2. **Interior: Simulation of hierarchical recovery model.** The `R` function, `two.grp.sim`, simulates the recoveries from paired releases for a specified number of years of study, `numyrs`. The other input parameters are the number of fish released in each group (`R1` and `R2`) and the expected values and standard deviations of the parameters, θ, S_{23}, p, and π.

```
#-------------------------------------------------------------------------
# --- Pgm to simulate the hierarchical processes of between year variation
# and within year variation in survival, capture, and then estimate
# expected ratio of survival probabilities (mu.theta)

two.grp.sim <- function(numyrs,R1,R2,mu.theta,sig.theta,mu.S23,sig.S23,
                  mu.p,sig.p,mu.pi,sig.pi) {

  temp <- alpha.beta(mu.theta,sig.theta)
  theta <- rbeta(numyrs,temp$alpha,temp$beta)

  temp <- alpha.beta(mu.S23,sig.S23)
  S23  <- rbeta(numyrs,temp$alpha,temp$beta)

  temp <- alpha.beta(mu.p,sig.p)
  p    <- rbeta(numyrs,temp$alpha,temp$beta)

  temp <- alpha.beta(mu.pi,sig.pi)
  pi.o <- rbeta(numyrs,temp$alpha,temp$beta)

  # recoveries from group 1
  y13 <- rbinom(numyrs,R1,theta*S23*p)
  y14 <- rbinom(numyrs,R1-y13,theta*S23*(1-p)*pi.o/(1-theta*S23*p))
  # recoveries from group 2
  y23 <- rbinom(numyrs,R2,S23*p)
  y24 <- rbinom(numyrs,R2-y23,S23*(1-p)*pi.o/(1-S23*p))

  theta.hat <- ((y13+y14)/R1)/((y23+y24)/R2)
  output <- list(theta.hat=theta.hat,y13=y13,y14=y14,y23=y23,y24=y24)
  return(output)
}
```

An example demonstrating use of `two.grp.sim`, along with output, is shown below.

```
two.grp.sim(numyrs=10,R1=60000,R2=75000,mu.theta=0.8,sig.theta=0.12,mu.S23=0.85,sig.S23=0.10,
    mu.p=0.002,sig.p=0.0003,mu.pi=0.008,sig.pi=0.005)
```

```
#$theta.hat
# [1] 0.8438486 0.8993476 0.7716049 0.7328767 0.7480971 0.9375000 0.4288026
# [8] 0.9076545 0.8216946 0.7474530
#
#$y13
# [1]  89  63 100  71  81 124  41  90 115  67
#
#$y14
# [1] 339 709 100 143 548  59  65 427 238 696
#
#$y23
# [1] 139  81 165 111 171 143 122  97 179 136
#
#$y24
# [1]  495  992  159  254  880  101  187  615  358 1140
```

Below is `R` code that uses `two.grp.sim` for 30,000 simulations, estimating θ in each case, calculates the empirical standard error of $\hat{\theta}$, and then compares this standard error to the theoretical approximation.

```
set.seed(201)
numsims <- 30000
numyrs.opt <- 10
numrel.opt <- 50000
mu.theta <- 0.6;     sig.theta <- 0.1
mu.S     <- 0.9;     sig.S23   <- 0.15
mu.p     <- 0.002;   sig.p     <- 0.0002
mu.pi    <- 0.0079;  sig.pi    <- 0.00627   #based on Ctland, DCC recoveries

mean.theta.vector  <- numeric(numsims)
for(i in 1:numsims) {
 out <- two.grp.sim(numyrs=numyrs.opt,R1=numrel.opt,R2=numrel.opt,
  mu.theta=mu.theta,sig.theta=sig.theta,mu.S=mu.S,sig.S23=sig.S23,
  mu.p=mu.p,sig.p=sig.p,mu.pi=mu.pi,sig.pi=sig.pi)$theta.hat
 mean.theta.vector[i] <- mean(out)
 }
empirical.se <- sd(mean.theta.vector)

#--- theoretical variance approximation
out <- theory.exp.var(R1=numrel.opt,R2=numrel.opt,n=numyrs.opt,
  mu.theta=mu.theta,sigma2.theta=sig.theta^2,mu.S=mu.S,sigma2.S=sig.S23^2,
  mu.p=mu.p,sigma2.p=sig.p^2,mu.pi=mu.pi,sigma2.pi=sig.pi^2)
```

```
#--- 95% confidence intervals, using theoretical SE
lb <- mean.theta.vector-2*out
ub <- mean.theta.vector+2*out
performance <- rep(FALSE,numsims)
performance[lb <= mu.theta & mu.theta <= ub] <- TRUE

#print output
cat("Empirical SE=",empirical.se,"\n",
    "Theoretical SE=",out,"rel err=",1-empirical.se/out,"\n",
    "CI coverage=",sum(performance)/numsims,"\n")

# Empirical SE= 0.03685179
# Theoretical SE= 0.03618268 rel err= -0.01849254
# CI coverage= 0.9508667
```

D.3. **Interior: Bootstrap estimate of variance of $\hat{\mu}_\theta$.** The `R` function, `two.grp.boot`, estimates the variance of $\hat{\mu}_\theta$ (the non-Bayesian estimate, see Equation 57 in Appendix A) using `B` bootstrap samples. Other inputs are number of release pairs (`numyrs`), number released from each group, and number of recoveries from each group. Conceptually, one can view locations 1, 2, 3, and 4 as a spatial sequence with 1 furthest upstream and 4 furthest downstream; `y13` is the number recovered from the first release group at "downstream" recovery location 3, below release location 2, and `y14` is the number recovered at downstream recovery location 4, below recovery location 4.

```
two.grp.boot <- function(B,numyrs,R1,R2,y13,y14,y23,y24,wts=NULL,wt.opt=FALSE) {
  #K. Newman, 3 October 2006
  # Modified 7 August 2007 to calculate weighted estimate
  #  Computes a bootstrap estimate of the SE of the estimated
  #    avg. ratio of upstream survival to downstream survival (mu.theta)
  #    given multiple years of paired release and recovery data.

  #    Uses a hierarchical bootstrap:
  #     (1) resample the release pairs (between year variation)
  #     (2) resample the recoveries (within year variation)

  #Not yet computationally efficient....
  mu.theta.star <- numeric(B)
  if(wt.opt) wts <- wts/sum(wts)  #scale to sum to 1.0
  for(b in 1:B) {
    #resample the pairs of release groups first
    n.star   <- sample(1:numyrs,numyrs,replace=TRUE)
    R1.star  <- R1[n.star]
    R2.star  <- R2[n.star]
    p13.star <- y13[n.star]/R1.star
    p14.star <- y14[n.star]/R1.star
    p23.star <- y23[n.star]/R2.star
    p24.star <- y24[n.star]/R2.star

    #next "resample" within each selected release group pairs

    # recoveries from group 1
    y13.star <- rbinom(numyrs,R1.star,p13.star)
    y14.star <- rbinom(numyrs,R1.star-y13.star,p14.star/(1-p13.star))
    # recoveries from group 2
    y23.star <- rbinom(numyrs,R2.star,p23.star)
    y24.star <- rbinom(numyrs,R2.star-y23.star,p24.star/(1-p23.star))
```

```
    theta.hat.star <- ((y13.star+y14.star)/R1.star)/
                      ((y23.star+y24.star)/R2.star)

    #Bootstrap estimate of mu.theta
    if(wt.opt) {
      mu.theta.star[b] <- sum(wts*theta.hat.star)
    } else {
     mu.theta.star[b] <- mean(theta.hat.star)
    }
  }
  boot.se <- sd(mu.theta.star)
  return(boot.se)
}
```

D.4. **DCC: Simulating effect of sample sizes on estimate of DCC effect.** The `R` code simulates the survival and recapture processes when the DCC is either open or closed and outputs a bootstrap estimate of the ratio of expected ratios of DCC closed to DCC open.

```
#DCC sample size determination
#  Based on underlying hierarchical model with multinomial dist'n
#  "True" parameter values based on results from Bayesian analysis
#  For specified b0 and b1 and var(theta)
#    DCC closed: for n/2 times (and R_1 = R_2)
#   (1) generate logit(theta_closed)
#   (2) generate r_{Ry -> CI}, r_{Ry -> Oc}
#   (3) generate observations
#    DCC open: for n/2 times (and R_1 = R_2)
#   (4) generate logit(theta_open)
#   (5) generate r_{Ry -> CI}, r_{Ry -> Oc}
#   (6) generate observations
#   then (7) estimate ratio of means
#   then bootstrap a SE for this ratio....
#    ..repeat the above

#WinBUGS results with last year deleted
b0 <- 0.83; b1 <- 2.29; sig2.theta   <- 7.44
mu.r.Ry.CI <- -6.98;    sig2.r.Ry.CI <- 0.39
mu.r.Ry.Oc <- -4.62;    sig2.r.Ry.Oc <- 0.97

R.Ct <- R.Ry <- 100000
num.reps.seq <- c(5,7,10,12); num.outer <- length(num.reps.seq)
numsims <- 100
ratio.matrix <- se.matrix <- matrix(NA,num.outer,numsims)
dimnames(ratio.matrix) <- dimnames(se.matrix) <- list(2*num.reps.seq,1:numsims)

for(rep in 1:num.outer) {
 num.reps.open <- num.reps.closed <- num.reps.seq[rep]
 print(c("Number of reps=",num.reps.open))
 for(i in 1:numsims) {
  #Simulating the gate-closed group
  theta.closed <- inv.logit(rnorm(num.reps.closed,b0+b1,sqrt(sig2.theta)))
  r.Ry.CI      <- inv.logit(rnorm(num.reps.closed,mu.r.Ry.CI, sqrt(sig2.r.Ry.CI)))
  r.Ry.Oc      <- inv.logit(rnorm(num.reps.closed,mu.r.Ry.Oc, sqrt(sig2.r.Ry.Oc)))
  y.Ct.CI.c    <- rbinom(num.reps.closed,R.Ct,theta.closed*r.Ry.CI)
  y.Ct.Oc.c    <- rbinom(num.reps.closed,R.Ct-y.Ct.CI.c,
                     theta.closed*r.Ry.Oc/(1-theta.closed*r.Ry.CI))
  y.Ry.CI.c    <- rbinom(num.reps.closed,R.Ry, r.Ry.CI)
```

```
y.Ry.Oc.c    <- rbinom(num.reps.closed,R.Ry-y.Ry.CI.c, r.Ry.Oc/(1-r.Ry.CI))
thetac.hat   <- ((y.Ct.CI.c+y.Ct.Oc.c)/R.Ct)/
                ((y.Ry.CI.c+y.Ry.Oc.c)/R.Ry)

#Now the gate-open group
theta.open   <- inv.logit(rnorm(num.reps.open,b0,sqrt(sig2.theta)))
r.Ry.CI      <- inv.logit(rnorm(num.reps.open,mu.r.Ry.CI, sqrt(sig2.r.Ry.CI)))
r.Ry.Oc      <- inv.logit(rnorm(num.reps.open,mu.r.Ry.Oc, sqrt(sig2.r.Ry.Oc)))
y.Ct.CI.o    <- rbinom(num.reps.open,R.Ct,theta.open*r.Ry.CI)
y.Ct.Oc.o    <- rbinom(num.reps.open,R.Ct-y.Ct.CI.c,
                   theta.open*r.Ry.Oc/(1-theta.open*r.Ry.CI))
y.Ry.CI.o    <- rbinom(num.reps.open,R.Ry, r.Ry.CI)
y.Ry.Oc.o    <- rbinom(num.reps.open,R.Ry-y.Ry.CI.c, r.Ry.Oc/(1-r.Ry.CI))
thetao.hat   <- ((y.Ct.CI.o+y.Ct.Oc.o)/R.Ct)/
                ((y.Ry.CI.o+y.Ry.Oc.o)/R.Ry)

ratio.pt.est <-  mean(thetao.hat)/mean(thetac.hat)
ratio.matrix[rep,i] <- ratio.pt.est

#--- bootstrap se for the ratio estimate
B <- 10000
ratio.boot <- numeric(B)

for(b in 1:B) {
    #resample the pairs of release groups first
    nc.star   <- sample(1:num.reps.closed,num.reps.closed,replace=TRUE)
    no.star   <- sample(1:num.reps.open,  num.reps.open,  replace=TRUE)

    p13c.star <- y.Ct.CI.c[nc.star]/R.Ct
    p14c.star <- y.Ct.Oc.c[nc.star]/R.Ct
    p23c.star <- y.Ry.CI.c[nc.star]/R.Ry
    p24c.star <- y.Ry.CI.c[nc.star]/R.Ry

    p13o.star <- y.Ct.CI.o[no.star]/R.Ct
    p14o.star <- y.Ct.Oc.o[no.star]/R.Ct
    p23o.star <- y.Ry.CI.o[no.star]/R.Ry
    p24o.star <- y.Ry.CI.o[no.star]/R.Ry

    #next "resample" within each selected release group pairs
    y13c.star <- rbinom(num.reps.closed,R.Ct,p13c.star)
    y14c.star <- rbinom(num.reps.closed,R.Ct-y13c.star,p14c.star/(1-p13c.star))
    y23c.star <- rbinom(num.reps.closed,R.Ry,p23c.star)
    y24c.star <- rbinom(num.reps.closed,R.Ry-y23c.star,p24c.star/(1-p23c.star))
    thetac.hat.star <- ((y13c.star+y14c.star)/R.Ct)/
```

```
                       ((y23c.star+y24c.star)/R.Ry)

      y13o.star <- rbinom(num.reps.open,R.Ct,p13o.star)
      y14o.star <- rbinom(num.reps.open,R.Ct-y13o.star,p14o.star/(1-p13o.star))
      y23o.star <- rbinom(num.reps.open,R.Ry,p23o.star)
      y24o.star <- rbinom(num.reps.open,R.Ry-y23o.star,p24o.star/(1-p23o.star))
      thetao.hat.star <- ((y13o.star+y14o.star)/R.Ct)/
                         ((y23o.star+y24o.star)/R.Ry)

      ratio.boot[b] <- mean(thetao.hat.star)/mean(thetac.hat.star)
    }
    boot.se <- sd(ratio.boot)
    se.matrix[rep,i] <- boot.se
    print(c("iter=",i,"pt est of ratio=",round(ratio.pt.est,2),"se =",round(boot.se,2)))
  }
}
```

D.5. **Interior: Sample size determination.** The `R` function, `sampsize.interior`, outputs either the release number `R` or the number of release pairs `n` required to achieve a specified standard error `targSE` for $\hat{\mu}_\theta$.

```
sampsize.interior <- function(nopt=TRUE,Ropt=FALSE, targSE,
   mu.theta,sigma2.theta,mu.S,sigma2.S,
   mu.p,sigma2.p,mu.pi,sigma2.pi) {
  # Sample size determination
  # Based on theory.exp.var() R function.

  #set nopt=TRUE and Ropt=R to achieve target SE
  #set nopt=n and Ropt=TRUE to achieve target SE

  if(nopt) R <- Ropt
  if(Ropt) n <- nopt
  R1 <- R2 <- R

  theta <- mu.theta; S<-mu.S; p <- mu.p; opi <- mu.pi #saves typing

  N1 <- theta*p*(1-theta*S*p)+theta*(1-p)*opi*
        (1-theta*S*(1-p)*opi)-2*theta^2*p*S*(1-p)*opi

  D1 <- R1*S*(p+(1-p)*opi)^2

  N2 <- theta^2*p*(1-S*p)+theta^2*(1-p)*opi*
        (1-S*(1-p)*opi)-2*theta^2*p*S*(1-p)*opi

  D2 <- R2*S*(p+(1-p)*opi)^2

  #-------- 2nd Derivative wrt Theta -------------
  d2N1     <- -2*S*p^2 - 2*S*(1-p)^2*opi^2- 4*S*p*(1-p)*opi
  d2N2     <- 2*p-2*S*p^2+2*(1-p)*opi- 2*S*(1-p)^2*opi^2- 4*S*p*(1-p)*opi
  d2.theta <- d2N1*D1^(-1) + d2N2*D2^(-1)

  #-------- 2nd Derivative wrt S_{23} -------------
  d1N1     <- d1N2 <-
             -theta^2*p^2-theta^2*(1-p)^2*opi^2- 2*theta^2*p*(1-p)*opi
  d1D1     <- R1*(p+(1-p)*opi)^2
  d1D2     <- R2*(p+(1-p)*opi)^2
  d2.S23   <- -2*d1N1*D1^(-2)*d1D1 + 2*N1*D1^(-3)*d1D1^2 +
             -2*d1N2*D2^(-2)*d1D2 + 2*N2*D2^(-3)*d1D2^2

  #-------- 2nd Derivative wrt p -------------
```

```
  d1N1    <- theta - 2*theta^2*S*p - theta*opi -
              theta^2*S*(-2+2*p)*opi^2 - 2*theta^2*S*(1-2*p)*opi
  d1N2    <- theta^2 - 2*theta^2*S*p - theta^2*opi -
              theta^2*S*(-2+2*p)*opi^2 - 2*theta^2*S*(1-2*p)*opi
  d2N1    <- d2N2  <- -2*theta^2*S*(1+opi^2-2*opi)
  d1D1    <- R1*S*(2*p+2*opi-4*p*opi+(-2+2*p)*opi^2)
  d1D2    <- R2/R1*d1D1

  d2.p     <- (d2N1 * D1^(-1) - 2*d1N1*D1^(-2)*d1D1 +
               2*N1*D1^(-3)*d1D1^2 - N1*D1^(-2)*R1*S*(2-4*opi+2*opi^2))  +
              (d2N2 * D2^(-1) - 2*d1N2*D2^(-2)*d1D2 +
               2*N2*D2^(-3)*d1D2^2 - N2*D2^(-2)*R2*S*(2-4*opi+2*opi^2))

  #-------- 2nd Derivative wrt pi -------------
  d1N1     <- theta*(1-p)   - 2*theta^2*S*(1-p)^2*opi - 2*theta^2*S*p*(1-p)
  d1N2     <- theta^2*(1-p) - 2*theta^2*S*(1-p)^2*opi - 2*theta^2*S*p*(1-p)
  d2N1     <- d2N2 <- -2*theta^2*S*(1-p)^2
  d1D1     <- R1*S*2*(1-p)*(p+(1-p)*opi)
  d1D2     <- R2/R1*d1D1

  d2.pi     <- (d2N1*D1^(-1) - 2*d1N1*D1^(-2)*d1D1 + 2*N1*D1^(-3)*d1D1^2 -
                2*N1*D1^(-2)*R1*S*(1-p)^2) +
               (d2N2*D2^(-1) - 2*d1N2*D2^(-2)*d1D2 + 2*N2*D2^(-3)*d1D2^2 -
                2*N2*D2^(-2)*R2*S*(1-p)^2)

 A       <-  R*(N1/D1+N2/D2)
 B       <-  R*(d2.theta*sigma2.theta + d2.S23*sigma2.S +
                     d2.p*sigma2.p    + d2.pi*sigma2.pi)

 if(nopt) {
  n <- (sigma2.theta+ (1/R)*(A+0.5*B))/targSE^2
  return(n)
  }
 else {
  R <- (A+0.5*B)/(n*targSE^2-sigma2.theta)
  return(R)
 }
}
```

Demonstration of usage:

```
mu.theta <- 0.8;     sig.theta <- 0.1
```

```
mu.S     <- 0.9;     sig.S23   <- 0.15
mu.p     <- 0.002;   sig.p     <- 0.0002
mu.pi    <- 0.0079;  sig.pi    <- 0.00627

sampsize(nopt=TRUE,Ropt=50000, targSE=0.05,
   mu.theta=mu.theta,sigma2.theta=sig.theta^2,
   mu.S=mu.S,sigma2.S=sig.S23^2,
   mu.p=mu.p,sigma2.p=sig.p^2,
   mu.pi=mu.pi,sigma2.pi=sig.pi^2)

#[1] 5.8491
```

Thus need 5.85 or 6 years of paired releases, each of size 50,000, to achieve a standard error of 0.05.

D.6. DA 8: Simulating the effect of sample size on the precision of β_1.

```
#--- Simulating hierarchical model and indirect fitting procedure
#  for Delta Action 8 experiments
#  and then calculating the Std Deviation of the estimates
b0    <- -0.4; b1 <- -0.57; sig.theta <- sqrt(0.79)
mu.rc <- -7.71;  sig.rc <- sqrt(0.1)
mu.ro <- -5.63;  sig.ro <- sqrt(0.64)

R.set <- c(50000, 100000, 150000); n.R <- length(R.set)
n.set <- c(15,20,25)     ; n.n <- length(n.set)
sd.mat.b1 <- mean.mat.b1 <- matrix(NA,n.R,n.n)
dimnames(sd.mat.b1) <- dimnames(mean.mat.b1) <-
         list(paste("R=",R.set),paste("n=",n.set))
numsims <- 1000
b1.vec  <- numeric(numsims)

inv.logit <- function(x) exp(x)/(1+exp(x))

for(i in 1:n.R) {
  R <- R.set[i]
  for(j in 1:n.n) {
    n <- n.set[j]
    cat("R=",R,"n=",n,"\n")
    for(k in 1: numsims) {
       #simulate parameters
       exports <- runif(n,1500,11000)
       std.exports <- (exports-6058)/3158
       temp    <- rnorm(n,b0+b1*std.exports,sig.theta)
       theta   <- inv.logit(temp)
       temp    <- rnorm(n,mu.rc,sig.rc)
       rc      <- inv.logit(temp)
       temp    <- rnorm(n,mu.ro,sig.ro)
       ro      <- inv.logit(temp)

       #simulate recoveries
       y.gs.ci <- rbinom(n,R,theta*rc)
       y.gs.oc <- rbinom(n,R-y.gs.ci,(theta*ro)/(1-theta*rc))
       y.ry.ci <- rbinom(n,R,rc)
       y.ry.oc <- rbinom(n,R-y.ry.ci,ro/(1-ro))

       #estimate theta's (divisions by R cancel)
       theta.hat <- (y.gs.ci+y.gs.oc)/(y.ry.ci+y.ry.oc)
```

```
       logit.theta.hat <- logit(theta.hat)
       miss <- is.na(logit.theta.hat) | is.infinite(logit.theta.hat)

       #regress theta.hats on exports
       temp <- lm(logit.theta.hat[!miss] ~ std.exports[!miss])
       b1.vec[k] <- coef(temp)[[2]]
    }
  sd.mat.b1[i,j] <- sd(b1.vec,na.rm=TRUE)
  mean.mat.b1[i,j] <- mean(b1.vec,na.rm=TRUE)
  }
}
```

D.7. **VAMP: Simulating effect of sample size on precision of parameter estimates.**

```
#--- Simulating hierarchical model and indirect fitting procedure
#  for VAMP experiments and then calculating the IQR of the estimates

numsims <- 10000

# Utility function
iqr <- function(x) {
 out <- diff(quantile(x,prob=c(0.25,0.75),na.rm=TRUE))
 return(out)
}

# Durham Ferry to Mossdale Section: function of flow
b0    <- -2.5 ; b1 <- 1.0; sig.df.md <- 1/sqrt(0.1)

# Mossdale to Dos Reis Section: function of flow, HORB, exports*(1-HORB)
g0 <- -1.5;  g1 <- 0.32; g2 <- 5;  g4 <- -1.4; sig.md.dr <- 1/sqrt(0.14)

# Dos Reis to Jersey Point Section: function of flow, HORB, exports
xi0   <- -1.5; xi1 <- 0.71; xi2 <- 5; xi3 <- -0.5; sig.dr.jp <- 1/sqrt(0.79)

# Jersey Point to Antioch, Chipps Island, and the Ocean
mu.jp.ant <- -6.34; sig.jp.ant <- 1/sqrt(2.4)
mu.jp.ci  <- -6.48; sig.jp.ci  <- 1/sqrt(12.4)
mu.jp.oc  <- -4.61; sig.jp.oc  <- 1/sqrt(0.7)

R.set <- c(50000, 100000, 150000); n.R <- length(R.set)
n.set <- seq(15,25,by=5)     ; n.n <- length(n.set)

iqr.mat.b1 <- median.mat.b1 <- matrix(NA,n.R,n.n)
iqr.mat.g1 <- median.mat.g1 <- iqr.mat.g2 <- median.mat.g2 <-
iqr.mat.g4 <- median.mat.g4 <- matrix(NA,n.R,n.n)
iqr.mat.xi1 <- median.mat.xi1 <- iqr.mat.xi2 <- median.mat.xi2 <- iqr.mat.xi3 <-
    median.mat.xi3 <- matrix(NA,n.R,n.n)

dimnames(iqr.mat.b1)  <- dimnames(median.mat.b1)  <-
dimnames(iqr.mat.g1)  <- dimnames(median.mat.g1)  <-
dimnames(iqr.mat.g2)  <- dimnames(median.mat.g2)  <-
dimnames(iqr.mat.g4)  <- dimnames(median.mat.g4)  <-
dimnames(iqr.mat.xi1) <- dimnames(median.mat.xi1) <-
dimnames(iqr.mat.xi2) <- dimnames(median.mat.xi2) <-
dimnames(iqr.mat.xi3) <- dimnames(median.mat.xi3) <-
```

```
         list(paste("R=",R.set),paste("n=",n.set))

b1.vec  <- g1.vec <- g2.vec <- g4.vec <- xi1.vec <-
  xi2.vec <- xi3.vec <-  numeric(numsims)

for(i in 1:n.R) {
  R <- R.set[i]
  for(j in 1:n.n) {
    n <- n.set[j]
    cat("R=",R,"n=",n,"\n")
    for(k in 1: numsims) {
       #simulate parameters
       flow        <- rgamma(n,1.4,0.00013)
       std.flow    <- (flow-10400)/8800
       exports     <- rgamma(n,3.62,0.0016)
       std.exports <- (exports-2200)/1150
       HORB        <- numeric(n)
       barrier     <- rbinom(sum(flow<=7000),1,0.5)
       HORB[flow <= 7000] <- barrier

       temp    <- rnorm(n,b0+b1*std.flow,sig.df.md)
       df.md   <- inv.logit(temp)

       temp    <- rnorm(n,g0+g1*std.flow + g2*HORB +
                   g4*std.exports*(1-HORB), sig.md.dr)
       md.dr   <- inv.logit(temp)

       temp    <- rnorm(n,xi0+xi1*std.flow+xi2*HORB + xi3*std.exports, sig.dr.jp)
       dr.jp   <- inv.logit(temp)

       temp    <- rnorm(n,mu.jp.ant,sig.jp.ant)
       ra      <- inv.logit(temp)

       temp    <- rnorm(n,mu.jp.ci,sig.jp.ci)
       rc      <- inv.logit(temp)

       temp    <- rnorm(n,mu.jp.oc,sig.jp.oc)
       ro      <- inv.logit(temp)

       #simulate recoveries at Antioch, Chipps Island, and Ocean
       temp <- df.md*md.dr*dr.jp; p1 <- temp*ra; p2 <- temp*rc; p3 <- temp*ro
       y.df.ant <- rbinom(n,R,p1)
       y.df.ci  <- rbinom(n,R-y.df.ant,p2/(1-p1))
       y.df.oc  <- rbinom(n,R-y.df.ant-y.df.ci,p3/(1-p2-p3))
```

```
temp <- temp/df.md; p1 <- temp*ra; p2 <- temp*rc; p3 <- temp*ro
y.md.ant <- rbinom(n,R,p1)
y.md.ci  <- rbinom(n,R-y.md.ant,p2/(1-p1))
y.md.oc  <- rbinom(n,R-y.md.ant-y.md.ci,p3/(1-p1-p2))

temp <- temp/md.dr; p1 <- temp*ra; p2 <- temp*rc; p3 <- temp*ro
y.dr.ant <- rbinom(n,R,p1)
y.dr.ci  <- rbinom(n,R-y.dr.ant,p2/(1-p1))
y.dr.oc  <- rbinom(n,R-y.dr.ant-y.dr.ci,p3/(1-p1-p2))

y.jp.ant <- rbinom(n,R,ra)
y.jp.ci  <- rbinom(n,R,rc)
y.jp.oc  <- rbinom(n,R,ro)

#estimate theta's (divisions by R cancel)
theta.df.md <- (y.df.ant+y.df.ci+y.df.oc)/(y.md.ant+y.md.ci+y.md.oc)
theta.df.md[theta.df.md >= 1 | is.infinite(theta.df.md)] <- 0.999
theta.df.md[theta.df.md <= 0] <- 0.001
miss.df <- is.na(theta.df.md)
logit.theta.df.md <- logit(theta.df.md[!miss.df])

theta.md.dr <-  (y.md.ant+y.md.ci+y.md.oc)/(y.dr.ant+y.dr.ci+y.dr.oc)
theta.md.dr[theta.md.dr >= 1 | is.infinite(theta.md.dr)] <- 0.999
theta.md.dr[theta.md.dr <= 0] <- 0.001
miss.md <- is.na(theta.md.dr)
logit.theta.md.dr <- logit(theta.md.dr[!miss.md])

theta.dr.jp <- (y.dr.ant+y.dr.ci+y.dr.oc)/(y.jp.ant+y.jp.ci+y.jp.oc)
theta.dr.jp[theta.dr.jp >= 1 | is.infinite(theta.dr.jp)] <- 0.999
theta.dr.jp[theta.dr.jp <= 0] <- 0.001
miss.dr <- is.na(theta.dr.jp)
logit.theta.dr.jp <- logit(theta.dr.jp[!miss.dr])

#regress theta.hats
# survival from Durham Ferry to Mossdale
temp <- lm(logit.theta.df.md ~ std.flow[!miss.df])
b1.vec[k] <- coef(temp)[[2]]

# survival from Mossdale to Dos Reis
temp <- lm(logit.theta.md.dr ~ std.flow[!miss.md] +
           HORB[!miss.md] + (std.exports*(1-HORB))[!miss.md])
g1.vec[k] <- coef(temp)[[2]]
g2.vec[k] <- coef(temp)[[3]]
```

```
      g4.vec[k] <- coef(temp)[[4]]

      # survival from Dos Reis to Jersey Point
      temp <- lm(logit.theta.dr.jp ~ std.flow[!miss.dr] + HORB[!miss.dr] +
               std.exports[!miss.dr])
      xi1.vec[k]<- coef(temp)[[2]]
      xi2.vec[k]<- coef(temp)[[3]]
      xi3.vec[k]<- coef(temp)[[4]]

    }
  iqr.mat.b1[i,j]   <- iqr(b1.vec)
  median.mat.b1[i,j] <- median(b1.vec,na.rm=TRUE)
  iqr.mat.g1[i,j]   <- iqr(g1.vec)
  median.mat.g1[i,j] <- median(g1.vec,na.rm=TRUE)
  iqr.mat.g2[i,j]   <- iqr(g2.vec)
  median.mat.g2[i,j] <- median(g2.vec,na.rm=TRUE)
  iqr.mat.g4[i,j]   <- iqr(g4.vec)
  median.mat.g4[i,j] <- median(g4.vec,na.rm=TRUE)

  iqr.mat.xi1[i,j]  <- iqr(xi1.vec)
  median.mat.xi1[i,j]<- median(xi1.vec,na.rm=TRUE)
  iqr.mat.xi2[i,j]  <- iqr(xi2.vec)
  median.mat.xi2[i,j]<- median(xi2.vec,na.rm=TRUE)
  iqr.mat.xi3[i,j]  <- iqr(xi3.vec)
  median.mat.xi3[i,j]<- median(xi3.vec,na.rm=TRUE)
  }
}
```

APPENDIX E. `WinBUGS` CODE WITH `R` INTERFACE

E.1. **DCC hierarchical model.** Negative binomial distribution for Level 1, logit transformation of θ for Level 2, gamma priors for precision for Level 3.

`R` code frontend to `WinBUGS`

```
library(R2WinBUGS)

input.data <- list(
 R.Ct     = c(96706, 100302, 107249, 106901, 62604, 100626,
         98866, 100919, 102480, 99827, 51211, 50659, 90720),
 R.Ryde=c(92693,    51103,   52741,  53961,  59998, 107161, 101320,
         51008,   53238, 53942, 51046, 50601, 51134),
 y.ct.ci = c(89, 73, 151, 37, 37, 38, 39, 43, 145, 5, 46, 19, 21),
 y.ct.oc = c(428, 1981, 1188, 1037, 399, 313, 1692, 1434, 936, 70, 240, 41, 84),
 y.ry.ci = c(96, 47, 104, 44, 38, 89, 75, 47, 145, 38, 58, 26, 8),
 y.ry.oc = c(368, 1607, 1076, 252, 268, 926, 1979, 1039, 1324, 285, 417, 82, 10),
 gate.pos=c(1,1,1,1,0,0,0,0,0,0,0,0,0), n=13)
n  <- input.data$n

init.val.generator <- function(n) {
   eps.theta   <- rnorm(n,0,0.1); eps.rc      <- rnorm(n,0,0.1)
   eps.ro      <- rnorm(n,0,0.1); sigma.theta <- runif(1,0,20)
   sigma.rc    <- runif(1,0,20);  sigma.ro    <- runif(1,0,20)
   b0          <- rnorm(1,-9,1);  b1          <- rnorm(1,-2,1)
   mu.rc       <- rnorm(1,-1,0.5);mu.ro       <- rnorm(1,-1,0.5)
   k.ci        <- sample(1:100,1);k.oc        <- sample(1:100,1)

   out <- list( b0 = b0,b1=b1,mu.rc=mu.rc, mu.ro= mu.ro,
     k.ci=k.ci,k.oc=k.oc)

   return(out)
}

init.values <- list(init.val.generator(n),
        init.val.generator(n), init.val.generator(n))

params <- c("b0","b1","mu.rc","mu.ro","sigma.theta","sigma.rc","sigma.ro",
    "k.ci","k.oc")

out.DCC.negbin <- bugs(data=input.data, inits=init.values,
  parameters.to.save=params, model.file=
  "C:/Documents and Settings/Ken Newman/Desktop/CalFed_Pat/Model_DCC_NegBin.txt",
 n.chains=3, n.iter=50000, n.burnin=10000,n.thin=10,debug=TRUE)
```

WinBUGS model code

```
# Code for DCC analysis of gate position effect on Courtland
#    releases'recovery rate (relative to Ryde releases) that are later recovered at
#    Chipps Island, and in the Ocean fisheries.

model {

    #Priors
       b0          ~ dnorm(0,1.0E-6); b1          ~ dnorm(0,1.0E-6)
       mu.rc       ~ dnorm(0,1.0E-6); mu.ro       ~ dnorm(0,1.0E-6)
       sigma.theta ~ dunif(0,20);     sigma.rc    ~ dunif(0,20)
       sigma.ro    ~ dunif(0,20)
       k.ci        ~ dunif(0,1000);   k.oc        ~ dunif(0,1000)
       tau.theta   <- 1/(sigma.theta*sigma.theta)
       tau.rc      <- 1/(sigma.rc*sigma.rc)
       tau.ro      <- 1/(sigma.ro*sigma.ro)

    for(i in 1:n) {

      # random effects
      eps.theta[i]      ~ dnorm(0.0, tau.theta)
      eps.rc[i]         ~ dnorm(0.0, tau.rc)
      eps.ro[i]         ~ dnorm(0.0, tau.ro)

     # rc = recovery probability at Chipps Island
     # ro = recovery probability in Ocean fisheries
     # theta is the ratio of Courtland survival probability to Ryde survival probability
      log(theta[i])      <- b0 + b1*gate.pos[i] + eps.theta[i]
      logit(rc[i])       <- mu.rc + eps.rc[i]
      logit(ro[i])       <- mu.ro + eps.ro[i]

      p.ct.ci[i]         <- k.ci/(R.Ct[i]*theta[i]*rc[i]+k.ci)
      p.ct.oc[i]         <- k.oc/(R.Ct[i]*theta[i]*ro[i]+k.oc)
      p.ry.ci[i]         <- k.ci/(R.Ry[i]*rc[i]+k.ci)
      p.ry.oc[i]         <- k.oc/(R.Ry[i]*ro[i]+k.oc)

      y.ct.ci[i]         ~ dnegbin(p.ct.ci[i],k.ci)
      y.ct.oc[i]         ~ dnegbin(p.ct.oc[i],k.oc)
      y.ry.ci[i]         ~ dnegbin(p.ry.ci[i],k.ci)
      y.ry.oc[i]         ~ dnegbin(p.ry.oc[i],k.oc)
   }
  }
```

E.2. **DCC hierarchical model with multivariate Level 2 distribution.** The `WinBUGS` model code is shown below.

```
model {

    #Priors
      b0          ~ dnorm(0, 1.0E-6)
      b1          ~ dnorm(0, 1.0E-6)
      mu.rc       ~ dnorm(0,1.0E-6)
      mu.ro       ~ dnorm(0,1.0E-6)
      Omega[1:3,1:3] ~ dwish(R[,],4)
      Sigma[1:3,1:3] <- inverse(Omega[,])


    for(i in 1:n) {

      #Mean structure
      mu[i,1] <- b0 + b1*gate.pos[i]
      mu[i,2] <- mu.rc
      mu[i,3] <- mu.ro

      #Correlated random effects
      Y[i,1:3] ~ dmnorm(mu[i,],Omega[,])

      theta[i] <- exp(Y[i,1])/(1+exp(Y[i,1]))
      rc[i]    <- exp(Y[i,2])/(1+exp(Y[i,2])+exp(Y[i,3]))
      ro[i]    <- exp(Y[i,3])/(1+exp(Y[i,2])+exp(Y[i,3]))


      p13[i]            <- theta[i] * rc[i]
      p14[i]            <- theta[i] * ro[i]
      condp14[i]        <- p14[i]/(1-p13[i])
      p23[i]            <- rc[i]
      p24[i]            <- ro[i]
      condp24[i]        <- p24[i]/(1-p23[i])

      #Two trinomial distributions for the recoveries
      y.ct.ci [i]       ~ dbin(p13[i], R.Ct[i])
      condR.Ct[i]       <- R.Ct[i]-y.ct.ci [i]
      y.ct.oc[i]        ~ dbin(condp14[i], condR.Ct[i])
      y.ry.ci[i]        ~ dbin(p23[i], R.Ryde[i])
      condR.Ryde[i]     <- R.Ryde[i]-y.ry.ci[i]
      y.ry.oc[i]        ~ dbin(condp24[i], condR.Ryde[i])

  }
}
```

E.3. **Interior hierarchical model.** Multinomial distribution for Level 1; logit (or log) transformation of θ for Level 2, uniform priors on σ for Level 3.

`R` code frontend to `WinBUGS`

```
 #  Georgiana Slough and Ryde releases

library(R2WinBUGS)

input.data <- list(
   R.gs= c( 33668, 31532, 31328, 33670, 61276, 66893, 69180,
                  68843, 65517, 64515, 77053, 55173, 68703, 72082,70414),
   R.ry= c(  34650, 30220, 31557, 30281, 46756, 49059, 48207, 48804, 53426,
                  49341, 52327, 49629,45981, 50397,51017),
   y.gs.ci= c(  5 ,4,2,5,2,18,12,12,3,21,18,1,5,10, 6),
   y.gs.oc= c( 80,11,101,146,7,240,173,150,43,151,248,68,50,NA, NA),
   y.ry.ci= c( 37,15 ,13 ,21,22,48,30,17,16,19,34,18,13,28, 23),
   y.ry.oc= c(292,29,266,240,41,167,182,156,128,161,520,147,128,NA, NA),
   n=15)

init.val.generator <- function(n) {
  eps.theta   <- rnorm(n,0,0.1); eps.rc      <- rnorm(n,0,0.1)
  eps.ro      <- rnorm(n,0,0.1); sigma.theta <- runif(1,1,2)
  sigma.rc    <- runif(1,1,2);   sigma.ro    <- runif(1,1,2)
  mu.theta    <- rnorm(1,-5,0.5);mu.rc       <- rnorm(1,-5,0.5)
  mu.ro       <- rnorm(1,-5,0.5)
  out <- list(eps.theta = eps.theta,eps.rc = eps.rc, eps.ro = eps.ro,
     mu.theta=mu.theta,mu.rc=mu.rc, mu.ro= mu.ro,
      sigma.theta = sigma.theta,sigma.rc = sigma.rc, sigma.ro = sigma.ro)
     # tau.theta = rgamma(1,0.1,0.1), tau.rc = rgamma(1,0.1,0.1), tau.ro  = rgamma(1,0.1,0.1))
  return(out)
}

init.values <- list(init.val.generator(n),
   init.val.generator(n), init.val.generator(n))
params <- c("mu.theta","mu.rc","mu.ro","sigma.theta","sigma.rc","sigma.ro")

out.int.multinom <- bugs(data=input.data, inits=init.values,
  parameters.to.save=params, model.file=
  "C:/Documents and Settings/Ken Newman/Desktop/CalFed_Pat/Model_Interior_Multinomial.txt",
 n.chains=3, n.iter=100000, n.burnin=50000,n.thin=1,debug=TRUE)
```

`WinBUGS` model code

```
model {
    #Priors for the Parameters in the logistic models
      mu.theta    ~ dnorm(0,1.0E-6)
      mu.rc       ~ dnorm(0,1.0E-6)
      mu.ro       ~ dnorm(0,1.0E-6)
      sigma.theta ~ dunif(0,20)
      sigma.rc    ~ dunif(0,20)
      sigma.ro    ~ dunif(0,20)
      tau.theta   <- 1/(sigma.theta*sigma.theta)
      tau.rc      <- 1/(sigma.rc*sigma.rc)
      tau.ro      <- 1/(sigma.ro*sigma.ro)

   for(i in 1:n) {
      eps.theta[i]     ~ dnorm(0.0, tau.theta)
      eps.rc[i]        ~ dnorm(0.0, tau.rc)
      eps.ro[i]        ~ dnorm(0.0, tau.ro)
      #logit(theta[i])     <- mu.theta + eps.theta[i]
      log(theta[i])     <- mu.theta + eps.theta[i]
      logit(rc[i])      <- mu.rc + eps.rc[i]
      logit(ro[i])      <- mu.ro + eps.ro[i]

      r.gs.ci[i]        <- theta[i] * rc[i]
      r.gs.oc[i]        <- theta[i] * ro[i]
      cond.gs.ro.rc[i]  <- r.gs.oc[i]/(1-r.gs.ci[i])
      cond.ro.rc[i]     <- ro[i]/(1-rc[i])
    }

   for(i in 1:(n-2)) {
      #Two trinomial distributions for the recoveries
      y.gs.ci[i]        ~ dbin(r.gs.ci[i], R.gs[i])
      cond.R.gs[i]      <- R.gs[i]-y.gs.ci[i]
      y.gs.oc[i]        ~ dbin(cond.gs.ro.rc[i], cond.R.gs[i])

      y.ry.ci[i]        ~ dbin(rc[i], R.ry[i])
      cond.R.ry[i]      <- R.ry[i]-y.ry.ci[i]
      y.ry.oc[i]        ~ dbin(cond.ro.rc[i], cond.R.ry[i])
  }

 #handling the missing ocean data in the last year
 for(i in (n-1):n) {
   y.gs.ci[i]        ~ dbin(r.gs.ci[i], R.gs[i])
   y.ry.ci[i]        ~ dbin(rc[i], R.ry[i])
 }
}
```

E.4. **DA 8 hierarchical model.** Multinomial distribution for Level 1; logit (or log) transformation of θ for Level 2; gamma priors for precision (or uniform for σ's) for Level 3.

`R` code frontend to `WinBUGS`

```
# Code for DA 8 analysis of exports effects on Georgiana Slough releases
#   that are later recovered Chipps Island, and in the Ocean fisheries.

library(R2WinBUGS)

exports.raw <- c(10434,5988,10403,9523,10570,3887,1868,1984,3237,4010,7789,5007,4016,6092,10837)
exports <- as.vector(scale(exports.raw))

input.data <- list(
   R.gs= c( 33668, 31532, 31328, 33670, 61276, 66893, 69180,
                  68843, 65517, 64515, 77053, 55173, 68703, 72082,70414),
   R.ry= c(  34650, 30220, 31557, 30281, 46756, 49059, 48207, 48804, 53426,
                  49341, 52327, 49629,45981, 50397,51017),
   y.gs.ci= c(  5 ,4,2,5,2,18,12,12,3,21,18,1,5,10, 6),
   y.gs.oc= c( 80,11,101,146,7,240,173,150,43,151,248,49,50,NA, NA),
   y.ry.ci= c( 37,15 ,13 ,21,22,48,30,17,16,19,34,18,13,28, 24),
   y.ry.oc= c(292,29,266,240,41,167,182,156,128,161,520,147,128,NA, NA),
   exports= exports, n=15)

n  <- input.data$n
init.val.generator <- function(n) {
 eps.theta <- rnorm(n,0,0.1); eps.rc    <- rnorm(n,0,0.1)
 eps.ro    <- rnorm(n,0,0.1)
 b0        <- rnorm(1,-9,1);  b1        <- rnorm(1,-2,1)
 mu.rc     <- rnorm(1,-1,0.5);mu.ro <- rnorm(1,-1,0.5)
 sigma.theta <- runif(1,0,20);sigma.rc <- runif(1,0,20);sigma.ro <- runif(1,0,20)
 out <- list(eps.theta = eps.theta,eps.rc = eps.rc, eps.ro = eps.ro,
     b0 = b0,b1=b1,mu.rc=mu.rc, mu.ro= mu.ro,
     sigma.theta = sigma.theta,sigma.rc = sigma.rc, sigma.ro = sigma.ro)
     #tau.theta = rgamma(1,0.1,0.1), tau.rc = rgamma(1,0.1,0.1), tau.ro  = rgamma(1,0.1,0.1))
 return(out)
}
init.values <- list(init.val.generator(n),init.val.generator(n),
   init.val.generator(n))

params <- c("b0","b1","mu.rc","mu.ro","sigma.theta","sigma.rc","sigma.ro","theta")

out.DA8.multinom <- bugs(data=input.data, inits=init.values,
  parameters.to.save=params, model.file=
  "C:/Documents and Settings/Ken Newman/Desktop/CalFed_Pat/Model_DA8_Multinomial.txt",
   n.chains=3, n.iter=200000, n.burnin=50000,n.thin=10,debug=TRUE)
```

WinBUGS model code

```
model {

    #Level 3: Priors for the Parameters in the logistic models
     b0          ~ dnorm(0, 1.0E-6)
     b1          ~ dnorm(0, 1.0E-6)
     mu.rc       ~ dnorm(0,1.0E-6)
     mu.ro       ~ dnorm(0,1.0E-6)
     sigma.theta ~ dunif(0,20);          tau.theta   <- 1/(sigma.theta*sigma.theta)
     sigma.rc    ~ dunif(0,20);          tau.rc      <- 1/(sigma.rc*sigma.rc)
     sigma.ro    ~ dunif(0,20);          tau.ro      <- 1/(sigma.ro*sigma.ro)

   #Level 2: Generating random effects and probabilities
   for(i in 1:n) {
      eps.theta[i]     ~ dnorm(0.0, tau.theta)
      eps.rc[i]        ~ dnorm(0.0, tau.rc)
      eps.ro[i]        ~ dnorm(0.0, tau.ro)

      log(theta[i])     <- b0 + b1*exports[i] + eps.theta[i]
      logit(rc[i])      <- mu.rc + eps.rc[i]
      logit(ro[i])      <- mu.ro + eps.ro[i]

      r.gs.ci[i]        <- theta[i] * rc[i]
      r.gs.oc[i]        <- theta[i] * ro[i]
      cond.gs.ro.rc[i]  <- r.gs.oc[i]/(1-r.gs.ci[i])
      cond.ro.rc[i]     <- ro[i]/(1-rc[i])
     }

   #Level 1: Obs'ns
   for(i in 1:(n-2)) {
      #Two trinomial distributions for the recoveries
      y.gs.ci[i]        ~ dbin(r.gs.ci[i], R.gs[i])
      cond.R.gs[i]      <- R.gs[i]-y.gs.ci[i]
      y.gs.oc[i]        ~ dbin(cond.gs.ro.rc[i], cond.R.gs[i])

      y.ry.ci[i]        ~ dbin(rc[i], R.ry[i])
      cond.R.ry[i]      <- R.ry[i]-y.ry.ci[i]
      y.ry.oc[i]        ~ dbin(cond.ro.rc[i], cond.R.ry[i])
   }

   #handling the missing ocean data in the last two years
   for(i in (n-1):n) {
     y.gs.ci[i]        ~ dbin(r.gs.ci[i], R.gs[i])
     y.ry.ci[i]        ~ dbin(rc[i], R.ry[i])
    }
 }
```

E.5. **VAMP hierarchical model.** Multinomial distribution for Level 1; logit transformation of θ for Level 2; uniform priors on σ's for Level 3.

`R` code frontend to `WinBUGS`

Creating input file.

```
#Flow at Durham Ferry: 2 day avg (day of and day after release) at Vernalis from DAYFLOW
DF.flow.raw <- c(rep(NA,22),6690,5665,4125,4135,3165,3356,3430,3370,3170,8250,8940,NA,NA)
DF.flow <- as.vector(scale(DF.flow.raw))
DF.flow[is.na(DF.flow)] <- -99

#Flow at Mossdale: 2 day avg (day of and day after release) at Vernalis from DAYFLOW
 MD.flow.raw <- c(2475,7140,2480,2500,1945,1400,1400,NA,1580, 3115,18700,21250,23100,6665,6565,NA,6135,
            NA, NA, 24950, 20250,  6905,
           6995, 5969, 4170,4145,3255,3356,3345,3370,3160,
         8195, 9085,  29350, 24650)
MD.flow <- as.vector(scale(MD.flow.raw))
MD.flow[is.na(MD.flow)] <- -99

#Exports at Mossdale: 2 day avg (day of and day after release)
  MD.exp.raw <-   c(5257,4096,7370,1797,10295,9400,3276,7610, 2087,1120,3707,3770, 3507,2040,1660,NA,2330,
         NA,NA, 805,1932,2683,
       2265,2238,1475,1566,1536,1523,1494,1481,1483,
        1961,2303,1538,6283)
MD.exp <- as.vector(scale(MD.exp.raw))
MD.exp[is.na(MD.exp)] <- -99

#Flow at Dos Reis: 2 Day average (day of and day after release) at Dos Reis
DR.flow.raw <- c(384,2492,391,677,-17,48,431,-49,
       466, 2891, 8267, 9316,  9545, 3296, 3113, 3113, 4709, 4709,4740,9645,
       8447, 3180,
       5918, 5062,   3630,    3610,2671,2814, 2904,   3017,  2831,
       3743, 4147, 10756, 10018)
DR.flow <-   as.vector( scale(DR.flow.raw))

#Exports at time of release at Dos Reis
DR.exp.raw <- c(5794,5626,5856,1798,
        10211.5,9597,2353,5990,1725,1598, 3684,3958,4209,1614,1629,1629,
       2329, 2329,2410,1722,1926,3105,
       2366, 2196,1482, 1495,1532,1507,1497,1479,1483,
       2293, 2300,1544,6046)
DR.exp <- as.vector(scale(DR.exp.raw))

#Flow at Upper Old River: median of 5 days, day of release + next 4 days
UOR.flow.raw <- c(1928,4842,2057,1522,2049,1060,934,796,1018,0,
```

```
     9192,9801,10066,3499,3378,3378,284,284,268,10356,9404,3429,
     296,560,687,654,549,570,297,299,297,
     3934,4529,11130,10423)
UOR.flow <- as.vector(scale(UOR.flow.raw))

#Temperatures at release
DR.temp <- c(21.1,20.0,21.1,21.7,20.6,20.0,20.0,15.6,NA,NA,13.9,17.2,18.3,NA,17.2,17.2,15.6,15.6,17.2,15.0,
        18.9,17.2,rep(NA,9),17.0,15.0,17.5,NA)
UOR.temp <- c(21.1,21.1,22.2,21.7,19.5,21.1,22.2,rep(NA,28))
JP.temp  <- c(rep(NA,3),20.0,17.8,17.2,20.0,17.2,17.8,17.2,15.6,NA,NA,16.7,17.8,18.9,17.2,17.8,19.4,17.2,18.9,
    17.2,17.8,17.2,20.0,22.8,18.0,17.5,16.5,14.0,21.4,18.0,19.0,19.0,19.5)
MD.temp <- c(rep(NA,8),17.2,15.6,13.9,16.7,17.2,15.6,17.8,NA,16.1,NA,NA,13.9,18.9,16.7,13.3,NA,19.4,21.1,13.9,
    17.5,15.2,15.7,17.0,NA,NA,18.0,19.5)
DF.temp <- c(rep(NA,22),13.9,17.2,21.7,18.9,15.0,17.0,15.0,16.5,15.5,16.0,14.9,NA,NA)

 #Stock origin
stock.origin <- c(rep("MRFF",4),rep("FRH",11),"MRFF","FRH",rep("MRFF",3),"FRH",rep("MRFF",14))
stock <- rep(1,length(stock.origin))
stock[stock.origin=="FRH"] <- 0

#Year of release
VAMP.Year <- c(85,86,87,89,89,90,90,91,94,94,rep(95,3),rep(96,3),rep(97,3),98,98,
  99,100,100,101,101,102,102,103,103,104,105,105,106,106)+1900

# Indicator variable for Head of Old River Barrier, 1=In  and 0=Out
HORB  <- c(rep(0,4),0, 0,0,0, 0,1, 0, 0,0, 0,  0, 0,1,1,1, 0, 0, 0,
            1, 1,1,1,1, 1, 1,1, 1,
            0, 0, 0, 0)

#proportion down Old River = 1-(San Joaquin/Vernalis);
# used some eq'n for 1985-1989, and used some model for 1990-2006
 p.OR <- c(0.81, 0.73, 0.90, 0.66,
        1.04, 1.19, 0.84, 1.26, 0.67, 0.11, 0.55, 0.58,0.59,0.53, 0.52,
        0.52,0.16,0.16,0.21,0.6,0.57,0.55,0.18,0.11,0.12,0.12,0.19,0.20,0.07,0.11,0.11,
        0.56, 0.55, 0.61, 0.59)

# 1989-1999,  MD, OR, DR, and JP releases; CI and Oc recoveries; 22 groups of releases
# 2000-2004, no Dos Reis releases, Antioch, Chipps Island, and Ocean recoveries, 9 groups of releases
# 2005-2006, no Ocean recoveries, 4 release groupings
n1 <- 22;   n2 <- 9;     n3 <- 4

 #----------------------------------------------------------------------------------------------------------------
 #Durham Ferry Release and Recovery Data
   R.DF  <- c(rep(NA,22),
       72094, 74001, 68192,  71744, 97318,  98082,  74377, 74491,   91867,
       93833, 91563, NA,NA)
```

```
  DF.index.2 <- 23:31; DF.index.3 <- 32:33
  y.DF   <- cbind(c(rep(NA,22), 27, 31, 76,29, 63,18, 6, 0, 2,6,  7,NA,NA),
                  c(rep(NA,22), 28, 22, 53, 9, 21,15, 3, 0, 3,12, 6,NA,NA),
                  c(rep(NA,22),693,162,366,92,270,58,19,10, 3,NA,NA,NA,NA),
                  c(rep(NA,22),521,279, 84, 39, 207,175,51,24,96,1527,844,NA,NA))

#------------------------------------------------------------------------------------------------------------------
 #Mossdale Release and Recovery Data
  R.MD <- c(rep(NA,8),51084,50726,100969,102562,104125,100742,99656,  NA,
        48730, NA, NA, 77430,  33800, 74646,
        46111, NA, 44923, 48888,  50411,  48924,  49827, 48317,  73258,
        NA, NA, 48828, 73764)

  MD.index.1 <-  c(9:15,17,20:22); MD.index.2 <- c(23,25:31); MD.index.3<- 34:35
  y.MD    <-  cbind(c(rep(NA,22),30,NA,33,19, 42, 7, 4, 0, 1,NA,NA,9,0),
                    c(rep(NA,8), 0, 2,20, 13, 8, 2, 1, NA,10,NA,NA, 88, 7, 36,
                      18, NA,  31, 8, 13, 5, 5, 1, 3,NA,NA,9,2),
                    c(rep(NA,8),62,89,461,392,353,100,26,NA,329,NA,NA,157,13,395,
                      381, NA,232,52,145,40, 8, 5,2,rep(NA,4)),
                    c(rep(NA,8),705,0,2682,1883,1628,1084,1432,NA,226,NA,NA,48,
                     192,2940,457,NA,48,36,234,129,0,12,30,NA,NA,18,48))
#------------------------------------------------------------------------------------------------------------------
 #Dos Reis Release and Recovery Data
  R.DR     = c(149968,95595,92612,76073,
    52962,105742,103533,102999,NA,NA, 50848,52097,  51665,
    NA,98638, 107961,49784,102431,46682,77180,47874, 49636,
    NA,NA,NA,NA,NA,NA,NA,NA,NA,
    69125, 68646,25463, NA)

  DR.index.1<-  c(1:8,11:13,15:22); DR.index.2 <- NULL;DR.index.3 <- 32:34
  y.DR <-  cbind(c(rep(NA,22),rep(NA,9),7,7,3,NA),
                c(94, 36, 79, 12,
                 11, 4, 4,17, NA,NA, 8, 21, 9, NA,3,10, 10, 16, 5, 93,17, 39,rep(NA,9),
                  3,6,7,NA),
                 c(NA, 2068, 1219, 78,
                 34,23,34,86,NA,NA,234,393,245,NA,67,58,259,348,90,145,56,376,rep(NA,9),
                  rep(NA,4)),
                 c(4450,2960,5469,428,2714,1766,150,7130,NA,NA,234,393,245,NA,0,0,125,394,
                    78,0,0,185,rep(NA,9),7,6,0,NA))
 #-----------------------------------------------------------------------------------------------------------------
 #Old River Release and Recovery Data
  R.OR     <- c(150048, 100181,92612, 74341,51972,106267,103595, rep(NA,28))
  OR.index.1 <- 1:7
  y.OR <- cbind(rep(NA,35),
                c(99,  21, 17, 4, 5, 2, 1,rep(NA,28)),
                c(NA,1139,500,16,38,14,11,rep(NA,28)),
                c(37299,62564,24019,1439,2916,2613,1346,rep(NA,28)))
```

```
 #-----------------------------------------------------------------------------------------------------------------
  #Jersey Point Release and Recovery Data
  R.JP<- c(rep(NA,3),56233,
    56816, 52962, 50143, 52139,50689, 53810,50779, NA, NA,  50041, 50820,
   51737, 49815,    51540,  47208, 50050, 31091, 48907,
   51098, 49871, 49161, 51107,  48496,  46469,  24441, 25732,  22708,
   22767, 23231, 26113, 24757)


  JP.index.1<- c(4:11,14:22); JP.index.2 <- 23:31; JP.index.3 <- 32:35
  y.JP <- cbind(c(rep(NA,22),97,152, 329, 96,190, 75, 71, 35, 22,
                  31,27,26,14),
                c(NA,NA,NA,56,53, 32, 56 ,94, 10, 16, 26,NA,NA, 25, 24, 39, 55, 27, 18,187,40, 59,
                  65, 78, 111, 44, 83, 46, 57, 39, 25,
                  32,38,58,44),
                c(NA,NA,NA,283,180,224,204,358,420,756,280,NA,NA,332,311,186,697,355,192,201,47,715,
                   1353,589,1031,581,951,597,263,415,117,
                   rep(NA,4)),
                c(NA,NA,NA,824,144,156,62,331,14,0,0,NA,NA,0,12,0,12,24,14,0,0,185,0,6,0,0,48,0,0,0,
                  12,0,0,0,0))

 #---Creating an input.data object for input to WinBUGS  -----------------------------------------
input.data <- list(
   n1=n1,n2=n2,n3=n3,
   R.DF = R.DF, n.DF.2=length(DF.index.2),n.DF.3=length(DF.index.3),
                DF.index.2=DF.index.2,DF.index.3=DF.index.3,
   y.DF.Ant=y.DF[,1],y.DF.CI=y.DF[,2],y.DF.Oc=y.DF[,3],

   R.MD = R.MD, n.MD.1 = length(MD.index.1),n.MD.2=length(MD.index.2),n.MD.3=length(MD.index.3),
          MD.index.1=MD.index.1,MD.index.2=MD.index.2,MD.index.3=MD.index.3,
          y.MD.Ant = y.MD[,1], y.MD.CI = y.MD[,2], y.MD.Oc = y.MD[,3],

   R.DR = R.DR, n.DR.1 = length(DR.index.1), n.DR.3 = length(DR.index.3),
     DR.index.1=DR.index.1,DR.index.3=DR.index.3,
    y.DR.Ant=y.DR[,1],y.DR.CI=y.DR[,2],y.DR.Oc=y.DR[,3],

   R.OR = R.OR, n.OR.1 = length(OR.index.1), OR.index.1=OR.index.1,
         y.OR.CI=y.OR[,2],y.OR.Oc=y.OR[,3],

   R.JP = R.JP, n.JP.1 = length(JP.index.1),n.JP.2=length(JP.index.2),n.JP.3=length(JP.index.3),
         JP.index.1=JP.index.1,JP.index.2=JP.index.2,JP.index.3=JP.index.3,
         y.JP.Ant=y.JP[,1],y.JP.CI=y.JP[,2],y.JP.Oc=y.JP[,3],
    MD.exp=MD.exp,
    DR.flow=DR.flow,
    DR.exp=DR.exp,
    # stock=stock
```

```
    #DF.flow=DF.flow
    #MD.flow=MD.flow,
    UOR.flow=UOR.flow
   )

 if(branch) {
  input.data[[length(input.data)+1]] <- p.OR
  names(input.data)[length(input.data)] <- "p.OR"
  input.data$p.OR[p.OR>1] <- 1
  input.data$p.OR[HORB==1] <- 0
  } else {
  input.data[[length(input.data)+1]] <- HORB
  names(input.data)[length(input.data)] <- "HORB"
  }
```

Sourcing the input file and calling `WinBUGS`.

```
library(R2WinBUGS)
#source the input data
branch <- TRUE
source("C:/Documents and Settings/Ken Newman/Desktop/CalFed_Pat/VAMP_inputdata.r")


 #---Creating a list of 3 lists of initial values for input to WinBUGS
n <- input.data$n1+input.data$n2+input.data$n3
init.val.generator <- function(n) {
  eps.df.md <- rnorm(n,0,1); eps.dr.jp <- rnorm(n,0,1); eps.or.jp <- rnorm(n,0,1)
  eps.jp.ant<- rnorm(n,0,0.1);eps.jp.ci<- rnorm(n,0,0.1);eps.jp.oc<- rnorm(n,0,0.1)
  b0 <- rnorm(1,-1,1)
  xi0<- rnorm(1,1,1); xi1 <- rnorm(1,0,0.1); xi2<- rnorm(1,0,0.1)  #xi3=rnorm(1,0,0.1)
  z0 <- rnorm(1,1,1); z1  <- rnorm(1,1,1);   z2 <- rnorm(1,1,1)
  mu.jp.ant <- rnorm(1,-4,1); mu.jp.ci <- rnorm(1,-4,1); mu.jp.oc <- rnorm(1,-4,1)
  sigma.df.md <- runif(1); sigma.dr.jp <- runif(1); sigma.or.jp <- runif(1)
  sigma.jp.ant <-runif(1); sigma.jp.ci <- runif(1); sigma.jp.oc <- runif(1)

  out <- list(eps.df.md = eps.df.md,eps.dr.jp = eps.dr.jp, eps.or.jp = eps.or.jp,
              eps.jp.ant=eps.jp.ant,eps.jp.ci = eps.jp.ci, eps.jp.oc = eps.jp.oc,
              b0 = b0,xi0=xi0,xi1=xi1,xi2=xi2,
              z0 = z0,z1=z1,z2=z2,
              mu.jp.ant=mu.jp.ant, mu.jp.ci=mu.jp.ci, mu.jp.oc=mu.jp.oc,
              sigma.df.md=sigma.df.md, sigma.dr.jp=sigma.dr.jp, sigma.or.jp=sigma.or.jp,
              sigma.jp.ant=sigma.jp.ant,sigma.jp.ci=sigma.jp.ci,sigma.jp.oc=sigma.jp.oc)
  return(out)
}

init.values <- list(init.val.generator(n),init.val.generator(n),
   init.val.generator(n))

#-----  Parameters for which MCMC samples are wanted
params <- c("b0","xi0", "xi1",  "xi2", #"xi3",
       "z0",  "z1", "z2",
      "mu.jp.ant","mu.jp.ci","mu.jp.oc",
      "sigma.df.md", "sigma.dr.jp","sigma.or.jp","sigma.jp.ant",
      "sigma.jp.ci", "sigma.jp.oc",
      "fit.MD.CI.1","fit.MD.Oc.1","fit.MD.CI.2","fit.MD.Oc.2",
      "fit.MD.CI.3","fit.MD.Oc.3")

#call to WinBUGS vi bugs() function
temp <- bugs(data=input.data, inits=init.values,
  parameters.to.save=params, model.file=
  "C:/Documents and Settings/Ken Newman/Desktop/CalFed_Pat/Model_VAMP_Branch.txt",
  n.chains=3, n.iter=250000, n.burnin=50000,n.thin=10,debug=TRUE)
```

WinBUGS model code

```
# Example Code for branching model used for VAMP data.
# Admittedly clunky use of conditional binomials instead of multinomial.

# Model:  DF->MD  = constant + noise
#         MD->DR  = constant
#         DR->JP  = f(Flow,Exports)+noise
#         OR->JP  = f(Flow,Exports)+noise

#*****************************************************************************************************
#Branching Model

model {

    #Priors for the Parameters in the logistic models
    # DF -> MD
    b0           ~ dnorm(0, 1.0E-6)

    # MD -> DR
    #g0           ~ dnorm(0, 1.0E-6)

    # DR -> JP
    xi0          ~ dnorm(0, 1.0E-6); xi1          ~ dnorm(0, 1.0E-6)
    xi2          ~ dnorm(0, 1.0E-6);

    # OR -> JP
    z0           ~ dnorm(0, 1.0E-6); z1          ~ dnorm(0, 1.0E-6)
    z2          ~ dnorm(0, 1.0E-6)

    # JP -> Ant, CI, Oc
    # chi        ~ dnorm(0, 1.0E-6)
    mu.jp.ant    ~ dnorm(0,1.0E-6);  mu.jp.ci     ~ dnorm(0,1.0E-6);
    mu.jp.oc     ~ dnorm(0,1.0E-6)

    sigma.df.md    ~ dunif(0,20); tau.df.md      <- 1/(sigma.df.md*sigma.df.md)
    #sigma.md.dr    ~ dunif(0,20); tau.md.dr      <- 1/(sigma.md.dr*sigma.md.dr)
    sigma.dr.jp    ~ dunif(0,20); tau.dr.jp      <- 1/(sigma.dr.jp*sigma.dr.jp)
    sigma.or.jp    ~ dunif(0,20); tau.or.jp      <- 1/(sigma.or.jp*sigma.or.jp)
    sigma.jp.ant   ~ dunif(0,20); tau.jp.ant     <- 1/(sigma.jp.ant*sigma.jp.ant)
    sigma.jp.ci    ~ dunif(0,20); tau.jp.ci      <- 1/(sigma.jp.ci*sigma.jp.ci)
    sigma.jp.oc    ~ dunif(0,20); tau.jp.oc      <- 1/(sigma.jp.oc*sigma.jp.oc)

    #------------------------------------------------------------------------------------------
    # Random effects generation; some unnecessary: early Antioch and recent ocean
    for(i in 1:(n1+n2+n3)) {
      eps.df.md[i]  ~ dnorm(0.0, tau.df.md)
```

```
  eps.dr.jp[i]  ~ dnorm(0.0, tau.dr.jp)
  eps.jp.ant[i] ~ dnorm(0.0,tau.jp.ant)
  eps.jp.ci[i]  ~ dnorm(0.0, tau.jp.ci)
  eps.jp.oc[i]  ~ dnorm(0.0, tau.jp.oc)
  eps.or.jp[i]  ~ dnorm(0.0, tau.or.jp)

 #Mossdale to Dos Reis survival
 # logit(S.md.dr[i]) <- g0 + eps.md.dr[i]
 S.md.dr[i] <- 1.0

 #Old River to Jersey Point survival
 #logit(S.or.jp[i]) <-  z0+   eps.or.jp[i]
 #logit(S.or.jp[i]) <-  z0+ z1*UOR.flow[i] + eps.or.jp[i]
 #logit(S.or.jp[i]) <-  z0+ z2*MD.exp[i]+  eps.or.jp[i]
 logit(S.or.jp[i]) <-  z0+ z1*UOR.flow[i] + z2*MD.exp[i]+  eps.or.jp[i]

 #Dos Reis to Jersey Point survival
 #logit(S.dr.jp[i]) <- xi0 +   eps.dr.jp[i]
 #logit(S.dr.jp[i]) <- xi0 + xi1*DR.flow[i]  + eps.dr.jp[i]
 logit(S.dr.jp[i]) <- xi0 + xi1*DR.flow[i] + xi2*DR.exp[i] + eps.dr.jp[i]

 #Mossdale to Jersey Point survival: a combination of probabilities
 S.md.jp[i] <- p.OR[i]*S.or.jp[i] + (1-p.OR[i])*S.md.dr[i]*S.dr.jp[i]

 logit(r.jp.ant[i])   <- mu.jp.ant + eps.jp.ant[i]
 logit(r.jp.ci[i])    <- mu.jp.ci  + eps.jp.ci[i]
 logit(r.jp.oc[i])    <- mu.jp.oc  + eps.jp.oc[i]
 #logit(r.jp.ant[i])   <- mu.jp.ant + chi*stock[i] + eps.jp.ant[i]
 #logit(r.jp.ci[i])    <- mu.jp.ci  + chi*stock[i] + eps.jp.ci[i]
 #logit(r.jp.oc[i])    <- mu.jp.oc  + chi*stock[i] + eps.jp.oc[i]

}

#---------------------------------------------------------------------------------------------
# Modeling the  Recoveries

# 1985-1999,  MD, DR, and JP releases; CI and Oc recoveries; 18 groups  ----------------


# Mossdale recoveries for 1989-1999 (11 releases)
for(j in 1:n.MD.1) {

   p1.MD1[j]      <- S.md.jp[MD.index.1[j]]*r.jp.ci[MD.index.1[j]]
   p2.MD1[j]      <- p1.MD1[j]*r.jp.oc[MD.index.1[j]]/r.jp.ci[MD.index.1[j]]

   cond.p2.MD1[j] <- p2.MD1[j]/(1-p1.MD1[j])
```

```
      y.MD.CI[MD.index.1[j]]   ~ dbin(p1.MD1[j] , R.MD[MD.index.1[j]])
      temp1[j]                 <- R.MD[MD.index.1[j]]  - y.MD.CI[MD.index.1[j]]
      y.MD.Oc[MD.index.1[j]]   ~ dbin(cond.p2.MD1[j], temp1[j])

      fit.MD.CI.1[j] <- R.MD[MD.index.1[j]]*p1.MD1[j]
      fit.MD.Oc.1[j] <- R.MD[MD.index.1[j]]*p2.MD1[j]
     }

    #Dos Reis recoveries for 1985-1999 (15 releases)
    #1985 has only CI recs
    p1.DR1[1]                 <- S.dr.jp[DR.index.1[1]]*r.jp.ci[DR.index.1[1]]
    y.DR.CI[DR.index.1[1]]    ~ dbin(p1.DR1[1],R.DR[DR.index.1[1]])

    for(j in 2:n.DR.1) {
      p1.DR1[j]                 <- S.dr.jp[DR.index.1[j]]*r.jp.ci[DR.index.1[j]]
      p2.DR1[j]                 <- S.dr.jp[DR.index.1[j]]*r.jp.oc[DR.index.1[j]]
      cond.p2.DR1[j]            <- p2.DR1[j]/(1-p1.DR1[j])
      y.DR.CI[DR.index.1[j]]    ~ dbin(p1.DR1[j],R.DR[DR.index.1[j]])
      temp2[j]                  <- R.DR[DR.index.1[j]]-y.DR.CI[DR.index.1[j]]
      y.DR.Oc[DR.index.1[j]]    ~ dbin(cond.p2.DR1[j], temp2[j])
     }

    #Old River recoveries for 1985-1999 (7 releases)
    #1985 has only CI recs
    p1.OR1[1]               <- S.or.jp[OR.index.1[1]]*r.jp.ci[OR.index.1[1]]
    y.OR.CI[OR.index.1[1]]  ~ dbin(p1.OR1[1], R.OR[OR.index.1[1]])

    for(j in 2:n.OR.1) {
      p1.OR1[j]               <- S.or.jp[OR.index.1[j]]*r.jp.ci[OR.index.1[j]]
      p2.OR1[j]               <- S.or.jp[OR.index.1[j]]*r.jp.oc[OR.index.1[j]]
      cond.p2.OR1[j]          <- p2.OR1[j]/(1-p1.OR1[j])
      y.OR.CI[OR.index.1[j]]  ~ dbin(p1.OR1[j], R.OR[OR.index.1[j]])
      temp.2a[j]              <- R.OR[OR.index.1[j]]-y.OR.CI[OR.index.1[j]]
      y.OR.Oc[OR.index.1[j]]  ~ dbin(cond.p2.OR1[j],temp.2a[j])
    }

    #Jersey Point recoveries for 1985-1999 (16 releases)
    for(j in 1:n.JP.1) {
      cond.p2.JP1[j]          <- r.jp.oc[JP.index.1[j]]/(1-r.jp.ci[JP.index.1[j]])
      y.JP.CI[JP.index.1[j]]  ~ dbin(r.jp.ci[JP.index.1[j]],R.JP[JP.index.1[j]])
      temp3[j]                <- R.JP[JP.index.1[j]]-y.JP.CI[JP.index.1[j]]
      y.JP.Oc[JP.index.1[j]]  ~ dbin(cond.p2.JP1[j], temp3[j])
    }

 #------
 # -----   2000-2004,  DF, MD,  and JP releases; Antioch, CI and Oc recoveries; n2=9 groups ----
 # -----     loop from 19 to 27
```

```
#Durham Ferry recoveries for 2000-2004 (9 releases)
for(j in 1:n.DF.2) {
  logit(S.df.md.DF2[j])       <- b0 +  eps.df.md[DF.index.2[j]]
  p1.DF2[j]  <-    S.df.md.DF2[j]*S.md.jp[DF.index.2[j]]*r.jp.ant[DF.index.2[j]]
  p2.DF2[j]      <- p1.DF2[j]*r.jp.ci[DF.index.2[j]]/r.jp.ant[DF.index.2[j]]
  p3.DF2[j]      <- p1.DF2[j]*r.jp.oc[DF.index.2[j]]/r.jp.ant[DF.index.2[j]]

  cond.p2.DF2[j] <- p2.DF2[j]/(1-p1.DF2[j])
  cond.p3.DF2[j] <- p3.DF2[j]/(1-p1.DF2[j]-p2.DF2[j])

  y.DF.Ant[DF.index.2[j]]   ~ dbin(p1.DF2[j], R.DF[DF.index.2[j]])
  temp4[j]                  <- R.DF[DF.index.2[j]]  - y.DF.Ant[DF.index.2[j]]
  y.DF.CI[DF.index.2[j]]    ~ dbin(cond.p2.DF2[j], temp4[j])
  temp5[j]                  <- temp4[j] - y.DF.CI[DF.index.2[j]]
  y.DF.Oc[DF.index.2[j]]    ~ dbin(cond.p3.DF2[j],temp5[j])
}

#Mossdale recoveries for 2000-2004 (8 releases)
for(j in 1:n.MD.2) {
  p1.MD2[j]   <- S.md.jp[MD.index.2[j]]* r.jp.ci[MD.index.2[j]]
  p2.MD2[j]    <- p1.MD2[j]*r.jp.ci[MD.index.2[j]]/r.jp.ant[MD.index.2[j]]
  p3.MD2[j]    <- p1.MD2[j]*r.jp.oc[MD.index.2[j]]/r.jp.ant[MD.index.2[j]]

  cond.p2.MD2[j]            <- p2.MD2[j]/(1-p1.MD2[j])
  cond.p3.MD2[j]            <- p3.MD2[j]/(1-p1.MD2[j]-p2.MD2[j])

  y.MD.Ant[MD.index.2[j]]   ~ dbin(p1.MD2[j], R.MD[MD.index.2[j]])
  temp6[j]                  <- R.MD[MD.index.2[j]]  - y.MD.Ant[MD.index.2[j]]
  y.MD.CI[MD.index.2[j]]    ~ dbin(cond.p2.MD2[j], temp6[j])
  temp7[j]                  <- temp6[j] - y.MD.CI[MD.index.2[j]]
  y.MD.Oc[MD.index.2[j]]    ~ dbin(cond.p3.MD2[j],temp7[j])

  fit.MD.CI.2[j] <- R.MD[MD.index.2[j]]*p1.MD2[j]
  fit.MD.Oc.2[j] <- R.MD[MD.index.2[j]]*p2.MD2[j]
}


#Jersey Point recoveries for 2000-2004 (9 releases)
for(j in 1:n.JP.2) {
  cond.p2.JP2[j]            <- r.jp.ci[JP.index.2[j]]/(1-r.jp.ant[JP.index.2[j]])
  cond.p3.JP2[j]            <- r.jp.oc[JP.index.2[j]]/(1-r.jp.ant[JP.index.2[j]]-r.jp.ci[JP.index.2[j]])

  y.JP.Ant[JP.index.2[j]]   ~ dbin(r.jp.ant[JP.index.2[j]], R.JP[JP.index.2[j]])
  temp8[j]                  <- R.JP[JP.index.2[j]]  - y.JP.Ant[JP.index.2[j]]
  y.JP.CI[JP.index.2[j]]    ~ dbin(cond.p2.JP2[j], temp8[j])
  temp9[j]                  <- temp8 [j]-  y.JP.CI[JP.index.2[j]]
```

```
  y.JP.Oc[JP.index.2[j]]    ~ dbin(cond.p3.JP2[j], temp9[j])
 }

# -----
# -----   2005-2006,  DF, MD,  DR and JP releases; Antioch, CI  recoveries; n3=4 groups   -------

#Durham Ferry recoveries (2 releases)
for(j in 1:n.DF.3) {
  logit(S.df.md.DF3[j])   <- b0 +  eps.df.md[DF.index.3[j]]
  p1.DF3[j]               <-    S.df.md.DF3[j]* S.md.jp[DF.index.3[j]]*r.jp.ant[DF.index.3[j]]
  p2.DF3[j]               <- p1.DF3[j]*r.jp.ci[DF.index.3[j]]/r.jp.ant[DF.index.3[j]]

  cond.p2.DF3[j]            <- p2.DF3[j]/(1-p1.DF3[j])

  y.DF.Ant[DF.index.3[j]]   ~ dbin(p1.DF3[j],R.DF[DF.index.3[j]])
  temp10[j]                 <- R.DF[DF.index.3[j]]  - y.DF.Ant[DF.index.3[j]]
  y.DF.CI[DF.index.3[j]]    ~ dbin(cond.p2.DF3[j], temp10[j])
}

#Mossdale recoveries (2 releases)
for(j in 1:n.MD.3) {
  p1.MD3[j]   <- S.md.jp[MD.index.3[j]]*r.jp.ant[MD.index.3[j]]
  p2.MD3[j]   <- p1.MD3[j]*r.jp.ci[MD.index.3[j]]/r.jp.ant[MD.index.3[j]]

  cond.p2.MD3[j]   <- p2.MD3[j]/(1-p1.MD3[j] )

  y.MD.Ant[MD.index.3[j]]  ~ dbin(p1.MD3[j], R.MD[MD.index.3[j]])
  temp11[j]                <- R.MD[MD.index.3[j]]  - y.MD.Ant[MD.index.3[j]]
  y.MD.CI[MD.index.3[j]]   ~ dbin(cond.p2.MD3[j] , temp11[j])
 fit.MD.CI.3[j] <- R.MD[MD.index.3[j]]*p1.MD3[j]
  fit.MD.Oc.3[j] <- R.MD[MD.index.3[j]]*p2.MD3[j]

}

#Dos Reis recoveries (3 releases)
for(j in 1:n.DR.3) {
  p1.DR3[j]        <- S.dr.jp[DR.index.3[j]]*r.jp.ant[DR.index.3[j]]
  cond.p2.DR3[j]   <- S.dr.jp[DR.index.3[j]]*r.jp.ci[DR.index.3[j]]/(1-p1.DR3[j])

  y.DR.Ant[DR.index.3[j]]   ~ dbin(p1.DR3[j] , R.DR[DR.index.3[j]])
  temp12[j]                 <- R.DR[DR.index.3[j]]  - y.DR.Ant[DR.index.3[j]]
  y.DR.CI[DR.index.3[j]]    ~ dbin(cond.p2.DR3[j], temp12[j])
 }

#Jersey Point recoveries (4 releases)
for(j in 1:n.JP.3) {
  cond.p2.JP3[j] <- r.jp.ci[JP.index.3[j]]/(1-r.jp.ant[JP.index.3[j]])
```

```
      y.JP.Ant[JP.index.3[j]]  ~ dbin(r.jp.ant[JP.index.3[j]] ,R.JP[JP.index.3[j]])
      temp13[j]                <- R.JP[JP.index.3[j]]  - y.JP.Ant[JP.index.3[j]]
      y.JP.CI[JP.index.3[j]]   ~ dbin(cond.p2.JP3[j], temp13[j])
    }
}
```

Document Content(s)